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Use of underpasses by animals on a fenced expressway in a suburban area in western Poland

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Abstract

Expressways act as barriers to animals that block free movement in their habitats, especially when the roads are continuously fenced to prevent collisions between animals and vehicles. Various types of animal passages have been repeatedly studied in terms of their utility, albeit rather less frequently in the suburban environment. We conducted our research in a section of the fenced expressway S3 connecting two closely located cities in western Poland (Lubuskie province). Over the course of one year, we monitored four underpasses intended for small- and medium-sized animals using tracks. The underpasses were inspected weekly. Animal traces most frequently found belonged to roe deer *Capreolus capreolus* (20.9%), red fox *Vulpes vulpes* (15.1%), wild boar *Sus scrofa* (14%), and domestic dog *Canis l. familiaris* (12.4%). Surprisingly, the results of our study indicate that underpasses for small and medium mammals are also used by ungulate mammals. The use of the underpasses varied seasonally, being the highest in spring (37.9%) and the lowest in winter (10.4%). Moreover, seasonal differences in the use of passages were related to particular species/groups of animal species. We found that 22% of animals that entered the passage did not completely traverse it. People accounted for 17.1% of all stated traces in the underpasses. Stagnant water in the underpasses reduced the number of predatory mammals and wild boars using the underpasses but did not affect the activity of roe deer. These studies indicate that animal underpasses located in suburban areas are used by many species of animals despite the activity of humans and domesticated mammals.

Keywords
barrier effect, expressway, suburban area, vertebrate, wildlife underpasses

Introduction

At the global scale, roads have a considerable impact on the surrounding wildlife (Clevenger 2012). Among the most important effects of road infrastructure are the fragmented areas occupied by wild animals and barriers that isolate local animal populations (Forman et al. 2003, Coffin 2007, McGregor et al. 2008, Ascensão et al. 2015, Chen and Koprowski 2016, Andersson et al. 2017). The effect of such barriers on wildlife depends on animal behavior, population distribution, and dispersal capacity (Forman et al. 2003), which applies to many species of animals, especially with regard to modern roads with wide road lanes (Rico et al. 2007). In addition, road traffic is a stressor for wild animals (Navarro-Castilla et al. 2014, Wiącek and Polak 2015).

Another equally important effect of road infrastructure is wildlife mortality due to collisions with vehicles (Trombulak and Frissell 2000). Animal mortality may be attributed to various factors related to their activity in road corridors, for example, crossing the road, settling in the neighborhood of the road, or using the road as a feeding ground (Sabino-Marques and Mira 2011). Worldwide, this problem (in various degrees) ranges from urbanized and industrialized areas to natural ecosystems and affects many animal species (Hels and Buchwald 2001, Hell et al. 2005, Gryz and Krauze 2008, Borkovcová et al. 2012, Brzeziński et al. 2012, Hothorn et al. 2012, Ruiz-Capillas et al. 2015, Visintin et al. 2016).

With new investments in road infrastructure, various solutions are used to prevent these collisions and to simultaneously allow animals to move around the area that the road crosses. The solutions include tunnels (e.g. for amphibians), underpasses, and overpasses. The size of a passage affects its usage by various animal species that show selectivity in this aspect, especially large animals (van Bohemen 1998, Gloyne and Clevenger 2001, Ford et al. 2017). The passages for animals significantly reduce the effect of fragmentation of habitats, improve the communication between populations, and limit wildlife activity within the road lane (Simpson et al. 2016). Also, road fencing or a combination of fencing and crossing structures reduce the risk of animal-vehicle collisions (Ascensão et al. 2014, Huijser et al. 2016, Rytwinski et al. 2016).

The usage of the passages by wildlife also depends on the location of the passages in the environment as well as their sizes and shapes. In numerous publications on the use of underpasses by animals, the problem of animals rejecting the option of moving under the road has not been raised. It is unknown how many individuals withdraw from passing under the road by using an underpass after having entered it. Furthermore, there are no known factors that have been reported to affect such animal behaviors.

This study was conducted with the aim of estimating the usage of underpasses under an expressway by wildlife in a suburban environment. We tested the hypotheses that (1) the number of animals that use underpasses varies during the year; (2) underpasses that differ in technical parameters are not used by animals to the same extent; (3) the stagnation of rainwater in underpasses does not affect their use by large animals, such as roe deer and wild boar; (4) animals that intend to migrate rarely abandon their attempts during the action; and (5) human activity in underpasses adversely affects their use by wildlife.

Materials and methods

Study area

This research covered a section (16 km) of the S3 expressway located in western Poland between the cities Zielona Góra (138,898 inhabitants) and Nowa Sól (39,459 inhabitants; Figure 1). The road is a part of the international E65 road, which is the element of the trans-European transport corridor. The S3 road follows the meridian line from the Baltic seaports Świnoujście-Szczecin in the north at the western Polish border to reach the border with Czechia in the south. Via ferry lines, this route provides the shortest direct connection between southern Scandinavia and the northern part of Czechia. In 2010, the average traffic on this route amounted to 16,891 vehicles/day (GPR 2010).

The section of the expressway that was monitored in this study was built in 2006–08, and it was the first two-lane road of an expressway type in the western part of Poland. The second two-lane roadway was built after the present studies have been completed, in 2015–18, and the construction included the reconstruction of animal passages. During the monitoring period of our study, the roadway was fenced and separated the surrounding areas, thus preventing animals from entering the road lane. The fence is 220 cm high. The mesh size is 20×30 cm. From the ground up to 100 cm, the mesh is dense and is of 5×30 cm size. It allows medium and small mammals to enter the road. During our study, we did not conduct any survey on the mortality of animals caused by collisions with vehicles.

The road runs in a lowland landscape. Vegetation on both sides of the road includes mainly pine forests, with the dominant Scots pine *Pinus sylvestris*, and an admixture of black locust *Robinia pseudoacacia* and Norway maple *Acer platanoides*. The undergrowth comprises shrubs such as: bird cherry *Padus avium*, alder buckthorn *Frangula alnus*, young Norway maple, and northern red oak *Quercus rubra*. In several places, the road adjoins meadows with willows *Salix* spp. Monitored passages are located in the same environmental conditions.

Species of medium- and large-sized mammals that occur in the area near the expressway and were included in hunters' inventories of the years 2012–13 include: red deer *Cervus elaphus* (19 individuals), roe deer *Capreolus capreolus* (330 individuals), wild boar *Sus scrofa* (70 individuals), red fox *Vulpes vulpes* (35 individuals), pine marten *Martes martes* and stone marten *Martes foina* (20 individuals), European badger *Meles meles* (19 individuals), raccoon dog *Nyctereutes procyonoides* (20 individuals), European polecat *Mustela putorius* (11 individuals) European hare *Lepus europaeus* (29 individuals) (data available from Polish Hunting Association in Zielona Góra).

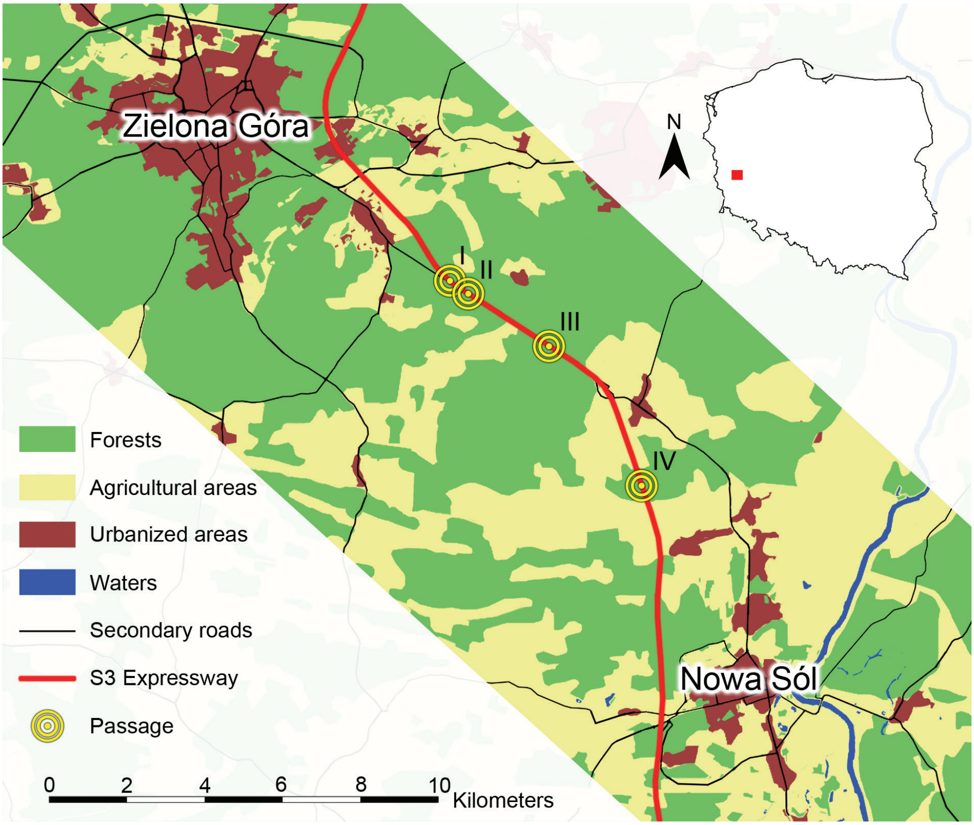

Figure 1. Distribution of monitored underpasses under the S3 expressway in western Poland.

Monitoring of underpasses

This research included four underpasses for small- and medium-sized animals (Figure 2). The longest distance between the first and fourth underpass was 6.6 km. The monitoring was carried out systematically once a week from April 1, 2012 to March 31, 2013. In total, 52 checks were carried out at each underpass. Each monitoring event comprised two visits on consecutive days. On the first visit, the sandy ground on the entire area of each underpass was raked (Figure 3). The track-beds in underpasses were 37 m long, 3–6 m wide, 196 m^2 raked area (underpass I), 17 m long, 4 m wide, 64 m^2 raked area (underpass II), 40 m long, 2 m wide, 71 m^2 raked area (underpass III), and 25 m long, 7 m wide, 160 m^2 raked area (underpass IV). On the second visit we identified the animal species based on the animal footprints on the ground. Identification of the footprints was made following Romanowski (1998) and Jędrzejewski and Sidorovich (2010). Furthermore, we monitored the movement of people in the underpasses.

We did not distinguish between species that – due to their similar size, body structure, and movement – could be easily misidentified. We described these as groups of

Figure 2. Monitored S3 expressway underpasses in western Poland.

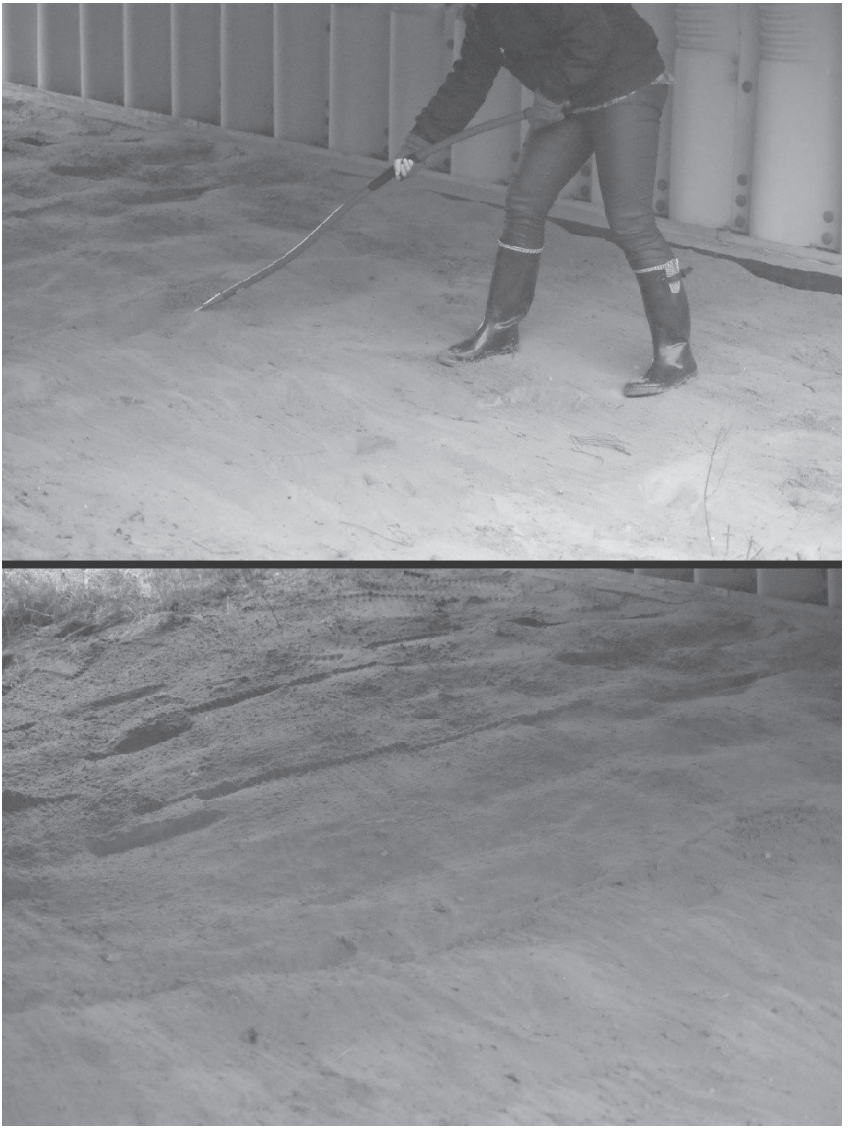

Figure 3. Preparation of track beds for survey of animals' activity in underpass in S3 expressway.

species: large mustelids: pine marten, stone marten, European polecat; small mustelids: stoat *Mustela erminea*, and least weasel *Mustela nivalis*; small mammals: rodents from genus *Apodemus* and *Microtus*, and soricomorphs.

The monitored underpasses are intended to aid small- and medium-sized animals. Along the section of the road we monitored, there are no other passages. The underpasses are elliptical in shape. They consist of sections characterized by different size parameters. Between the sections, there are openings in which animals are exposed to traffic-related factors (e.g. noise, lighting; Table 1).

Table 1. Type, dimensions, openness index (OI) and function of the monitored crossing structures in the S3 expressway in western Poland.

Number of crossing		Dimensions (m)				Crossing type
		Width	Height	Length	OI	
I	section Ia	6.4	2.2	8.1	1.74	underpass for medium mammals
	section Ib	6.4	2.5	16.2	0.99	
	section Ic	3.1	1.9	13.1	0.45	drainage
II		3.8	1.5	16.8	0.34	underpass for small mammals
III	section IIIa	1.75	1.7	7.8	0.30	drainage
	section IIIb	1.75	1.45	18.7	0.14	underpass for small mammals
	section IIIc	1.9	1.1	13.1	0.16	
IV	section IVa	6.5	2	7.3	1.78	underpass for medium mammals
	section IVb	6.5	2	17.3	0.75	

We calculated the openness index (OI) according to the following formula:

$$\text{Openness index} = (\text{width} \times \text{height}) / \text{length}$$

We calculated the index of use (UI) of the underpasses for particular animal species/groups by the formula:

Index of use = number of individuals of each species found in the underpass / number of underpass checks

We determined the percentage of a particular species in relation to the total number of individuals found to have used the underpass, and the percentage of individuals of a given species in relation to the total number of recorded animals. We analyzed the variability of wildlife activity in months and seasons: spring (March–May), summer (June–August), autumn (September–November), and winter (December–February). We calculated the Shannon Diversity Index (H) for every wildlife underpass.

For the calculations, the R program (R Core Team, 2018) was used.

Results

During the year-round monitoring, we recorded traces of 364 animals in the four underpasses under the S3 road. This translates to an average of seven animals per crossing monitoring event. Of the 15 animal species/groups we found, the most frequently recorded animals included: roe deer (UI = 1.46), red fox (UI = 1.05), and wild boar (UI = 0.98). Moreover, the underpasses were intensively used by domestic dogs *Canis l. familiaris* (UI = 0.86; Figure 4).

The use of the underpasses by wildlife was variable. The most intensively used underpasses were I (UI = 2.70) and IV (UI = 2.42). Underpasses II and III were used less frequently, and their utilization rate amounted to 0.94 and 0.92, respectively.

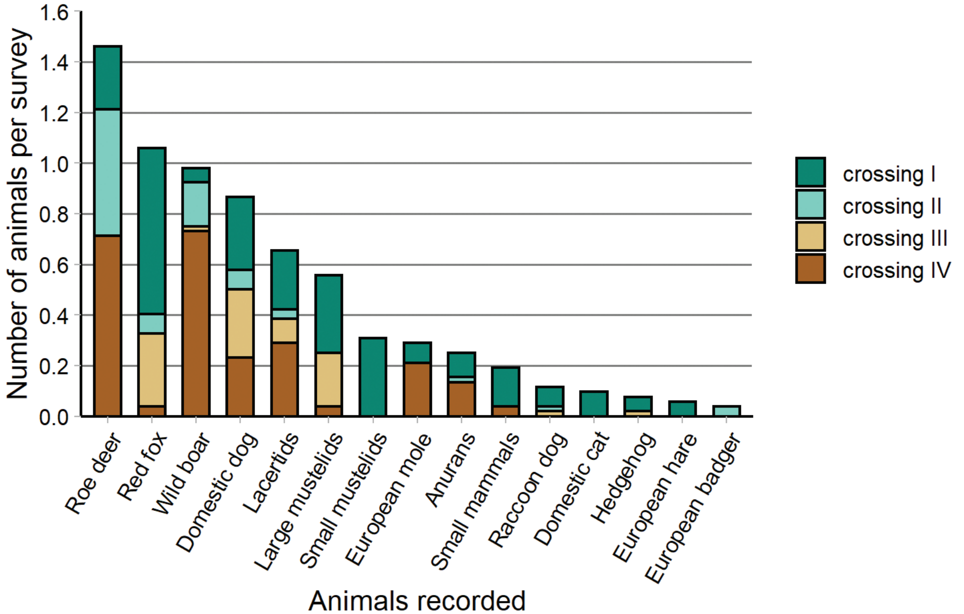

Figure 4. Activity of animals that explored and crossed the S3 expressway underpasses in suburban areas in western Poland.

The differences in the underpass efficiencies are statistically significant (χ^2 = 244.92, df = 42, p < 0.001). Additionally, underpasses I and IV featured higher values of H index (Table 2).

Individual animal species showed preferences for select underpasses. Wild boar did not select all the underpasses with equal frequency (χ^2 = 69.39, df = 3, p < 0.001), and the species was most frequently found in Underpass IV. Roe deer more frequently chose underpasses IV and II than I and III (χ^2 = 40.53, df = 3, p < 0.001). Large mustelids preferred underpasses I and III (χ^2 = 23.55, df = 3, p < 0.001), whereas small mustelids used only Underpass I (χ^2 = 48.00, df = 3, p < 0.001).

We discovered a seasonal diversity in wildlife activity in the underpasses (χ^2 = 86.251, df = 42, p < 0.001; Table. 3). The greatest activity was observed in the spring, and the underpasses were most intensively used in April, May, and June (Figure 5). This activity was reduced by half in winter.

Roe deer revealed higher activity in the spring and summer seasons (χ^2 = 19.47, df = 3, p < 0.001). Wild boar used the underpasses mainly in spring. In the remaining seasons, wildlife rarely used the underpasses and, in winter, the underpasses were almost unused (χ^2 = 43.51, df = 3, p < 0.001). Small mustelids were most frequently using the underpasses in summer and autumn. However, in spring and winter, their activity decreased (χ^2 = 11.00, df = 3, p = 0.011). Moreover, increased activity of domestic dogs was recorded in spring (χ^2 = 11.80, df = 3, p = 0.008). Half of the total number of the recorded species/groups was found to be inactive in winter (anurans, lacertids, European hare, hedgehog, wild boar, European badger, and raccoon dog) (Table 3).

Table 2. Wildlife activity in the S3 expressway underpasses in suburban areas. All animals observed in the underpasses were counted, including the ones that crossed the road and those which abandoned their attempts.

Animal species / group of species	Crossing								Total	
	I		II		III		IV			
	N	%	N	%	N	%	N	%	N	%
Anurans	5	3.6	1	2.0	0	0	7	5.6	13	3.6
Lacertids	12	8.5	2	4.1	5	10.4	15	11.9	34	9.3
European mole	4	2.8	0	0	0	0	11	8.7	15	4.1
Small mammals	8	5.7	0	0	0	0	2	1.6	10	2.8
European hare	3	2.1	0	0	0	0	0	0	3	0.8
Hedgehog	3	2.1	0	0	1	2.1	0	0	4	1.1
Roe deer	13	9.2	26	53.1	0	0	37	29.4	76	20.9
Wild boar	3	2.1	9	18.4	1	2.1	38	30.2	51	14.0
Red fox	34	24.1	4	8.2	15	31.2	2	1.6	55	15.1
European badger	0	0	2	4.1	0	0	0	0	2	0.6
Raccoon dog	4	2.8	1	2.0	1	2.1	0	0	6	1.7
Domestic cat	5	3.6	0	0	0	0	0	0	5	1.4
Domestic dog	15	10.6	4	8.2	14	29.2	12	9.5	45	12.4
Large mustelids	16	11.4	0	0	11	22.9	2	1.6	29	8.0
Small mustelids	16	11.4	0	0	0	0	0	0	16	4.4
Total	141	100.0	49	100.0	48	100.0	126	100.0	364	100.0
Shannon diversity index H'	3.393		1.183		1.284		2.426		–	

Table 3. Seasonal activity of wildlife in the S3 expressway underpasses in suburban area in western Poland.

Animal species/ group species	Spring		Summer		Autumn		Winter	
	N	%	N	%	N	%	N	%
Anurans	2	1.5	4	3.9	7	8.3	0	0
Lacertids	18	13.0	11	10.6	5	6.0	0	0
European mole	6	4.4	3	2.9	4	4.8	2	5.3
Small mammals	6	4.4	1	1.0	2	2.4	1	2.6
European hare	1	0.7	1	1.0	1	1.2	0	0
Hedgehog	3	2.2	0	0	1	1.2	0	0
Roe deer	23	16.7	32	30.8	15	17.9	6	15.8
Wild boar	32	23.2	10	9.6	9	10.7	0	0
Red fox	11	8.0	14	13.5	17	20.2	13	34.2
European badger	1	0.7	0	0	1	1.2	0	0
Raccoon dog	3	2.2	2	1.9	1	1.2	0	0
Domestic cat	1	0.7	1	1.0	1	1.2	2	5.3
Domestic dog	21	15.2	6	5.8	9	10.7	9	23.7
Large mustelids	9	6.5	10	9.6	6	7.1	4	10.5
Small mustelids	1	0.7	9	8.7	5	6.0	1	2.6
Total	138	100.0	104	100.0	84	100.0	38	100.0
Seasonal %	**37.9**		**28.6**		**23.1**		**10.4**	

During the monitoring period, we found that rainwater stagnates periodically in underpasses II, III, and IV. However, water did not stagnate in Underpass I. Underpass IV was flooded with water in 17% of control, Underpass II in 77% of control, and Underpass III in 35% of control. The differences in the period of water stagnation in the underpasses are statistically significant (χ^2 = 52.701, df = 3, p < 0.001). Wild boar

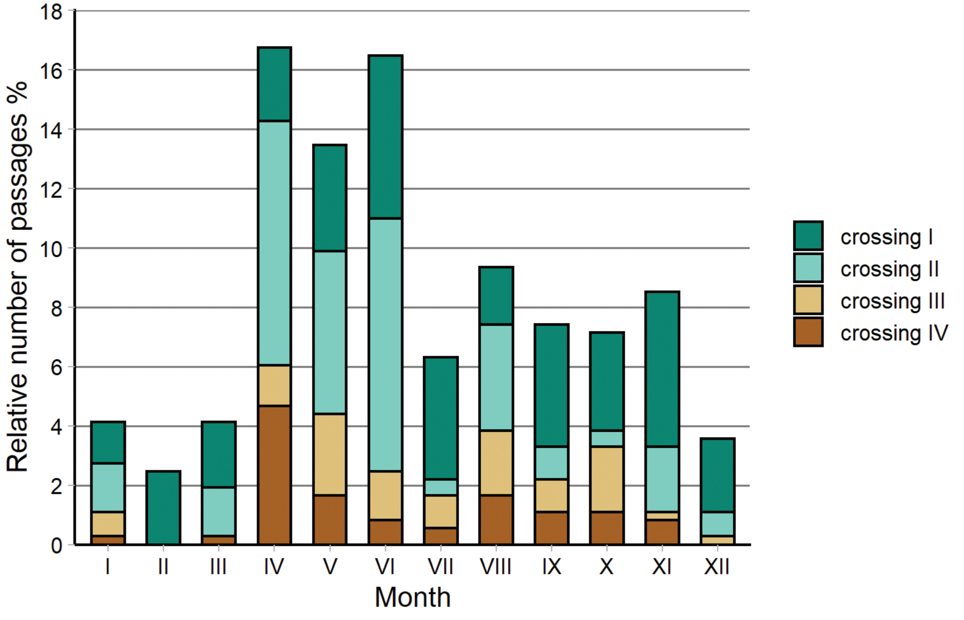

Figure 5. Use of S3 expressway underpasses in western Poland by wildlife that explored and crossed the road.

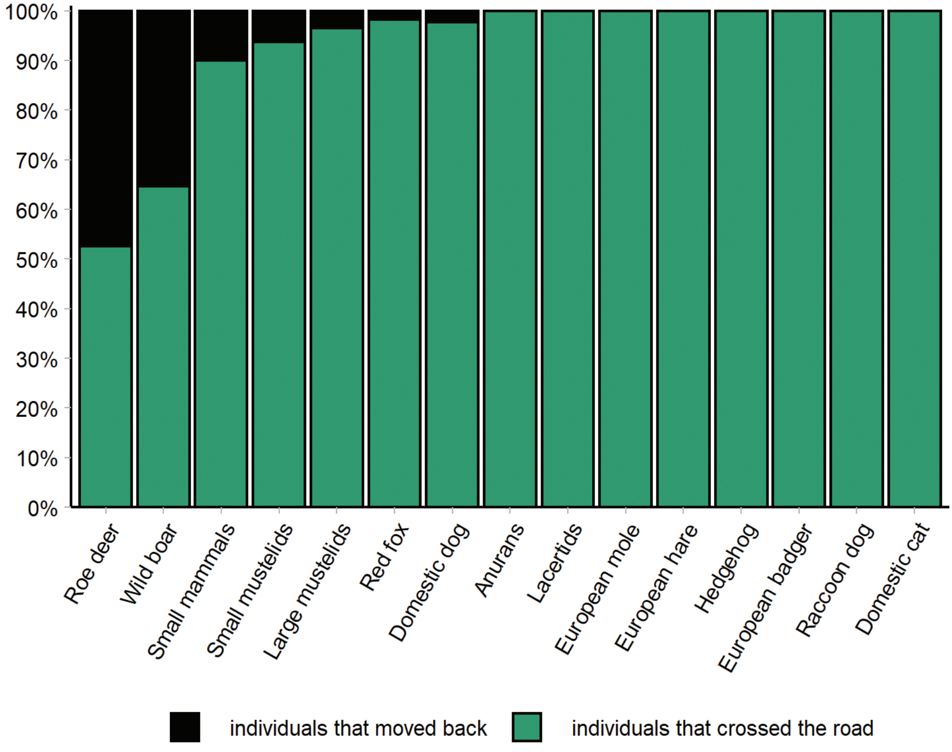

Figure 6. Proportion of animals which crossed and did not cross the S3 expressway using the underpasses.

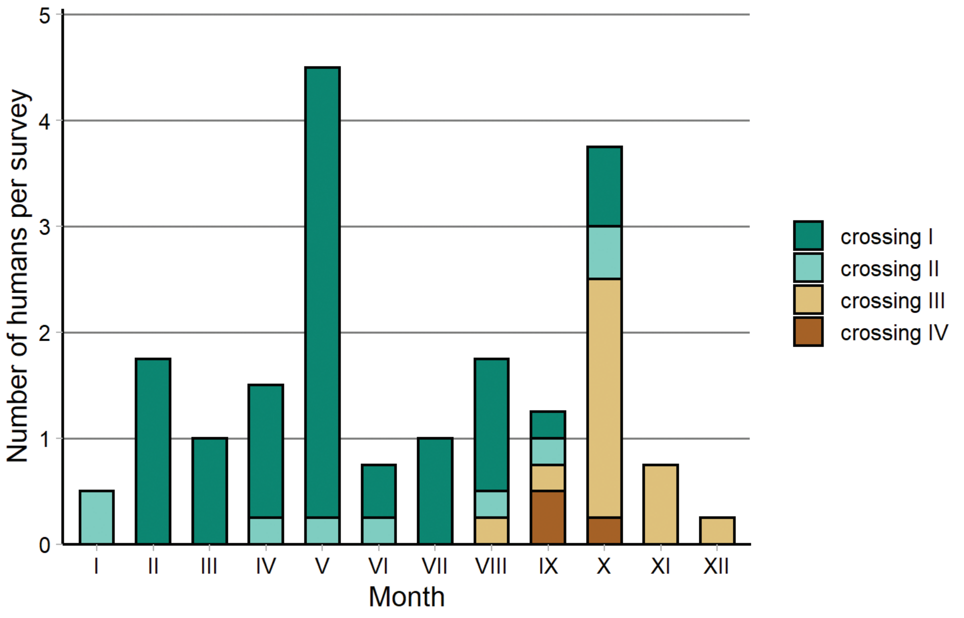

Figure 7. Monthly use of the S3 expressway underpasses by humans.

avoided underpasses where there was stagnating water ($\chi^2 = 46.394$, df = 3, $p < 0.001$), whereas roe deer did not reveal any activity alterations and used the underpasses with equal frequency regardless of water stagnation ($\chi^2 = 19.4$, df = 3, $p < 0.001$). Only 4% of carnivorous mammals used the underpasses when they were flooded.

Some animals (22%, Figure 6) abandoned their route to the other side of the road through the underpasses. These were mainly roe deer, wild boars, large and small mustelids, small mammals, foxes, and dogs. Among the species that abandoned attempts to cross the road, roe deer (90%) and wild boar (55%) predominated (Figure 5). Underpass IV was the most frequently abandoned crossing.

During the year, we also found human activity in the underpasses (75 persons). People used individual underpasses to a different degree ($\chi^2 = 64.68$, df = 3, $p < 0.001$). The largest proportion of footprints (64%) were found in Underpass I, localized closest to the town Zielona Góra. In the remaining underpasses, human activity was lower (Figure 7).

Discussion

Many factors affect the use of underpasses by wildlife, for example, appropriate design, size parameters (dimensions), and appropriate location (Forman et. al. 2003, Kleist et al. 2007, Grilo et al. 2008). The results of this study show that underpasses for animals under the fenced S3 expressway were used by wildlife despite their structural features that expose wildlife to noise and car lights. The utilization rate of the monitored underpasses is higher than for similar underpasses in Spain (Mata et al. 2008).

The problem of underpass use by animals is widely studied worldwide in regard to various aspects, e.g., vegetation covering the area near entrances to the underpass, road fencing, and distance to urban areas (e.g. Clevenger et al. 2001, Ascensão and Mira 2007). The final results of monitoring are largely influenced by the specificity of the composition of local wildlife populations. In Poland, all newly built motorways and expressways are fenced and associated with animal passages. It is difficult to compare the results obtained in western Poland with those from other national surveys, although monitoring is carried out for numerous new road investments in Poland. However, scientific institutions or people interested in publishing the results (with the commissioner's consent) rarely participate in such research projects. Therefore, it is difficult to estimate a complete overview of the effectiveness of the constructed animal passes.

There is a significant publication that discusses the usage of underpasses under expressways by wildlife in the mountains in the south of Poland (Mysłajek et al. 2016). The authors indicate a higher efficiency of viaducts, which, on an annual scale, are used more intensively. The results obtained in our research confirm the observations described in the abovementioned publication – that is, the underpasses are most frequently used by roe deer and fox. Red foxes prefer smaller passages and use them more often than other mammals. Red foxes were not sensitive to landscape parameters and road traffic in contrast to roe deer (Seiler and Olsson 2009). In our research, wild boars were frequent users of the underpass. This result is in contrast to observations in mountain areas (Mysłajek et al. 2016).

Furthermore, in western Poland we observed a much smaller difference between the numbers of domesticated and wild species despite the passages being situated in urbanized areas. In southern Poland, domesticated species accounted for 25% of all recorded animals (Mysłajek et al. 2016). In examined underpasses, we noted high activity of domestic dogs, which could deter the activities of wild species. The penetration of dogs into rural areas is a common problem in Poland (Krauze-Gryz and Gryz 2014). Results of other research stress the significant relationship between the distance from urban areas and the usage of passes by domesticated animals. These studies also direct attention to the importance of localization of passes for animals away from urban areas (Ascensão and Mira 2007).

Species of mammals observed in passages under S3 road are characteristic of woodland areas of western Poland (Gabryś et al. 2005). In the underground passages, we did not find any large ungulate mammals (e.g. red deer) due to small dimensions of these passages. The size of the passage is of key importance here, because the red deer prefer larger openings (Ballók et al. 2010). Moose *Alces alces* can be seen in the immediate vicinity of the road. In the close neighborhood, there were some attempts by moose to get into the road lane despite the security measures applied (Ważna et al. 2014). After finishing our research, the S3 expressway was rebuilt. New overpasses for large mammals were created and the situation on the road has improved. This is very important also for the wolf *Canis lupus* population, which is now expanding in western Poland (Nowak et al. 2017). The species was not observed in our research, which can be explained by both the type of passages and the vicinity of the city. Some species observed in passages occurred rarely as a result of the local population size. The population of the hare in Poland is low, especially in forest environments (Kamieniarz et al. 2013). Badgers prefer fertile mixed forests and are rarely found in poor pine forests (Kowalczyk et al. 2003). Similarly, hedgehogs *Erinaceus* spp. prefer open suburban areas (Reeve 1994). We did not observe tracks of the red squirrel *Sciurus vulgaris*, either, despite the passages being situated in forests.

The use of underpasses by roe deer and wild boar is surprising because the underpasses were intended for small- and medium-sized animals and underpasses I, II and III were characterized by low openness ratio index. Underpass IV was used most frequently by roe deer and wild boar possibly due to the higher value of openness ratio index. Nevertheless, we confirmed the observations of Mata et al. (2008) that small passages reduce the barrier effect for these species. Roe deer seems to be a species with a high adaptability to difficult conditions of mobility. It has been observed that during summer heat, the roe deer stay in the small amphibian crossings under highway during the day, thus protecting themselves from the sun (Skierska and Cichocki, own observations). Various studies found that many animals use drainage culverts even though they were not originally designed for wildlife. They are important for animals for the crossing of the roads (Ng et al 2004). Small drainage culverts were used by North American species, such as cervids (e.g. mule deer *Odocoileus hemionus*) or large carnivorous mammals (e.g. black bear *Ursus americanus*, bobcat *Lynx rufus*) (Clevenger and Waltho 2000, Krawchuk et al. 2005, Marangelo 2019). However, drainage culverts cannot replace conventional wildlife passages for mammals, mainly because the high-water levels and the use of polyethylene as construction material decrease the number of successful passages. Only half of the species observed outside of the drainage culverts were detected making full crossings (Brunen et al. in press).

The results of our study indicate significant seasonal differences in the use of animal passages. The examined road underpasses were used most intensively in spring and least frequently in winter. The results confirm the observations made by Mysłajek et al. (2016), where analogous relationship was reported. Furthermore, it is associated with a reduced tendency of wildlife migration and road crossing in winter (Kämmerle et al. 2017). In winter, no individuals of some species were observed in the underpasses because, in Central Europe, many animals hibernate in winter (anurans, lacertids, hedgehogs, etc.) or show reduced activity (European badger, raccoon dog, etc.). From spring to autumn, animals are more active due to the seasonal breeding and rearing the young. In addition, in autumn, the recorded annual sizes of animal populations reach the maximum numbers (e.g. red fox population) (Goszczyński 1989). In Western Europe, where the climate is warmer, seasonal differences are less distinct (Yanes et al. 1995, Ascensão and Mira 2007, Mata et al. 2009).

The results of this research indicate that a large proportion of animals that attempt to move through the underpass under a road abandon these attempts. Standard monitoring with the use of strips of sand did not allow us to record the number of animals that turned back before traversing the passage. We assume that animals that have passed through the monitored strip and turned back, in some cases, might have been even counted twice. Villalva et al. (2013) reported that the use of underpasses that remain flooded for most of the year (more than 3 cm of water-depth) is less frequent than the use of dry passages. In our studies, only a small percent of carnivorous mammals used the underpasses when they were flooded. Especially foxes and badgers prefer culverts that are dry throughout the year (Villalva et al. 2013). In our study, underpasses with stagnating water were also avoided by wild boar.

Human presence, moreover, has an impact on the use of underpasses. The fewer people use an underpass, the more animals tend to use it (Grilo et al. 2008, Barrueto et al. 2014, Clevenger and Barrueto 2014). In our study, people most frequently used the underpass I, which was localized near the city. The interference by humans could have had a negative effect on use of the passage by ungulate species. People most frequently used the underpasses in May and October. In May, the temperatures rise in this part of Europe and, therefore, city residents eagerly choose activities in surrounding forests. In October, on the other hand, human activity increases due to the tradition of mushroom picking. In the remaining months of the monitoring, human activity was distinctly lower. In May and October, we observed lower numbers of wildlife in the underpasses in comparison to other spring and autumn months.

The obtained results indicate the importance of planning and construction of animal passages even in urbanized areas which do not display unique natural characteristics. Underpasses are an important element to prevent the isolation of local populations and, presumably, could reduce the negative impact of urban development.

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RESEARCH ARTICLE

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Transformative learning and grassroots climate adaptation: case studies in Vietnam's Mekong delta

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Abstract

This paper aims to understand how T-learning helps communities achieve better sustainability outcomes. On the basis of an intensive literature review and field research conducted in the Mekong Delta of Vietnam, the paper proposes a substantial linkage between T-learning and sustainability. It first outlines the environmental changes in Vietnam's Mekong Delta, which appear to serve as "disorienting dilemmas" that force local people to learn and gradually shift their farming practices to align with a climate-resilient development. The paper relies on the outcomes of household surveys, field observations and focus group discussions to explore the impacts of T-learning on building adaptive capacity and sustainability transition in two community-based projects in Can Tho City and Ca Mau province in the Mekong Delta. Our findings reveal that T-learning enables experts and practitioners to introduce new ideas and accordingly mobilize local people to make changes without inciting doubt, dismay or concern. In an ideal T-learning approach, small-scale farmers learn from being under the supervision of experts in "field-based schools" that offer real-life experience and encourage learners to shift their livelihoods to eco-friendly agricultural practices. The paper sheds new light on how a critical approach to education for sustainable development through T-learning can be, under specific conditions, one strategy. It concludes that T-learning should be acknowledged as a potentially important part of the broader approach to climate-resilient development in vulnerable grassroots communities.

Keywords

climate-resilient development, climate adaptation in Mekong Delta, community action, education for sustainable development (ESD), mangrove-shrimp farming system, transformative learning

Introduction

As progress in global climate negotiations remain limited, greater attention is being given to the increasing number of grassroots sustainability initiatives (Mezirow and Taylor 2009; Cole 2015; Kent 2016). In Vietnam, the government has proactively introduced a number of environmental policies recently in its quest for sustainable development. However, limited resources and climate governance capacity have challenged and impeded their efforts to mitigate and adapt to the tangible impacts of climate and human-caused environmental changes (Mongabay 2016; The Diplomat 2017a). While awaiting the government's responses on the climate change national initiative, smallholder farmers in the Mekong Delta have proactively found new strategies to adapt to the changing environment expressed by erratic rainfall, increased flooding, extended droughts and salt-water intrusion (Chiem 2012; The Diplomat 2017b). Their new farming models, supported by non-state actors such as experts and NGOs, have proved successful and have been widely acknowledged as a climate-resilient alternative (Chandra et al. 2016; Kent 2016). The key to their success is that their farming models can increase their incomes while ensuring environmental friendliness, and thus proving the possibility of scaling up (Chiem 2012; Quang and Weatherby 2019).

The emergence of grassroots climate adaptation initiatives calls for adult learning strategies that promote the adaptive capacity of grassroots communities, and enable communities to develop sustainably. Recent scholarship has sought to theorize transformative learning, or T-learning, in terms of its potential to promote sustainability transition (Moore 2005; Wals and Corcoran 2006; Taylor and Cranton 2012). However, it remains unclear how T-learning might help communities achieve better sustainability outcomes, and there are few empirical examples that demonstrate the impacts of T-learning on community-based collective climate actions. This further highlights the need to continue theorizing grassroots climate action in terms of their sustainability transition potential with which T-learning is an integral part in intra- and inter-community education. This paper aims to address these two gaps.

We study the impacts of T-learning on grassroots sustainable development in the case of specific agricultural areas in the Mekong Delta, where local communities are most vulnerable to the negative impact of environmental changes, due to their heavy dependence on natural resources of water, soil, weather, and flora and fauna (Mongabay 2016). Conceptually, the process of T-learning emerged in response to the "disorienting dilemma" – an experience, or self-perception, that no longer fits into a new situation (Mezirow and Taylor 2009), and thus, forces people to reconsider their beliefs and lifestyles through "critical reflection" in the context of dialogue with their community. In disaster-prone regions, such as the Mekong Delta, ongoing environmental injustices serve as a key "disorienting dilemma" for individuals (e.g. farmers, women, and ethnic groups) who must shift their behaviors and lifestyle choices to align with a low-carbon future that is sustainable.

The good news might be that there is an increased interest in developing approaches that are locally effective and can be rolled out locally under the banner of "grassroots sustainability initiatives" (Mezirow and Taylor 2009; Chiem 2012; Kent 2016). This is not only about technical fixes to arrest adverse climate impacts – it is about local-level learning and harvesting ideas; about the potential of affected rural groups to mobilize and participate in novel networks – ideally including sympathetic local (commune/district) government officials. Yet, the catalysts in the cases presented below are what we may call "civil society networks" – a mix of dedicated and motivated people ready to work together: male and female farmers, agricultural and water management experts, academics, local community-based organizations (CBOs) and NGOs.

Against this background, this paper seeks to address the questions as follows: what is grassroots T-learning and how does it promote community climate action in disaster prone areas such as the Mekong Delta? Second, the potential for T-learning exists to influence grassroots activism against climate change, thus holding the key to sustainability transition and broader climate change governance. So, in what ways can T-learning promote and underpin the community-based collectives to climate resilient development in accordance with sustainability needs? In other words, does T-learning lead to sustainability? If yes, how can it best be implemented as an alternative approach to sustainable development at the local level?

This paper aims to clarify the importance of T-learning in grassroots climate action and why it should be acknowledged as a ground-up approach to education for sustainability. It first presents an overall understanding of T-learning and the prevailing approach in academic environments that stresses the relationship with grassroots T-learning. It then provides a real-life example of T-learning theory in action and analyzes T-learning's significant impacts on local sustainability-driven changes. The factors constituting the success of grassroots T-learning in achieving more widespread adoption outside are also mentioned in this section. The next section discusses the relationship between T-learning and sustainable community development through which the role of T-learning as a critical ground-up approach to education for sustainability is clarified and resolved naturally. The paper concludes with a discussion on issues and challenges facing grassroots T-learning, including the significant role of local youth and students in up-scaling T-learning activities.

Understanding T-Learning: from theory to practice

Originated by Jack Mezirow (1990; 1991), T-learning is known as a theory that describes a process of examining, questioning, and revising people's perceptions of their experiences that they interpret in their own way. As the goal of education is, among other things, to find universal truths and constructs that are independent of our knowledge of them, we develop habitual expectations and assumptions based on past experiences and expect things to be as they were before. But when we encounter a situation that is not congruent with our expectation, we begin to reconsider the existing perspectives that guide our decision making and actions and enter into a process that could lead to a transformed perspective (Taylor and Cranton 2012). Some scholars define T-learning as a learning process that "transforms problematic frames of reference to make them more inclusive, discriminating, reflective, open, and emotionally able to change" (Mezirow and Taylor 2009; Howie and Bagnall 2013). However, the common notion of T-learning is the dominance of individualization of responsibility for mainstream change. In some contexts, social change may need to precede individual change, and in others, individual change drives social transformation. Thus, an individual shift in perspective holds the key to broader community and social change.

Mezirow (2009) argues that people likely consider changing their view of the world when they face a "disorienting dilemma" – an experience that no longer fits into emerging circumstances or beliefs. When faced with a disorienting dilemma, people are forced to reconsider their understanding and look for a new, appropriate way to fit the new experience into the rest of their worldview. This process of "self-adjustment" often happens through "critical reflection" in the context of dialogue with other actors, including academics and those who pursue interests conflicting with theirs (Howie and Bagnall 2013). Such a transformative process is comprised of ten phases as follows: A disorienting dilemma →Self-examination →A critical assessment of assumptions → Recognition of a connection between one's discontent and the process of transformation →Exploration of options for new roles, relationships, and action →Planning a course of action →Acquiring knowledge and skills for implementing one's plan →Provisional trying of new roles →Building competence and self-confidence in new roles and relationships →A reintegration into one's life on the basis of conditions dictated by one's new perspective (Mezirow 2009).

T-learning is an emerging approach increasingly preferred at school and community education. At public schools, teachers utilize disorienting dilemmas to challenge students' thinking, encouraging them to use critical thinking and questioning to verify their underlying assumptions and beliefs, and look for new experiences or perspectives (Christie et al. 2015). In the context of academic learning environments, disorienting dilemmas often occur when teachers provide space to critically engage with new ideas. To utilize T-learning in classrooms, teachers firstly need to provide enough space and opportunities for students' critical thinking by enabling students to engage with new content through journaling, engaging in dialogue with their peers, and critically questioning their own assumptions and beliefs. Once students have challenged their own assumptions and beliefs, it is critical for teachers to provide the opportunity for students to act on their newfound beliefs.. This step is necessary since "true transformation" cannot take place as long as students are able to actively take steps that acknowledge their new belief (which is either right or wrong) (Howie and Bagnall 2013; Christie et al. 2015).

However, teachers must consider sustaining students' transformed perspective by providing opportunities to relate to others going through the same transformative process. Transformation often happens in community as students bounce ideas off one another and are inspired by the changes that their friends and acquaintances make. In other words, the disorienting dilemmas in academic environments and those in communities look more or less alike, and students likely prefer to act as their parents and neighbors usually do – whose ways are sometimes different, or even contradict what they gleaned at school.

Despite this understanding and relationship between fostering T-learning at school and in communities, the role of T-learning in the community generally remains under-researched in Vietnam. We recognize that local farming communities can be acknowledged as a natural point for sustainability education. Their position in policy processes, which is often marginalized, motivates them to support equitable development approaches as both the first beneficiaries and the future victims of mismanagement.

On the other hand, the Mekong Delta will soon be the country's "next environmental hotspot" due to the proliferation of factories and other potential polluters along the waterways (The Diplomat 2017a). So, the logic behind it is that if local communities want sustainable development, they need transformative learning to improve their own resilience capacity and become aware of, and implement, clear, workable alternatives. Pursuing climate-smart livelihoods would help them gain better incomes but avoid far-reaching environmental impacts that their children will be forced to bear in the rather near future. Local peasants therefore have an opportunity to help determine an alternative policy to self-help climate resilient development in the Delta. But this is only true if they are fully engaged in the T-learning process, which offers an ideal platform for enhancing their capacity and real-life experience (Mezirow and Taylor 2009; Christie et al. 2015).

The following section presents the development of grassroots T-learning in the Mekong Delta through which major elements that frame the T-learning approach and the impacts of T-learning on local sustainability transition are identified and analyzed.

Background to study: dawn of T-Learning in the Mekong Delta

The Mekong Delta is an interesting case study of grassroots climate action given that it well represents the adverse impacts of climate and human-caused environmental changes on local communities and there have been a large number of adaptation strategies implemented by state and non-state actors (Mongabay 2016; The Washington Times 2016; The Diplomat 2017a, b; Strauch et al. 2018). As a result, over time it has become like a laboratory of different approaches to meet ever increasing challenges. Some came in the shape of central government policy dictates from Ha Noi, some were promoted through external donor agencies, and others initiated by individual farmers with or without the support of local CBOs and NGOs. In terms of policy, many interventions did not take heed of the ongoing concrete practices, experiences, and possibly effective solutions of individual farmers who were by necessity already probing new solutions to meet daily challenges (The Diplomat 2017a,b; Quang and Weatherby 2019).

In considering T-learning, we also draw attention to farmers' climate vulnerability and adaptive capacity. Scaling down to local level, two community-based climate adaptation projects in Phong Dien District (Can Tho City) and Phong Dien Commune (Ca Mau Province) that are different in terms of geographical and socio-economic features were selected as case studies (see Figure 1). This section targets realities in these two areas in the Mekong Delta by way of two detailed case studies. Phong Dien is a

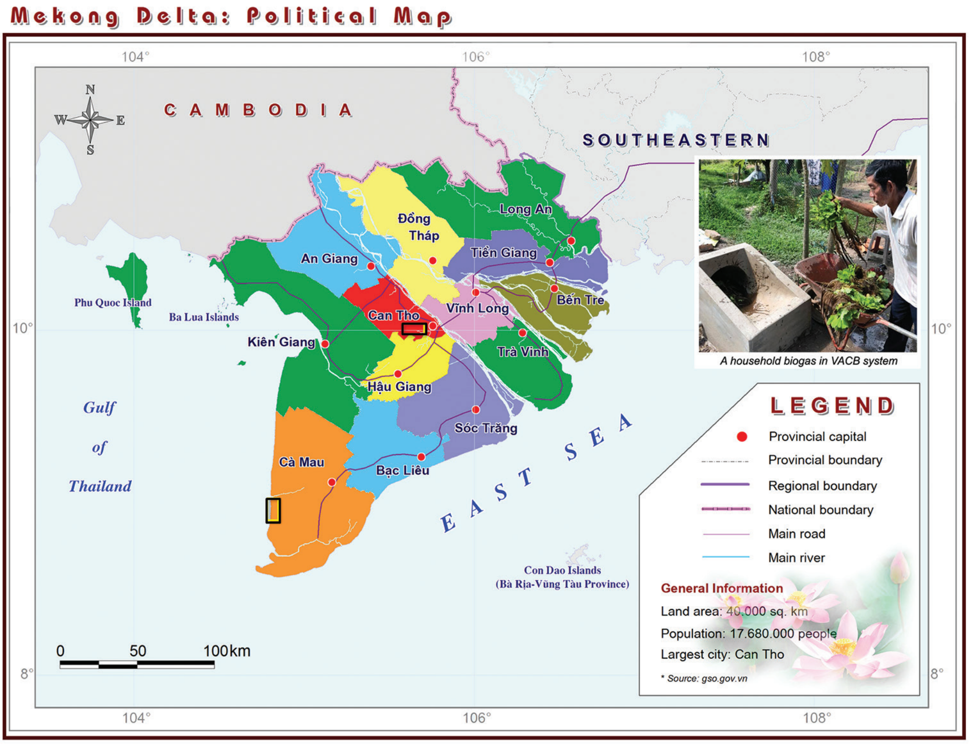


Figure 1. Areas of study (marked as black rectangles) in the Mekong Delta (by Authors).

district on the outskirts of Can Tho City – which is the central city in the Mekong Delta. It is well known for its floating market, paddy fields, and picturesque rural canals – and surrounded by water in massive waterways all somehow linked to the mighty Mekong. In contrast, the Phong Dien Commune of Ca Mau Province could hardly be more remote as it is located in the southernmost tip of Vietnam on the Gulf of Thailand. Its population is largely poor, unskilled and much more exposed to sea level rise, intrusion of salty water and extreme weather conditions. Since 2000, local farmers in Phong Dien Commune have been mobilized to switch from rice farming to shrimp farming, followed by industrialization, which has caused ecological conflicts due to huge deforestation and environmental pollution (Quang and Weatherby 2019). The following subsections aim to provide field-based analysis and some research findings to contribute to theorizing the role of T-learning in grassroots sustainable transition and climate-resilient development in the Mekong Delta.

T-learning in freshwater-based agriculture

Even while there has been relatively little attention, T-learning has been practiced in the Mekong Delta already since around 2000. It started with the engagement of a few agricultural and environmental academics and experts from Can Tho University, starting with a limited sample of six smallholder peasants in Phong Dien District.

Owning relatively small lands of less than one hectare up to 2 hectares and using mostly family labor engaging in monoculture, notably growing one crop of rice annually, much of this was for private consumption. As rice production grew ever more problematic given climate change with yields declining year by year, they believed they were smart to shift to planting orchards with oranges and mangos. Things went well for a time. Yet they were in for a bad surprise when – in the early 1990s – extreme weather conditions and a drop in fruit prices following much more production led numerous farmers to experience financial hardship – and to bankruptcy in some cases.

The evolution of these processes of joint "learning by doing" engaging peasants and experts will be depicted in this section, targeting innovative methods under what has come to be known as the VACB model. The VACB is a poly-culture model combining 4 elements: Vườn (literally meaning orchard), "Ao" (fish farming/fishpond), "Chuồng" (livestock farm), and Biogas. The objective of this model is to increase and stabilize farmer revenues and reduce the environmental burden caused by traditional intensive monoculture. This farming system is also family-managed, with practically all labor coming from the household.

The selected farmers are those who have years-long experience in farming and recognized prestige in their villages and who committed to sharing their experiences and progress reports with their neighbors. They were supported to set up a few "sample fields" where this low-carbon and climate-resilient agricultural VACB model was employed.

In the VACB model, ***orchards (V)*** usually vary from a few hundred to five thousand square meters and are comprised of fruit- or nut-producing trees that are generally grown for commercial production. Commonly grown fruit crops include orange, pomelo, mengteng (a sour, lychee-like fruit), durian, rambutan, and mangosteen. Vegetables grown include green onion, sweet potato, cress, tomato, cabbage and water spinach. Both perennial and annual crops are planted to provide year-round food to the house and products for the market. ***Fishponds (A)*** are usually constructed close to the house and surrounded by orchards. There can be a few small fishponds in a 1-ha orchard, with different shapes and an average depth of 1.2–2 m. ***The livestock pens (C)*** for pigs are constructed at the corner of the orchard close to the pond. Pig dung no longer gets washed into the river or becomes concentrated around the farm because it is drained by an installed bio-digester that transforms livestock manure through anaerobic digestion into fertilizer for algae (a commonly used food source for fish) and methane gas – an environmentally benign bio-gas (Bosold 2012). ***The biogas system (B)*** digests pig dung and vegetation and generates the methane gas byproduct, which is used for cooking, generating electricity, and pumping water for irrigation in the orchards. Digested and clean organic material then are released to the surrounding fishponds where it acts as fertilizer (Bosold 2012).

After two years of implementation, the VACB sample fields have resulted in fruitful outcomes with higher incomes but minimized polluting emissions. Many research findings confirmed that the VACB model is especially beneficial for women as it reduces the time that women spend in collecting fuel, cooking, and cleaning cookware

Table 1. Number of VACB participants by gender, age, and ethnic group.

Year	Participants	Gender		Age			Ethnicity	
		Male	Female	18–45	46–60	> 60	Vietnamese	Khmer
1996	6	6	0	2	3	1	6	0
2000	110	93	17	31	37	41	102	8
2008	300	269	31	87	101	112	277	19
2012	625	497	128	137	176	312	594	31
2017	642	513	129	135	184	323	597	45

Source: Chiem (2012) and Authors' 2017 surveys

dirtied by wood-smoke. It also saves them money by eliminating the cost of commercial gas or firewood and improves their health by managing animal waste and reducing indoor air pollution from woodstoves (Bosold 2012; Chiem 2012; Clare 2017).

Since 2000, the number of participants (family representatives) has rapidly increased year by year, from 110 in 2000 to 625 in 2012 (Chiem 2012), mainly due to technical and financial supports from Can Tho University and NGOs. From 2013 to 2017, the nationwide decrease in pig prices, along with other economic shocks associated with reduced support from Can Tho University, impeded the expansion of the VACB model to other communes (see Table 1).

T-learning in a disaster-prone area: narratives from MEF's project

Obviously, in relatively remote rural areas amongst male and female farmers who have not benefited from much education – with little teaching or training in terms of creativity or independent reflection – awareness of massive, cross border and global climate change developments and impacts, is limited. Government-led climate response policies have been tentative, with examples where initial solutions became problems themselves (Mongabay 2016; The Diplomat 2017a, b). Most farmers were, and are, expected to fend for themselves and there was little evidence of community-based approaches of sharing ideas, plans and actual novel practices. But in 2018, the Mekong Environment Forum (MEF) started to implement a project to engage with, and support, local communities. MEF brought together academics, agricultural experts, male and female farmers as well as village youths who are assumed to want to learn and hopefully initiate change in their local areas. The project was implemented with financial support from the U.S. Consulate in Ho Chi Minh City, under the name "Flying Cranes Project". It has a concrete problem-solving agenda in addressing key environmental threats: extreme weather and environmental conditions, and local non-sustainable economic activities, which, in turn, often contribute to water pollution.

The project objective was to build and develop community capacity in response to environmental changes through "learning by doing" and "adult learning process" (T-learning) approaches taught through a series of citizen science training workshops.

To meet those objectives and promote grassroots sustainable transition, MEF has implemented the following activities (Mekong Environment Forum 2018):

- Five experts and eight volunteer students from Can Tho University worked together to teach local farmers and youth new technologies and mobilize them to use these techniques in their day-to-day work. The goal was to gradually shift participants' livelihoods from traditional farming practices to a modern, eco-friendly agricultural model that could meet people's economic needs without degrading local ecosystems or increasing social disorder. Twenty small-scale shrimp farmers in Phong Dien commune (a coastal commune in Ca Mau Province) were selected to engage in T-learning under the supervision of experts and volunteers.
- A 2-hectare sample field was set up in the commune by the project to employ a climate-resilient poly-culture model. This model enables farmers to diversify their crops, shifting from intensive shrimp production to poly-crop in the same pond. Thus, it helps increase household incomes and economic self-reliance since farmers can harvest different profitable crops (seagrass, fish, crab) day-to-day while waiting for the main crop (shrimp). The poly-culture model encourages farmers to restore mangrove cover in the shrimp ponds to reduce impacts from weather extremes (such as high temperatures and cyclones), increase the local ecosystem's ability to absorb waste, and to offer natural food and shelter for naturally-occurring harvestable species (oysters, shrimps, fish and crabs).

In the demonstration site, land-owners were supervised by experts to do farming in a sustainable manner while other smallholders were invited to visit and observe how new techniques work, how water quality is naturally purified by the restored seagrass and mangroves, and how the poly-culture improves revenues through add-on crops. Three field-based meetings have been organized at the sample field – a kind of informal school where participants met regularly to share information, make regular field observations, and learn new techniques through practice.

Farmers were asked to compare what they learnt from the field-based school with their own past experiences in order to better understand how eco-friendly farming practices enable them to reach a long-term balance between nature and economic return. Most participating farmers agreed that the mangroves and seagrass help reduce their spending on food for shrimp and fertilizers for water treatment. They also learnt that the poly-culture may bring less shrimp productivity than they expect, but it demonstrates the potential to offer much more stable and sustainable income sources than traditional shrimp farming. The poly-culture model is a solution for the ecological conflict between mangrove conservation and shrimp farming in Mekong Delta coastal provinces. Their responses provided feedback to the team of experts and contributed to revisions of the model that will help this approach be more effective if it is applied elsewhere. The process also provided useful field experience for experts and students and will contribute to their professional development and future research.

Research results and discussion

Whereas learning ultimately is a matter for the individual, T-Learning explicitly targets the community. Assuming that learning is much enriched if their knowledge – what individuals have learnt but also what they learnt by doing – is shared, T-learning is ultimately about community sharing and learning. On the other hand, "community" cannot be assumed as each community is marked by divisions: of wealth, land ownership, gender and political affiliation. Yet all members share similar conditions in terms of the environment, the economy, culture and society. Conceptually, Sattanno et al. (2017) envision that a sustainable community is a "community where the air and water are clean, water supplies fully meet demand, everyone enjoys access to locally supplied safe and healthy foods, wildlife flourishes, and the landscape is pleasing to the eye. Within this community, full participation and a spirit of cooperation pervade decision-making." This, admittedly, is an almost romantic ideal of a self-sustained sustainable community, yet it may serve as a benchmark to measure when and where such conditions are being met.

Bridger and Luloff (1999), Fonchingong and Fonjong (2003), and Mezirow (2009) suggest five major indicators that measure sustainable community development, namely: (i) economic diversity and resilience; (ii) grassroots self-reliance; (iii) energy and environmental security; (iv) biodiversity conservation; and (v) social justice. This article employs the first four out of these five indicators as an analytical toolbox to understand in what ways T-learning has significantly contributed to local sustainability transition in the two areas of study.

T-learning helps increase local economic diversity and resilience

In the Flying Cranes Project, the project team organized two training workshops in Phong Dien commune (March and May 2019, respectively) to raise awareness about environmental changes, water insecurity, and sustainable development concepts among local community members. Before each workshop, the team carried out surveys to collect information and understand the urgent local needs. After completing the workshop, participants were asked to fill out a questionnaire with closed and open questions. Our comparison of the survey results from before and after the workshop indicates that locals' awareness of the role mangroves play in environmental protection and local water security was significantly improved. Below are some measureable outcomes excerpted from the project report (Mekong Environment Forum 2018).

- 35% increase in productivity and economic efficiency;
- Comparatively higher levels of income and economic diversity: after four months participating farmers have harvested 3 different crops from the same pond: fresh crab, shrimp and fish. The average income per monoculture crop (4 months) of each household before participating in the project was VND

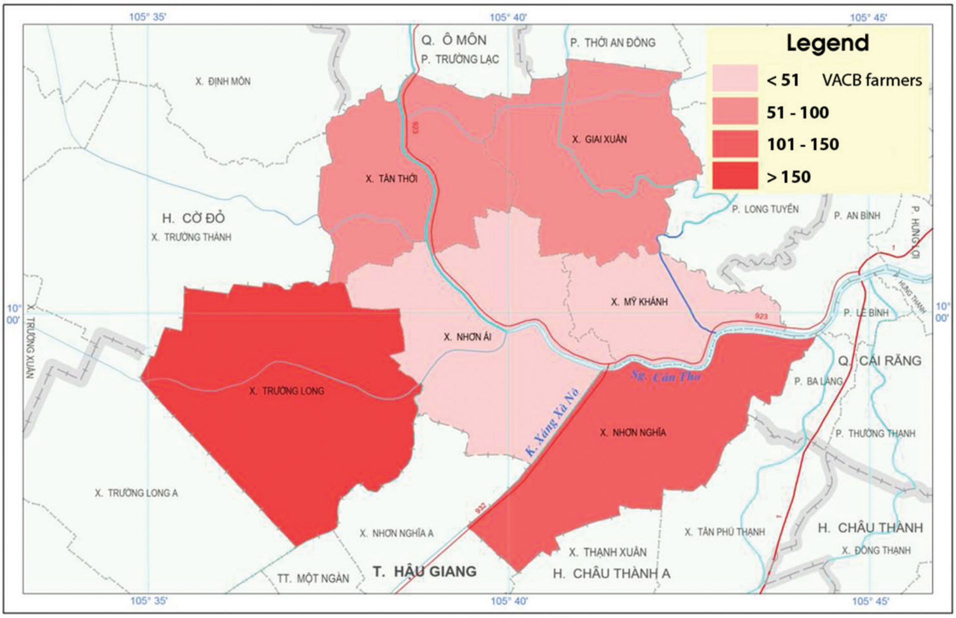
12,600,000 (approximately US$560). The average income after the first polyculture crop harvested in early September 2018 was VND 17,000,000 (approximately US$ 756). With the polycrop, farmers can harvest some kinds of fish inhabiting the mangrove and seagrass in the shrimp pond on a daily basis. The fish species are natural inhabitants from the river and grow up by themselves thanks to the food and habitat provided by the mangrove and seagrass;

- Cost savings and additional revenues:
  - In a traditional 4-month monoculture crop, a 1-ha shrimp pond needs VND 4,500,000–6,000,000 (approximately US$ 200–300) for fertilizers and pesticides.
  - Mangrove, seagrass and new techniques improve the water quality, reducing the costs for fertilizers, waste water treatment, and preventing common diseases. Participating farmers have invested VND 1,300,000 – 2,000,000 (less than US$ 100) per poly-culture crop for fertilizers to stabilize pH and water quality in response to weather uncertainties.
  - Shrimp is the main crop, but harvesting crab, seagrass (bulrush), and fish from nature provides additional daily income for shrimp pond owners while they await shrimp growth.

Let us now consider the evidence that was collected regarding the impacts for farmers who employ the VACB system. In 2017–18, surveys followed by in-depth interviews covering 120 farmers were conducted in four communes of Phong Dien District: Truong Long, Nhon Nghia, Giai Xuan, and My Khanh (see Figure 2). Information was gathered on household-level impacts of VACB project in terms of economic, energy, environmental, and sustainability areas. The outcome of comparing the revenues generated from VACB and from traditional crops is shown in Tables 2 and 3 respectively below. Most VCAB farmers managed to double their incomes, and in addition, to spread their risks through other subsidiary crops. Importantly, such households have reduced their debts and fewer incidences where they feel forced to migrate to cities and/or work as the number of wage laborers fell.

This is confirmed in a household survey indicating a reduced dependency on remittances from family members working elsewhere (Table 2). Many VACB farmers are now in a position to enroll children in higher education or specific professional training. On the whole they appear to have gained a stronger economic condition as they are more resilient, making new choices possible that used to be elusive. Farmers adopting the VCAB system may now diversify to work with crops or animals – smartly adjusting to changes, for example an unexpected drought/flood or a price fall. Hence they may be able to reduce working time in their fields as the system is entirely closed. This leads Eyler (2019) to say that VACB farmers "bring in nothing from outside of their farm, no pesticides, fertilizers, or antibiotics to maintain its productivity".

In responses to our surveys, VACB farmers in Phong Dien stated that their daily life now includes feeding their livestock, tending their orchards, and filling biogas digesters with pig dung, water cabbage, or biomass. "We really enjoy this farming model,



Scale 1: 100 000

Figure 2. Distribution of VACB system by communes in Phong Dien District (by T-learning research group in Can Tho University).

Table 2. Common VACB crops and average household income in Phong Dien District.

System components	Crops		Average revenue (in VND)	Shares to family income (%)
	Main crops	Additional crops		
Orchard (5,000 sq. m)	Orange		22,000,000	13.0
	Mengteng		16,000,000	9.5
	Pomelo		11,000,000	6.5
		Vegetables	4,000,000	2.4
Fishpond (1,000 sq. m)	Snake fish		15,000,000	8.9
	Bronze featherback		12,000,000	7.1
	Red tilapia		12,000,000	7.1
		Snail	13,000,000	7.7
Pigpen (10 pigs)	Pig		42,000,000	24.9
		Chicken/duck	8,000,000	4.7
Biogas	Methane gas*		14,000,000	8.3
Sub-total			**169,000,000**	**100.0**
Other income sources				
Temporary work (seasonal income-generating jobs)			–	–
Remittance from family members			–	–
Total			**169,000,000**	**100.0**

*Using methane gas for family cooking, irrigation and lighting helps a six-member VACB household saves approx. VND 14,000,000 by reducing need for commercial gas and electricity each year.
Source: household survey in December 2017 (n = 120)

Table 3. Average annual incomes with traditional crops in Phong Dien District.

Income sources	Average revenue (in VND)	Shares to family income (%)
Rice farming	26,000,000	35.6
Temporary work (seasonal income-generating jobs)	8,000,000	11.0
Remittance from family members	24,000,000	32.9
Poultry farm	15,000,000	20.5
Total	73,000,000	100.0

Source: pre-project household survey and in-depth interviews in 2017 (n = 120) and interviews with non-VACB farmers in 2018 (n = 35)

and maintaining the system doesn't require a lot of work. Now the system can take care of itself. Sometimes, I don't have to tend to it for a few weeks," said Mr. Le Hoang Thanh, one of the proudest and most ingenious VACB farmers in the Mekong Delta.

Participants have helped university experts to train other monoculture farming households in making the transition and have also been invited to conventional events, workshops, and TV talk shows to share their success stories.

Table 3 shows that farmers who have kept on farming in the traditional ways and often grow rice as a monoculture crop, do earn less, and are less able to cope both with climate change impacts and fluctuating market prices. It is important to note that many small-scale rice farmers are women. With their incomes irregular and less predictable, they keep searching for additional incomes though temporary, poorly-paid cleaning or productive work or other income-generating activities. This appears to specifically apply to farmers with less than 0.5 hectares of land. The incidence of sons and daughters migrating to big cities or industrial zones in search of better paid work is highest here, just like the importance of monthly remittances to their families. These may make up as much as almost one-third of their family annual income (Table 3).

So although the T-learning process endeavors to engage with all sort of farmers: bigger and smaller, rice or mango, male or female, young(er) and old(er), it is critical to stress that not all of them can be easily motivated or supported to change their ways. There is a cultural, socio-economic dynamic here. Nearly 80% of the Mekong Delta people are engaged in agriculture and fishery, and have done so for generations in the context of the one party-state of Vietnam. They are often rather passive in terms of self-reliance and self-confidence, their attitudes no doubt stemming from the ideology "the state leads and all should follow" (The Diplomat 2017a). Such historical, cultural and political factors need to be acknowledged in any intervention including novel models of T-learning. Innovation, creativity and publicly proposing new ideas can be a bridge too far for many: people may remain "very superstitious and overly protective," and not open-minded (Eyler 2019). When proposing and establishing T-Learning, it is critical to first map such information and build it carefully from there – at the risk of people not getting engaged and actually becoming a challenge to new ideas or solutions.

T-learning as a tool to build and sustain community self-reliance

The basic indication of sustainability is self-reliance, especially economic self-reliance (Bridger and Luloff 1999; Fonchingong and Fonjong 2003). A community demonstrates its self-reliance by showing that its members are confident and have the capacity and skills to garner and hold economic resources to meet their essential needs in a sustainable manner (Godfrey 2008). The measure of community self-reliance is based on a diverse set of indicators which are grouped into five clusters: (i) economic inclusive development, (ii) gender equity and female empowerment, (iii) water and energy security, (iv) community education, (v) community climate resilience. These five clusters and attendant component indicators were designed in accordance with the Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs).

Table 4 outlines the progress that the VACB communities in Phong Dien District have made in the given self-reliance indicator clusters. Targets were set to clarify what is meant by "demonstrated progress," and to clearly state expectations.

Given the figures shown in Table 4, the VACB communities in Phong Dien District have achieved two-thirds (17 out of 25) of targets set to demonstrate their self-reliance. The self-reliant VACB communities have also demonstrated progress in key goals that constitute the MDGs and SDGs, namely: Mobilized communities that continuously set and achieve their own development goals (Cluster 1); Empowered women and girls (Cluster 1 and 2); Improved access to safe drinking water and sanitation facilities (Cluster 3); Improved literacy and education (Cluster 1 and 4); Improved gender-equal access to and use of development resources (Cluster 2, 3 and 5); Improved land productivity and climate resilience of smallholder farmers (Cluster 5).

When the VACB communities have achieved the targets set to demonstrate their self-reliance, the VACB project gradually activates its exit strategy by reducing financial inputs and scaling down supporting activities with the exception of less-frequent staff visits and a post-project three to five months later in a select number of locations. Given that community leadership plays a key role in aiding the continuity and development of grassroots innovations, which operate in niches and require nurturing, the project's exit strategy also emphasizes training in community leadership and management.

Before this milestone was achieved, local communities went through a transition period during which T-learning workshops were the key activity to introduce new ideas and solutions without inciting doubt, dismay or concern. The workshops targeted local farmers, women, and ethnic minority representatives, many of whom are relatively conservative and not open-minded. For many years, local farmers have experienced noticeable changes to their environment that adversely affect their crop productivity, such as rising temperatures, irregular flooding and droughts, and environmental degradation.

In our training workshop, Lam Thi Suol, 41, an ethnic Khmer farmer in Phong Dien Commune, explained how she and her neighbors have been experiencing environmental changes in her village. "*It seems to be almost 2 times hotter than it was ten years ago. Drought season seems to last longer and longer with uncertain, unpredictable precipitation… In the past, we could drink water directly from rivers or pools while working in*

Table 4. Measuring VACB community self-reliance in Phong Dien District.

Cluster	Component Indicator	End target (locally set target)	Current progress
1. Economic inclusive development (MDG 1 and SDGs 1, 2: No poverty – No Hunger)	Proportion of community members are trained in income generating or livelihood activities	60–70%	63%
	Proportion of population participating in community activities, workshops, and meetings	50%	44%
	Number of community facilitators supported by local government	10 per commune	10 per commune
	Proportion of individuals reporting the ability to change their communities	10 per commune	10 per commune
	Proportion of population garnering economic surplus (revenue exceeds costs)	80% on	88%
	Proportion of ethnic minorities being benefited from the project.	60–70%	83%
	Proportion of project participants reporting the ability to meet their economic development goals	100%	100%
	Number of female trainees in workshops	45–50%	37%
2. Gender equality and women's empowerment (MDG 3 and SDG 5)	Proportion of women serving as T-learning group facilitators	30–40%	40%
	Family decision-making power	equal power	equal power
	Proportion of women supported by the project	45–50%	37%
3. Household water and energy security (MDG 7 and SDGs 6, 7)	To what extent communities are satisfying their household water and sanitation needs and improving hygiene for public health	3.0 (Capable) 4.0 (Effective)	3.0 (Capable)
	Proportion of households applying modern waste water treatment system introduced by the project (reduced household waste-water discharge)	100%	68%
	Households are able to generate electricity from renewable energy sources to meet their household basic needs (lighting, cooking, and irrigation)	Yes	Yes
	Decrease in purchasing household electricity from national power grid	Yes	Yes
	Decrease in commercial gas consumption	Yes	Yes
4. Community education	Proportion of community members trained in thematic workshops	60–70%	40%
	Proportion of households with at least one person mastering in VACB-related techniques and skills	50%	40%
	Intra-community information-sharing platform (social networks, smart phones, mobile apps, etc.)	Frequent	Frequent
	Community awareness of climate change effects and environmental issues	High	High
5. Community climate resilience (MDG 7 and SDGs 13, 15)	Misconception of climate change	No	No
	Proportion of population trained in food security and sustainable agriculture	60–70%	40%
	Proportion of households trained cost-benefit analysis	50%	40%
	Proportion of smallholders applying improved management practices and technologies on farms	60–70%	40%
	Presence of climate-resilient demonstration field in each commune	Yes	Yes

Source: household survey and in-depth interviews in 2017 (n = 120) *the rice fields. But in recent years, you see, the rivers get heavily contaminated due to saline intrusion, so we have to stop using this major water source, even for irrigation,*" she said.

Suol is among millions of farmers and fishermen in the Mekong Delta who completely rely on the waterways' fish resources and agricultural production for their subsistence, and have observed the changing circumstances over many years. With very low literacy rates, however, they were unable to understand the root causes of the problems they have been facing, and as a result, failed to search for a sustainable and resilient model that they could adapt their life to.

Thus, a series of T-learning workshops were regularly organized to build confidence, capacity and skills at the household and community levels. Suol and 650 other farmers in Phong Dien District (Can Tho City) and Phong Dien Commune (Ca Mau Province) have been invited to attend these workshops.

The T-learning activities in VACB and Flying Cranes projects demonstrate that changes in livelihood constitute a process of transformation in which trainees, or "T-learners," have gradually changed their mind, perception, attitude and confidence through new experiences. During the workshops, emerging environmental changes and challenges appear to serve as a disorienting dilemma forcing T-learners to reconsider their traditional perspectives and farming habits. Since most training workshops took place in local fields (orchards, fishing ponds, pastures, paddy fields, etc.), they can be described as "field-based schools" – a kind of institutional platform where participants (particularly farmers and experts) meet regularly to make information sharing, regular field observations and learn new techniques on the job. Local farmers are expected to compare what they have learnt from the field-based schools with past experiences to pursue eco-friendly farming practices that enable them to meet economic needs without degrading the local environment. In this T-learning process, local farmers were asked to work in groups in accordance with their expertise, interests, and geographical proximity.

More than 12 professional courses have been offered by CTU experts on different VACB-related topics, from horticultural diversification, swine farming techniques, swine disease prevention and treatment, fish hatching and fish stock management, to biogas plant construction and maintenance. Each training course, which was structured around a theoretical component followed by practical sessions, lasted normally from one to three days or sometimes longer and enrolled 30–40 farmers, women, and ethnic minority representatives. A few outstanding trainees from these courses were appointed to work as group facilitators to sustain and lead T-learning activities after the project completed.

T-learning promotes household-level energy and environmental security

The third sustainability dimension stresses the energy and environmental security which means that "the use of energy and material is in balance with the local ecosystem's ability to absorb waste" (Bridger and Luloff 1999). The VACB model in the

Mekong Delta is a visible example for this. In the VACB system, T-learning workshops have been organized to provide local farmers with techniques and knowledge to effectively use electricity while correctly managing the waste from agricultural activities such as straw, muck, biomass, etc. for household-level energy generation.

Since its inception until 2017, the VACB project has assisted local people in building 642 biogas digesters (Table 1). The project also organized pre- and post-installation training seminars to circulate digester-building techniques. The Viet Nam News (2014) reported that recent research findings estimate that a 2-cubic-meter bio-digester can reduce up to 3 tonnes CO_2, and each household using biogas can save 19,904 tonnes CO_2 equivalent per year due to displacing wood fuel and lowering deforestation in local forest.

The T-learning approach was also employed to make and promote behavioral changes essential to realizing the full benefits of bio-digesters. For generations, rural women have always completely relied on firewood for daily cooking. The traditional fuel, mostly collected from forests, is a free energy source for local residents; meanwhile biogas installation usually costs a family an average of VND 3,000,000 to 5,500,000 (approx. US$130–250) depending on biogas container size. Nonetheless, our household survey in December 2017 showed that using biogas for family cooking, irrigation and lighting purposes helps VACB farmers save up to VND 14,000,000 (approx. US$600) each year by reducing their need for commercial gas and electricity (Table 2). Thus, T-learning workshops were carefully designed to introduce bio-digesters as a clean, reliable and cost-effective source of power. In these workshops, we did invite farmers, who have successfully implemented the biogas system, to share their real-life experience and cost-benefit analysis. Their success stories are the ideal way to present and justify the significance of biogas. Participating farmers were asked to compare what they learnt from the field visit to biogas systems with their traditional fuel in order to better understand how the new solution matters. By doing so, T-learning activities build credibility and support for a new direction.

T-learning and biodiversity conservation

Somewhat related to the third dimension, a sustainable community is underpinned by biodiversity conservation and wise stewardship of natural resources. The results and narratives from the Flying Cranes Project are analyzed herein to clarify how T-learning contributes to fostering this sustainability dimension.

As sea level rise and saltwater intrusion into farmlands become more prolific, more and more rice farmers in coastal areas of Ca Mau Province are switching to shrimp farming as a way to sustain their livelihood. Many small-scale shrimp farmers preferred farming in an intensive way because of the higher yield. Intensive farming of shrimp crops, however, is doing harm to local ecosystems due to the overuse of chemicals to maintain water quality and mangrove clearance for shrimp farming expansion (Anh et al. 2010; Truc et al. 2018; Mongabay 2018). While local governments and greedy economic interests seem intent on boosting this high intensity, artificial style of shrimp farming, ecological conflicts are also emerging as new threats undermining years of economic progress following on from Vietnam's newfound strength – the shrimp farming industry (Quang and Weatherby 2019). In a clash between intensive shrimp farmers trying to expand their business at all costs, and the need to protect and preserve the local ecological riches, conservation and stability is clearly losing out.

The Flying Cranes Project was designed to help address these conflicts. The pre-project survey highlights that before participating in the project, most local farmers developed intensive shrimp ponds in which they had to invest a lot of money, much of which came from loans from banks, on food for the shrimps, medicines, fertilizers, and other chemicals to use in the pond to ensure productivity. To provide more space for shrimp farming, mangroves were cleaned out since local people believe that tannic acid extracted from mangrove trees is poisonous, harmful to their shrimp productivity. The overuse of fertilizers, medications, and chemicals has resulted in negative impacts on local environment, causing serious water pollution and soil quality deterioration (Anh et al. 2010; Truc et al. 2018). As a result, local farmers were unable to sustain their shrimp ponds due to frequent epidemic diseases caused by poor water quality as well as changes in weather patterns due to climate change. After years of borrowing money, and ultimately harvests that failed, many shrimp pond owners have no choice but to sell their land to pay debts and migrate to big cities to look for off-farm jobs because they were unable to make ends meet with traditional shrimp-raising methods (Mekong Environment Forum 2018).

In response to this situation, local governments in the Delta have implemented a conservation program that requires any farming activity to meet environmental standards and prohibits mangrove clearance. However, the reality is that most shrimp farmers are reluctant to change unless they have hit rock bottom (Mongabay 2018).

Through the Flying Cranes Project's training workshops in Phong Dien Commune (Ca Mau Province), educators raised the visibility of the deplorable environmental, economic and human rights impacts of non-sustainable development projects and old-fashioned farming practices and the viability of better options. They provided information on a wide range of water and energy issues. Also, they worked to generate awareness that efficiency and small-scale, decentralized and eco-friendly solutions are essential for meeting economic needs, alleviating poverty and protecting local ecosystems. The polycrop – an integrated farming system of shrimp, mangrove and natural marine species – was introduced and employed in a sample field in the commune.

The combination of using mangrove, seagrass, and polycrop techniques appears to be a viable alternative to help the local community meet their economic needs and maintain their livelihoods while reducing pressure on ecosystems. The significant reduction in fertilizers and chemicals reduces polluted waste water from shrimp ponds (see Tables 5, 6). Mangrove and seagrass help to naturally purify water and filter pollutants in the ponds. Participating farmers also learnt that fish and sick shrimps are also a major food source for crabs. Without crabs in the pond, some sick shrimps could fuel a possible epidemic disease that would wipe out the whole shrimp pond. However, crabs will eat the sick shrimps and thereby help prevent outbreaks. Farmers concluded that

Table 5. Pollution caused by intensive shrimp farming in the Mekong Delta.

Indicator	Measured		Per ton of shrimp (average 3.5 ton/ha)	
	Value	Unit	Value	Unit
Waste water	18,260–22,640	m^3 ha^{-1} $year^{-1}$	5,300–7,200	m^3 ton^{-1}
BOD content	1,082	mgL^{-1}	259	kg ton^{-1}
COD content	1,866	mgL^{-1}	769	kg ton^{-1}
TSS content	6,524	mgL^{-1}	1,170	kg ton^{-1}
Total N content	49.6	mgL^{-1}	30	kg ton^{-1}
Total P content	23.8	mgL^{-1}	3.7	kg ton^{-1}
N-NH3 content	14.3	mgL^{-1}	4.8	kg ton^{-1}

Source: Anh et al. (2010) and Truc et al. (2018)

Table 6. Average water quality observed and calculated in different periods of polyculture farming.

Indicator	Pollutant load		Vietnam Standards (QCVN 11-MT:2015)	
	Value	Unit	Value	Unit
Waste water(*)	0	m^3/ha/crop	0	m^3/ha/crop
BOD content	0.032	kg/m^3	0.039	kg/m^3
COD content	0.081	kg/m^3	0.117	kg/m^3
TSS content	0.102	kg/m^3	0.16	kg/m^3
Total N content	22.71	g/m^3	48	g/m^3
Total P content	10.32	g/m^3	15.6	g/m^3
N-NH3 content	0.08	g/m^3	0.1	g/m^3

* Normally, water used in polyculture farming ponds is reused for the next crops. No wastewater, therefore, is discharged into rivers.
Source: Mekong Environment Forum (2018)

the polycrop method results in fewer epidemic disease risks than with intensive shrimp ponds. Since all pond owners discharge waste water directly into the river – which is the major water source for the whole village – switching to a polyculture model is an important investment not only for farmers but their communities more broadly.

A few weeks later, the project team came back to assess how well local farmers apply new knowledge, techniques and skills learnt from the workshops to their work and life. We recognized that local farmers have begun to change their perception and habits. Some tried to sustain the last piece of mangroves in their ponds while some others agreed to diversify their crops with high-yield marine species. They also used water monitoring techniques more frequently to observe the water quality of both river and groundwater. Understanding the negative impacts caused by wastewater discharged from neighboring intensive shrimp ponds, some farmers raised their concerns over the current policy that encourages intensive shrimp farming, but lacks serious consideration for environmental justices.

The progress from Flying Cranes Project demonstrates the role T-learning plays in transforming local perspectives and traditional practices. New ideas are often associated with difference, change, and upheaval, especially when introduced into a well-established community culture. In Phong Dien Commune, where shrimp farmers traditionally perceived mangroves as the "enemy" of shrimp productivity, and where intensive shrimp farming remains most preferred as its potential earnings are higher, it is unlikely to persuade people to re-forest in their shrimp ponds. Thus, the positively changing perspective and habits of farmers engaged in the Flying Cranes Project demonstrates that T-learning workshops and attendant real-life experience can be an effective strategy to mobilize and support local farmers to transition to more harmonious agricultural paradigms.

The above-mentioned results and analyses reaffirm an important argument of this paper: T-learning can be seen as an appropriate form of education for sustainability since it offers unique learning opportunities for adult learners to gradually change their perspectives and behaviors through real-life experiences in on-the-ground activities. In our projects, T-learning demonstrates that it's an effective educational approach to sustainable transition communities that remain overly protective and reluctant to embrace innovative strategies. T-learning activities were designed to utilize and combine tacit knowledge, such as the ability to work, modern techniques, and community leadership, to empower local people to change and respond to their concerns in proper, sustainable, and impactful ways. In the T-learning process, smallholders are individuals who learn to change themselves and then circulate their new experiences to inspire and facilitate their neighbors to change. As the progress of T-learning has formed a nexus of multi-stakeholder relationship (local farmers, academics, policy makers, enterprises and investors), individual changes quickly increase the likelihood of a broader social change being sparked by interacting with other stakeholders and actors in the nexus.

T-Learning in sustainable transition: impediments and the role of students

The results of VACB and the Flying Cranes Project outline some issues and emerging challenges that need to be addressed in up-scaling T-learning activities in the Mekong Delta. Our focus group discussions and in-depth interviews with 120 T-learning farmers in October and December 2017 highlight a few factors and barriers that are obstructing the transformative process in grassroots communities. These are outlined in Table 7.

The first prominent challenge to the continuity and expansion of T-learning based projects is the limited support from donors (such as universities, economic stakeholders, NGOs, etc.). Almost 90% (n = 107) of respondents argued that they need seed funding, technical training and other skills to transition away from traditional practices to the new mode of livelihood. In order to help farmers who participate in T-learning projects, increased financial and technical support as well as training activities are crucial components to address the problems that remain in local communities, especially those in disaster-prone areas.

The second challenge is the lack of infrastructure to facilitate community learning (n=83). T-learning farmers live in rural villages where the means of communication and transportation remain limited or outdated. Many villages do not have adequate public spaces for community learning activities. As a result, T-learning workshops in the Mekong Delta often take place in the homes of farmers where the proper equip-

Table 7. Major factors and issues challenging the development of T-learning.

No.	Factor description	Frequency (# of respondents)
1	Lack of financial and technical supports	107
2	Lack of facilities for community learning	83
3	Policies and supports from local government	57
4	Poor commitment (farmer learners may stop pursuing the grassroots innovations whenever they find other solution which they believe can bring them higher potential earnings)	42
5	Lack of intra- and inter- community information sharing	28

Source: focus group discussions in 2017 (n = 120)

ment for training is not available, such as blackboards, flipcharts, office supplies, and projectors. Additionally, both the homeowners and participants usually find this arrangement uncomfortable.

Policies and support from local authorities also play an important role. 57 farmers who were interviewed (47.5%) pointed out that even though the T-learning process has promoted sustainability transition and poverty reduction in communities, local government authorities remain passive and, thus, have not really embraced T-learning initiatives. This explains why local government budgets are not reallocated to fund community learning centers and support training workshops. Consequently, T-learning project organizers have no choice but to apply for limited funding from donors and sponsors, such as NGOs and university research grants.

Another challenge that needs to be addressed is farmers' lack of commitment towards T-learning projects. About 35% (n = 42) of respondents contend that they might stop following farming practices introduced by T-learning activities to try other solutions if they see it could bring in higher potential earnings. This can lead to disruption and waste of supportive inputs offered by T-learning projects.

The fifth barrier impeding the up-scaling of T-learning activities is the lack of information shared between T-learning farmers and their neighbors, between farmers and experts, as well as inter-community communication. Smartphones, internet-based social networks (Facebook, Zalo, Youtube, etc.) and online resources are the most popular convenient methods of communicating and sharing information. About 23.3% (n = 28) of respondents said that they do not have a smartphone and are not familiar with those social networking apps and websites. They also find it difficult to learn and apply new techniques, especially those that require technological equipment, such as mobile sensors, to share their experience and field-work results with their neighbors, local experts, and other communities at large.

To that end, our T-learning projects have spotted many group participants who are young, well-educated farmers and university students. They have served as a bridge between local farmers and experts by helping to communicate concerns and share solutions. They have also helped connect local T-learning groups with international communities, including academic institutions and journalists. Some T-learning demonstration sites and participants, like Mr. Le Hoang Thanh, have been widely recognized in books, PhD dissertations, and international magazines. Thus, local youth and students become the best choice to take over this position in T-learning projects.

Unfortunately, young people's participation remains limited in the grassroots transformative learning process in the Mekong Delta. Young farmers and students are the next generation in communities who will in time inherit the mantle of their family's farming livelihood or leadership. They typically have greater access to higher education than previous generations and keep themselves well-informed of the latest technological developments. Given the fact that local youth and students are likely to shoulder the negative impacts posed by present-day developments, it is vital that they assume an increased role in the grassroots T-learning process. Furthermore, engaging in T-learning projects offers local students ample opportunity to employ what they have learnt in school to assist their community. The real-life experience from demonstration sites, in turn, provides best "disorienting dilemmas" and aspirations for their self-reflection, self-adjustment and changes. Without such a connection between grassroots T-learning and school-based T-learning, students may not effectively promote the transforming process.

Concluding remarks

Against the backdrop of a relatively acute environmental crisis in parts of the Mekong Delta, this paper aimed to outline an innovative approach of "bottom-up" learning and sharing amongst and for at-risk grassroots communities: T-learning evolved as a counterforce to rather "top-down" climate change policy by starting from local realities. It includes both a focus on specific local environmental problems, and targeting local consultation, mapping and sharing learning-by-doing processes, and community strengthening through capacity development. There have been rather too many ill-conceived development projects with ever changing components, leading to what we can term "disorienting dilemmas" that force poorly-educated small-scale farmers, women, and ethnic minorities often in remote areas to transition to a low-carbon, sustainable economy.

Based on a detailed investigation of two Mekong Delta districts where T-learning has been introduced in recent years, initial findings indicate that T-learning can be a viable, effective and attractive approach to empower peasants to have a voice and to be taken seriously as practitioners or citizen scientists in their own domain. Comparing case studies from Phong Dien District and the quite different Phong Dien Commune did indeed confirm that community climate-resilient initiatives may need different framing and targeting due to various physical and socioeconomic conditions, and what works in one context or area may not work in another. Yet, the T-learning strategy implemented in the two case studies itself proved neutral and effective as a tool to be employed uniformly. It was shown that T-learning should be considered as an adult-learning approach which allows for, even promotes novel grassroots innovations. And if it works well, new insights, unexpected views or interpretations can in turn be applied by policy makers for development and implementation.

As was shown in the two case studies, the success or effectiveness of T-learning is greatly enhanced if local level policy makers get engaged in such learning and knowledge sharing processes. Yet T-learning harbors more appropriate climate and environmentally-friendly methods. The case studies showed that it already led to increased self-confidence among affected farmers, while reducing levels of doubt, dismay or concern. For many people, T-learning was a unique experience as they were taken seriously as adult learners. Local farmers broadened their horizons, and participated in sessions and seminars, meeting and talking to likeminded individuals in similar fixes. Impacts were also shown in terms of community development as new ties and alliances emerged beyond households, and among local stakeholders. Key strategies in this specific type of adult education include concrete matters such as initial seed funding and technical training, the transfer of specific technology or methods, capacity development for community leadership and improved participant commitment.

Finally, the paper contributes field-based evidence to demonstrate that T-learning is indeed a viable bottom-up approach to come to grips with very urgent negative dynamics of environmental distress and alarming signs of climate change affecting the Mekong Delta farmers. It offers a model of local level engagement which can contribute to climate-resilient development for vulnerable grassroots communities in Vietnam, and neighboring countries that share many of the same issues. Four major measures of sustainable community development that T-learning has significantly contributed in the research sites include economic diversity and resilience; grassroots self-reliance; energy and environmental security; and biodiversity conservation. With a view to further enhancing the relevance and geographical spread of the approach it is proposed to work towards establishing "field-based schools" which can be a transfer point for real-life local experiences and lessons learnt and shared under such an incremental learning process by doing trajectories. If these were to also include policy makers and, where interested, commune and higher level officers join and get engaged, it could grow into novel and constructive ways of multi-stakeholder climate action.

Mekong Delta farmers have shown themselves over many years to be flexible by adapting to ever changing environments and climate impacts. T-learning offers the potential to start from their realities, their trials and errors to keep afloat in view of the sustainable livelihoods that they deserve. Once convinced through local discussions, expert advice and ideally government blessing, they will be more willing to change their practices and work collectively towards a better future.

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RESEARCH ARTICLE

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Snake oil and pangolin scales: insights into wild animal use at "Marché des Fétiches" traditional medicine market, Togo

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Abstract

Traditional medicine beliefs are culturally important in some West African communities, where there is a thriving domestic consumer demand for wild animal derivatives. Yet, such practices can threaten the conservation of wild populations and negatively impact animal welfare. To identify those species most likely to be affected, we investigated wildlife derivative trade at the largest fetish market of West Africa in Togo. Specifically, we asked what wild animals or animal products were most profitable, which wild animals were perceived by vendors to have increased most in rarity and what they were used for. A key question was whether vendors also sold plant-based alternatives. Vendors provided 36 local animal names, from which we inferred an estimated 281 species. Thirteen percent of these inferred species are categorised on the IUCN Red List as threatened (*n* = 35); 26% are declining (*n* = 72). The most commonly cited most profitable wildlife derivatives were "Pangolin" and "Python"; the most commonly cited most profitable live wild animal was "Chameleon". Overall, wildlife use was predominantly spiritual rather than medicinal. Plant-based alternatives were available, but comprised < 40% of sales and appeared to be considered less important or less useful than wild animal products. The legal status of this domestic trade in Togo is unclear given the existence of potentially conflicting national legislation. In addition to further research focused on the actual impacts on populations and individuals of the species indicated, socio-economic importance of this trade, societal pressures driving consumer demand and an assessment of the feasibility of sustainable plant-based alternatives is warranted.

Keywords
Animal Welfare, Conservation, *Phataginus tricuspis*, *Python regius*, Wildlife Trade

Introduction

For millennia, traditional healers have used wildlife with the intention of maintaining human well-being and to treat, diagnose or prevent sickness, based on both observable physical symptoms or perceived supernatural forces (Alves and Rosa 2013). Such practices remain widespread; in the 1990s, approximately 80% of the global human population was thought to still rely primarily on animal and plant-based medicines (WHO/IUCN/WWF 1993). As a result, wildlife used as traditional medicine remains extremely varied, involving a vast array of species from all taxonomic groups (e.g. Soewu 2008; Williams et al. 2014; Svensson et al. 2015). Although, in some situations, traditional medicine is categorised, controlled and practised publicly, in others it remains clandestine, supernatural and localised (World Health Organization 2002).

Traditional medicine and fetish beliefs have been identified as being important for the culture of African people, especially in the central (Pauwels et al. 2003), southern (Simelane and Kerley 1998; Herbert et al. 2003) and western (Fretey et al. 2007) countries where there is a thriving domestic consumer demand for wild animals and their derivatives (e.g. Djagoun et al. 2018). It has been suggested that their decision to consult a traditional healer and/or purchase traditional medicine may be because traditional healers are far more accessible than university-trained medical doctors to most of the population in these countries, particularly those living in rural areas, where there is a relatively low ratio of doctors to patients (Williams 2007; Williams and Whiting 2016).

When carried out unsustainably, the use of wildlife as traditional medicine, whether used legally or illegally, can threaten the conservation of wild populations through biodiversity loss and species loss (Moorhouse et al. 2020). It also has negative impacts on wild animal welfare during capture, captive breeding, transport, sale and slaughter (Baker et al. 2013). Furthermore, from a domestic perspective, more than half of human global population growth between now and 2050 is expected to occur in Africa (United Nations 2018). From an international perspective, there also are concerns that illegal actors are increasingly sourcing wildlife from African countries for traditional medicine uses elsewhere [e.g. African pangolins (Manidae spp.) for use in China (Ingram et al.

2018)]. In light of these predicted trends alone, it is clear that Africa will play an increasingly central role in shaping the scope and scale of the use of wildlife as medicine and its impact on the animals involved, in the decades to come (Williams et al. 2014).

One of the difficulties in tackling potentially unsustainable wildlife trade is identifying those species that are most at risk and thus warrant intervention. In this regard, market surveys can be useful where wildlife and their derivatives are sold (Harris et al. 2015). The trade in wildlife as traditional medicine in southern Africa is thought to be significant and widespread; however, it remains poorly understood (and little recognised in scientific literature) with only baseline data having been collected for a relatively few select areas in Southern Africa (but see, Simelane and Kerley 1998; Whiting et al. 2011; Segniagbeto et al. 2013; Williams and Whiting 2016; Djagoun et al. 2018; Dossou et al. 2018). In Togo and other West African countries, studies are particularly lacking. A previous study of the "Marché des Fétiches" (French for fetish market), situated in Lomé (the largest fetish market in West Africa) by Segniagbeto et al. (2013) was restricted to reptiles. These initial studies point to the growing need for baseline data on the species most used, the nature of their use and the socio-economic importance of the trade and to identify those species that might be threatened by over-exploitation or subject to inhumane use. Studies to better understand consumer demand and to consider appropriate alternatives, such as sustainable "herbal" (plant-based) substitutes (Moorhouse et al. 2020), have also been recommended.

The focus of our study was the traditional medicine market, the "Marché des Fétiches", in Lomé, the capital city of Togo. Through socio-economic questionnaires, we aimed to gain insight into the diversity of species sold and their commercial and medicinal value. In particular, we sought to identify: (1) those species perceived to be most commercially profitable by traders (i.e. those that sold for most money), both in terms of live animals and their derivatives; (2) those species deemed to have increased most in rarity; and (3) initial information regarding the vendors' knowledge of any herbal alternatives to these wildlife-based derivatives. Our objective was to identify potential conservation threats and welfare concerns, to provide preliminary information on the nature of consumer demand and the current availability of plant-based alternatives.

Methods

Survey area

The "Marché des Fétiches" is situated in Akodessewa in the east of Lomé, the capital city of Togo (Segniagbeto et al. 2013). Since the late 1990s, the "Marché des Fétiches" has grown to be the largest market for traditional medicine in West Africa (Segniagbeto et al. 2013). Although bush meat is sold at other markets in Lomé, it has not been openly observed for sale at the "Marché des Fétiches" (Segniagbeto, pers. comm.). The market ultimately services the urban population from the city, as well as rural and urban healers and consumers from neighbouring areas seeking to purchase products which they are unable to source locally (Segniagbeto et al. 2013). The market was moved from Bè market "Marché de Bè" to Akodessewa in 1998 and, since 2013, has also operated as a tourist attraction. As such, the throughput and turnover of some wildlife derivatives may be low in comparison to other markets elsewhere (with parts of some species remaining at stalls for years, serving as ornaments to draw tourist attention, with only small pieces being sold at irregular intervals). Wildlife trade is conducted openly at the market, even though some species are protected under national legislation. For example, Segniagbeto et al. (2013) reported the sale of several reptile species [e.g. marine turtles (Chelonioidea) and pythons (Pythonidae)] that were legally protected in Togo under Article 62, Section 2, Chapter II of law N° 2008-005, regulating environment protection and wildlife conservation.

Data collection

Interviews were conducted by four local field staff asking a set of predetermined questions that included open-ended, closed and multiple-choice questions (see Appendix 2). Interviews were conducted in Ewe, Fon and French and later translated into English. Surveys were carried out with vendors at five of the eight stalls that were in operation at the time. Vendors were interviewed once in September (22nd–23rd) 2018 on trade in wildlife and a second time in February (19th–20th) 2019 on plant-based alternatives. Vendors who were willing to participate in the study were identified through a process of chain referral (Newing 2011), whereby participants recommended other potential participants or persuaded others to take part. In accordance with the British Sociological Association Statement of Ethical Practice (BSA 2017), informed consent was obtained verbally from every survey participant prior to the interview, participants were made aware of their rights to voluntarily participate or to decline, no identifying participant or household data were collected and the database collated was entirely anonymous. In addition, vendor stands were coded in the database and names not reported to further protect study participants from harm or discrimination (St. John et al. 2016).

Specifically, vendors were asked to identify and rank the 10 wild animals (using local common names and excluding invertebrates) that they currently considered to be the most profitable (with wildlife body parts and live animals considered separately) and the 10 wild animals that they considered to have most increased in rarity (and therefore inferred reduced availability) over the past five years. Vendors were also asked to provide additional information including the wildlife body parts sold, their minimum and maximum price, estimated number of units sold (in the last year, last five years and last 10 years) and their intended medicinal / spiritual purpose. Interviews also involved additional questions focused on "Python" (*Python* spp.) and "Pangolin" (Manidae spp.) as these common names were most commonly cited as being the most profitable wildlife species sold as derivatives at the market following initial questions (see Appendix 2). Python/pangolin-specific questions focused on specific body parts sold, purpose and price per item, source locations, estimated number of animals sold, customer type [tourists (1 visit), casual customers (< 5 visits per year) and regular customers (> 5 visits per year)] and species availability (a mean "availability score" was calculated based on respondents' answer to the question on how available pangolin / python is now, compared to five years prior) (see Appendix 2).

The same vendors were also asked questions related to the sale of plants as traditional medicine (see Appendix 2). Initial questions focused on whether they had any awareness of plant-based items that could be used to treat medical and/or spiritual issues and, if so, could they identify the three most common plant-based items sold and state their purpose. They were also questioned regarding whether they themselves sold any plant-based items, if not why this was the case and, if so, to provide an estimate of the proportion of their sales that involved plant-based items. Vendors were also specifically asked about their awareness of any plant-based items that could be used as direct replacement for "Python" (*Python* spp.) and "Pangolin" (Manidae spp.). The availability of plant-based items at a herbal market in Lomé was confirmed using local common names (see below) provided by vendors.

For both wildlife and plants, local common names provided by vendors in Ewe and Fon were translated into English. A list of inferred species and their respective scientific names were assigned to each common name based on the documented presence of wild populations in Togo, according to Amori et al. (2016) and Segniagbeto et al. (2007, 2011, 2014, 2015). Where taxonomy differed in more recently published assessments, we used scientific names according to the International Union for Conservation of Nature Red List of Threatened Species (IUCN 2020, hereafter the IUCN Red List). For all species, information regarding their conservation status was also gathered from global species assessments on the IUCN Red List because national level assessments are not yet available for Togo. Threat status was recorded in accordance with the 2001 IUCN Red List Categories and Criteria system (version 3.1) as Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC) or Data Deficient (DD). For all species, information regarding their international legal trade status was gathered from the Convention on the International Trade in Endangered Species of Flora and Fauna website (https://www.cites.org).

Data analysis

We used descriptive statistics to describe patterns and trends in the data to determine if the frequency of species and type of wildlife product, cited as being the most profitable body part, were distributed similarly. Statistical analysis was carried out using R statistical software version 3.4.1 (R Core Team 2017). Wilcoxon-signed rank tests were used to compare cost between medicinal and spiritual sales and a Spearman correlation was used to test for a relationship between product cost and the number of items sold (please note, costs were not adjusted to allow per kg comparison). Monetary values were reported in West African CFA Francs (CFA) and converted to US dollars (USD) using 1 CFA = 0.0017 USD (conversion rate as of 21.06.19, https://www.xe.com). To provide a preliminary visual overview of the types of uses for animals and/or their derivatives sold, uses communicated by the traders were simplified, summarised and then categorised into short word strings. The words in the strings were hyphenated in places to keep them together to generate word clouds produced by the "wordcloud" package in R in which the sizes of the words are proportional to the frequency with which the words (i.e. uses) occurred (i.e. were mentioned by traders). The packages "tm", "SnowballC" and "RColorBrewer" were also used to create the word clouds (cf. Forrester et al. 2017). A word cloud was generated for the number of times a common name was associated with a use, thereby indicating the animals with the most number of uses mentioned by the traders. We did not attempt to categorise uses into themes or to carry out an in-depth thematic analysis, due to consideration of content variability (i.e. vendor answers relate to both product value and rarity of a range of different types of products that likely differ in their uses) and small sample size (five vendors interviewed). The reported frequency in the word clouds reflects both the number of vendors using a particular word and the number of times the same word was used by a vendor. Therefore, the resulting word clouds, provided herein, cannot be used to distinguish between words that were used repeatedly by only a single vendor and those that were used repeatedly by several vendors.

Results

Three male and two female vendors, whose ages ranged from 17 and 45 years, participated in our study. Participants consisted of both married and single individuals from the Fon and Watchi tribes who lived in households with between two and six people, with between zero and six children. All participants were educated to primary school level, all were animists and were originally from Benin (Abomey), having moved to Lomé, Togo. All participants stated that they used traditional medicine as their main form of income (actively trading between two and 30 years) with an estimated income of between 1,644 USD and 20,552 USD per year.

Overall, during our questionnaire, participants used 36 distinct different common names to refer to the wildlife species traded (Fig. 1a; Suppl. material 2). The most frequently mentioned common names (*n* = 130 total responses from five vendors for the ten most profitable body part / live animal that you currently sell including the price and purpose) were "Lion" (*Panthera leo*) (*n* = 9; 7% of responses), "Python" (*Python* spp.) (*n* = 8; 6%), "Chameleon" (*Chamaeleo* spp.) (*n* = 8; 6%), "Viper" (Viperidae) (*n* = 7; 5%), "Pangolin" (Manidae) (*n* = 7; 5%), "Big cat" (Felidae) (*n* = 7; 5%), and "Crocodile" (Crocodylidae) (*n* = 7; 5%) (Fig. 1a). The most frequently-cited type of product traded was a live animal (*n* = 43; 33%), followed by the entire dead animal (*n* = 31; 24%), skin (*n* = 20; 16%) and head (*n* = 19; 15%) (other parts sold included bile, bones, feathers, feet, head, scales, skin, teeth and toes, Appendix 2). Overall, 28 different medicinal and spiritual uses were cited by participants (Fig. 1b). The most commonly-cited uses (*n* = 117 total uses from five vendors for the ten most profitable

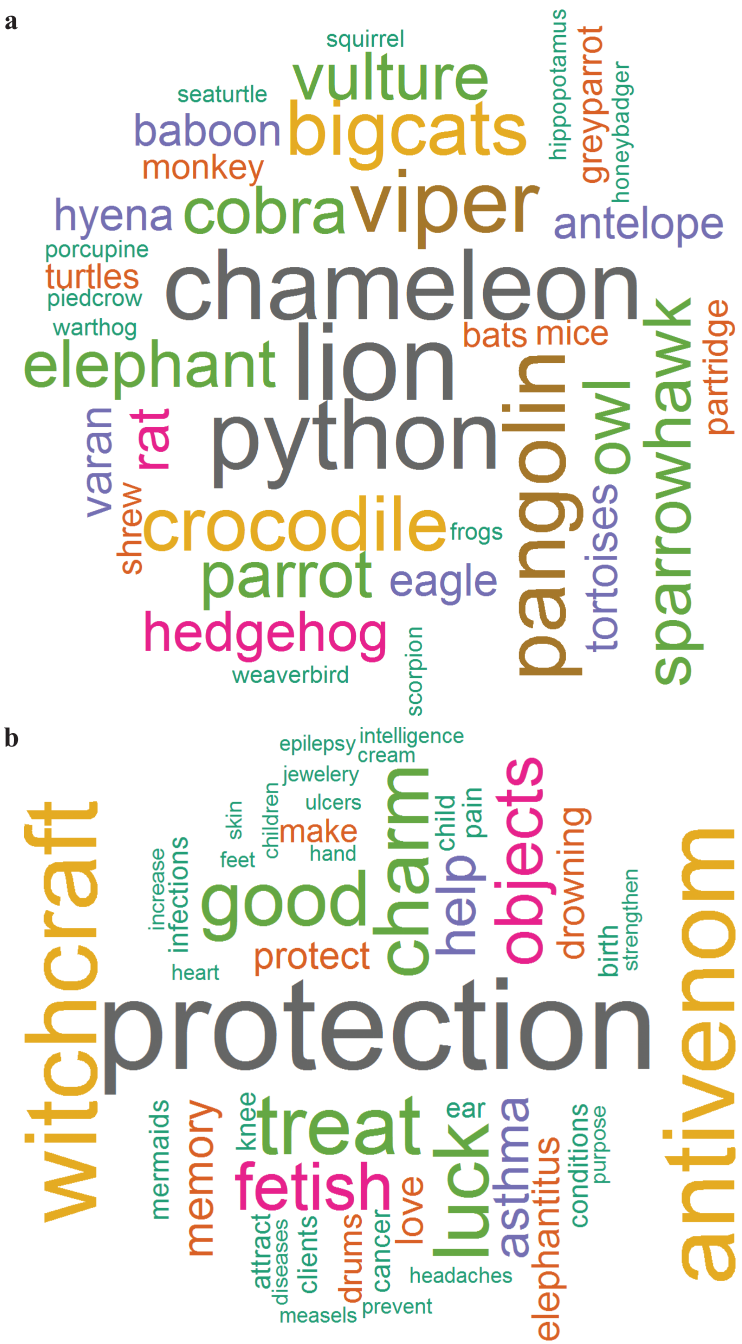

Figure 1. Word cloud of **a** the cited common names provided by vendors when asked to list the most profitable wildlife derivatives, most profitable live wild animals and those species that have most increased in rarity (n = 130 total responses) and **b** the cited purposes provided by vendors when asked to list the most profitable wildlife derivatives, most profitable live wild animals and those species that have most increased in rarity (n = 117 total responses). Size of text is proportional to frequency of words in interviews. Frequency reflects both the number of vendors using the word and the number of times the word was used by the vendor.

body part / live animal that you currently sell including the price and purpose) were "protection" (*n* = 18; 15%), "anti-venom" (*n* = 15; 13%), "witchcraft" (*n* = 15; 13%) "good luck charms" (*n* = 11; 9%) and "fetish objects" (*n* = 9; 8%) (Fig. 1b).

Across all species and product types, at the time of asking, items sold for between 0.26 USD (for a single "Chameleon" body part) and 765 USD [for a "Hippopotamus" head (*Hippopotamus amphibius*)] and the number of items sold per vendor for each product ranged between 10 [for individual live "Cobra" (Elapidae), "Monitor lizard" (Varanidae), "Python" and "Viper"] and 600 items (for live "Chameleon") (Suppl. material 1). The most expensive individual items were derived from "Hippopotamus" (765 USD), "Warthog" (*Phacochoerus africanus*) (425 USD), "Hyena" (200 USD), "Lion" (79 USD), "Sea turtle" (Cheloniidae / Dermochelyidae) (77 USD) and "vulture" (Accipitridae) (72 USD), followed by "Squirrel" (Sciuridae), "Baboon" (Cercopethicidae), "Parrot" (Psittaciformes), "Crocodile" (Crocodylidae), "Pangolin" (Manidae) and "Eagle" (Accipitridae) (min/max = 18/43 USD, Appendix 2). The items sold in the highest numbers were live "Chameleon" (600 animals), "Viper" (500 animals), "Honey badger" [*Mellivora capensis* (300 animals)], "Cobra" (200 animals), "Monkey" [Cercopithecidae (200 animals)] and "Turtle" [Testudines (200 animals)] (Appendix 2). The least expensive individual items were derived from "Chameleon" (0.26 USD), "Frog" [Amphibia (0.34 USD)], "Pangolin" (0.34 USD), "Sparrow Hawk" [*Accipiter* sp. (0.34 USD)] and "Shrew" [Soricidae (0.51 USD)] (Appendix 2). The items sold in the least numbers were live "Cobra", "Python", "Monitor lizard" and "Viper" (all 10 animals, respectively) (Appendix 2). No correlation was found between minimum price and the number of items sold (rho = 10.17, *n* = 41, P = 0.29).

The two most commonly cited "most profitable wildlife derivatives" originated from "Pangolin" (four of the five vendors interviewed) and "Python" (four vendors), followed by "Lion" (three vendors), "Owl" (Strigidae spp.) (three vendors) and "Viper" (three vendors) (Fig. 2). All five vendors listed "Chameleon" as amongst the most profitable live wild animals. The other most profitable live wild animals were "Cane Rat", "Cobra", "Monitor lizard", "Python", "Turtle" and "Viper" (all three of the five vendors, respectively) (Fig. 2). In total, 15 species were cited as profitable as both derivatives and as live animals by at least one of the five vendors; ten were cited only as profitable as derivatives and seven species only as profitable as live animals (Fig. 2). With regards to increased rarity, all vendors suggested that "Lion" and "Big cats" had declined. The other species stated to have most increased in rarity were "Baboon", "Crocodile", "Elephant", "Hyena" and "Pangolin" (all two of the five vendors, respectively) (Fig. 2). Seventeen species were identified as having become rare by at least one of the vendors.

Overall, during our questionnaire, participants used 16 different common names to refer to the plants sold as traditional medicine (Suppl. material 2), although the five vendors appeared to sell different plant species (there was no single plant species sold by all five vendors). The most commonly-cited plant-based alternatives were "Akouema" (*n* = 3; 60%) and "Hehema" (*n* = 3), followed by "Ahehe" (*n* = 2), "Midohoungbe" (*n* = 2) and "Olikpekpe" (*n* = 2). All five participants acknowledged their awareness

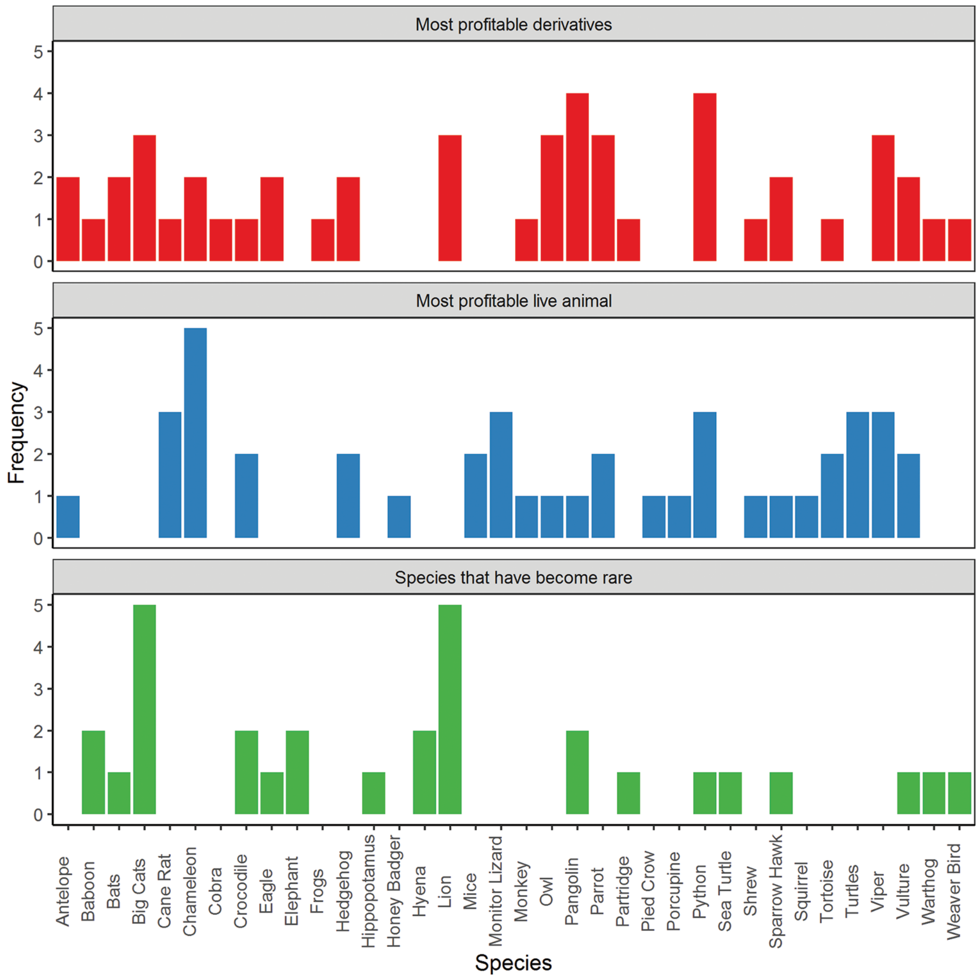

Figure 2. Frequency of species described by respondents as having the most profitable derivatives, most profitable as a live animal and species they considered to have most increased in rarity.

of herbal alternatives; however, only three confirmed that they prescribe any medical treatments / spiritual items that are plant based. All five participants reported that > 60% of the products sold were of wild animal origin. They also stated that animal derivatives were required in combination with herbal products; and one suggested that wild animal-based derivatives were more powerful. Although herbal vendors provided samples for all of the plant-based products, none of the samples could be identified due to the partial dried nature of the specimens.

Overall, we estimate that the 36 distinct common names potentially refer to at least 281 different extant species in Togo, including 49 amphibians (Amphibia), 59 birds (Aves), 140 mammals (Mammalia) and 33 reptiles (Reptilia) (assuming that a common name could refer to multiple species in the same taxa, for example, order, family or genus) (Suppl. material 2). With regards to international conservation status, seven of these inferred species are currently considered to be Critically Endangered [Togo slippery frog (*Conraua derooi*), Nubian flapshell turtle (*Cyclanorbis elegans*), White-backed vulture (*Gyps africanus*), Rüppell's vulture (*Gyps rueppelli*), Slender-snouted Crocodile (*Mecistops cataphractus*), Hooded vulture (*Necrosyrtes monachus*) and White-headed vulture (*Trigonoceps occipitalis*)], four species are Endangered [Green sea turtle (*Chelonia mydas*), African grey parrot (*Psittacus erithacus*), Egyptian vulture (*Neophron percnopterus*) and Lappet-faced vulture (*Torgos tracheliotos*)], 24 are Vulnerable, 11 are Near Threatened, 216 are Least Concern, 12 are Not Evaluated and seven are Data Deficient [i.e. Togo screeching frog (*Arthroleptis brevipes*), Necas's chameleon (*Chamaeleo necasi*), Kintampo rope squirrel (*Funisciurus substriatus*), *Hylomyscus pamfi* (Rodentia: Muridae), Eroded hingeback tortoise (*Kinixys erosa*), *Leimacomys büttneri* (Rodentia: Muridae) and Walter's duiker (*Philantomba walteri*)] (Appendix 1; Suppl. material 2).

With regards to their population status, eight inferred species have wild populations considered to be increasing, 80 that are stable, 72 that are decreasing and 121 of unknown population status (Appendix 1; Suppl. material 2). With regards to international legal status, eight inferred species [Cheetah (*Acinonyx jubatus*), *Chelonia mydas*, Leatherback sea turtle (*Dermochelys coriacea*), Olive Ridley sea turtle (*Lepidochelys olivacea*), White-bellied pangolin (*Phataginus tricuspis*), African dwarf crocodile (*Osteolaemus tetraspis*), leopard (*Panthera pardus*) and *Psittacus erithacus*] are currently listed on CITES Appendix 1, four species have populations listed on Appendix 1 and Appendix 2 (*Caracal caracal*, *Crocodylus niloticus*, *Loxodonta africana* and *Panthera leo*), 65 species are listed on Appendix 2 and 202 are not currently listed on any of the CITES Appendices (see Appendix I; Suppl. material 2). Vendors also inferred an additional 91 species (32%) that are not currently considered as threatened, but have greatly increased in rarity from their perspective (Fig. 2).

Species case studies (pangolin and python)

Pangolin findings

A total of eight of the ten different stated pangolin body parts are used for medicinal purposes according to the vendors who participated in this study (Fig. 3). Three of the five vendors referred to the use of pangolin "scales" and two to the use of pangolin "foot", the "entire animal", "head" or "penis" (Fig. 3). With regards to medicinal use, a total of nine different treatments were cited; however, the treatment of asthma was most frequently cited by vendors (n = 5 / 15 responses; 33%) (Fig. 4a). Vendors stated that the sale of an entire pangolin could fetch up to 51 USD and a penis up to 43 USD (mean price per body part and purpose shown in Fig. 3).

Each of the five vendors reported a different pangolin body part used for spiritual purposes: the "entire animal", "foot", "head", "sex organ" or "tongue" (Fig. 3). Two vendors reported that, with regards to spiritual use, pangolin body parts were used to remove

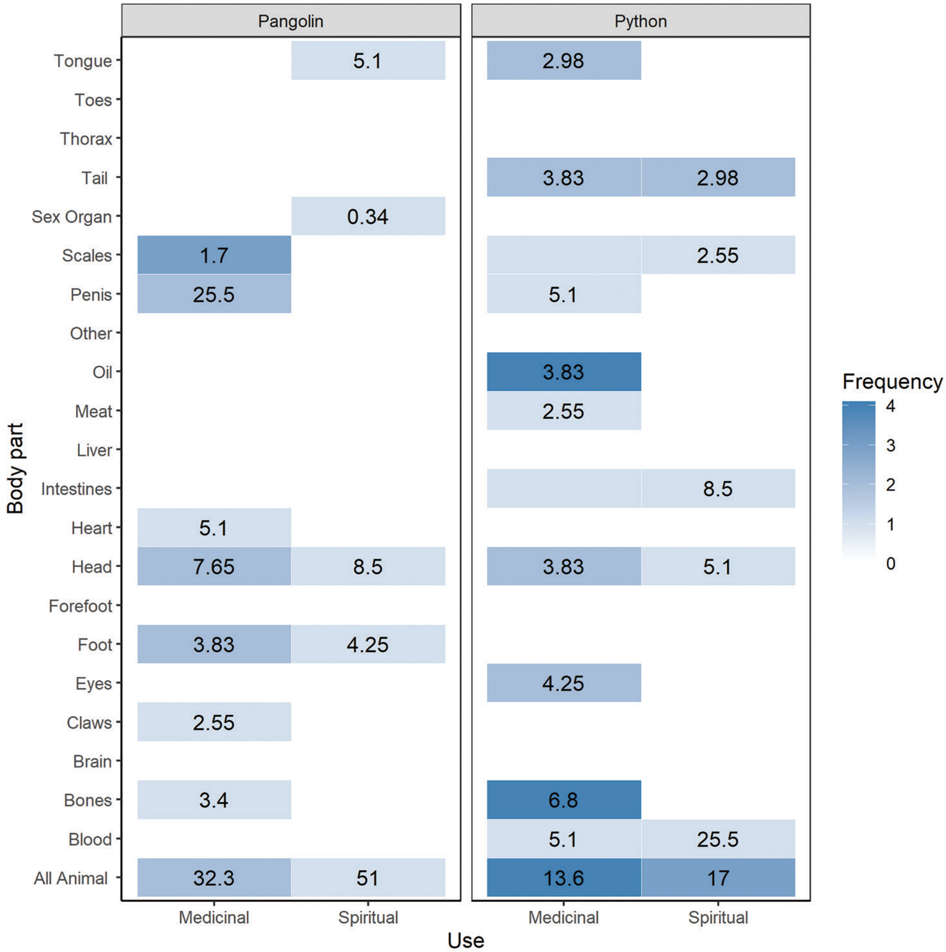

Figure 3. Frequency of cited purpose and body part used for the two focal species "Pangolin" and "Python" with information on average prices in USD provided in the blue cells. Blank cells refer to body parts that were mentioned by vendors but no price information was provided. Shading of the blue cells reflects frequency with darker blue being more frequent.

a curse; the other three vendors each gave different spiritual uses: "luck", "brings money" and "protection" (Fig. 4a). Vendors stated that the sale of 10 scales could fetch up to 3 USD and a head up to 9 USD (means shown in Fig. 3). The mean cost across all body parts was higher when sold for spiritual purposes (13.8 ± 21 USD) than for medicinal purposes (10.3 ± 11.8 USD), but was not significantly different ($W = 17.5$, $P > 0.05$).

With regards to reported source country, two of the vendors stated that they source pangolin derivatives from within Togo, all of the vendors stated that they source pangolin derivatives from Benin, one of the vendors stated that they source them from Ghana and four of the vendors stated that they source them from Nigeria. Three vendors stated that they source pangolin derivatives directly from hunters and three that

Figure 4. Word cloud of the cited medicinal and spiritual purposes of pangolin (n = 19 total responses) **a** and python (n = 28 total responses) **b** provided by vendors. Size of text is proportional to frequency of words in interviews. Frequency reflects both the number of vendors using the word and the number of times the word was used by the vendor.

they source them from middlemen. On average, vendors stated that they sold the equivalent of 30 pangolins over the last year, 137 over the last five years and 281 over the last 10 years. The mean availability score of pangolins over the last five years was 4.5 with three of the vendors stating that there were "quite a lot less" pangolin available compared to five years previous. Vendors identified four different local common names ("Kangao", "Midohoungbe", "Olikpekpe" and "Tchechema") with reference to plant species that could be sold in place of pangolin derivatives for medicinal and/or spiritual purposes (Suppl. material 2).

Python findings

All of the 12 different stated python body parts are used for medicinal purposes, according to the vendors who participated in this study (Fig. 3). Four of five vendors reported selling python "bones", the "entire animal" and python "oil" for medicinal purposes, two vendors reported selling the "eyes", "head", "tail" and "tongue" (Fig. 3). With regards to medicinal use, a total of ten different treatments were cited; however, general "protection" (n = 5 / 20; 25%) was most frequently cited by vendors, followed by use of oil for massages (Fig. 4b). Vendors stated that the sale of an entire python could fetch up to 26 USD, bones and a spoonful of oil up to 9 USD (means shown in Fig. 3).

A total of six of the 12 different python body parts are used for spiritual purposes, according to the vendors who participated in this study (Fig. 3). Two of the five vendors reported selling the "entire animal" (n = 2 / 5; 40%) and one each the "blood", "intestines", "scales" and "tail" (Fig. 3). Two specific spiritual uses were given for python body parts: witchcraft and as anti-venom; the ability to protect against witchcraft being most frequently cited by vendors (for all python body parts; n = 7 / 8; 88%) (Fig. 4b). Vendors stated that the sale of a spoonful (5 ml) python blood could fetch up to 26 USD and intestines could fetch up to 9 USD (Fig. 3). The mean cost across all body parts was higher when sold for spiritual purpose (10.3 ± 9.2 USD) than for medicinal purposes (5.2 ± 3.2 USD) but was not significantly different (W = 22, P > 0.05).

One of the five vendors stated that they do not sell pythons, because it is considered as a sacred animal by the "Pedah" ethnic group. The four vendors that did sell pythons reported that they sourced them from within Togo, from Benin and from Nigeria. One of these four vendors also stated that they source pythons from Ghana. On average, vendors reported that they have sold the equivalent of 109 pythons over the last year, 338 over the last five years and 675 over the last 10 years. The mean availability score of pythons over the last five years was 4.5 with two vendors stating that there were "quite a few less" and two that there were "quite a lot less" available compared to five years previously. Vendors identified four different local common names ("Akouema", "Canabis", Djokotche" and "Zodi") with reference to plant species that could be sold in place of python derivatives for medicinal and/or spiritual purposes.

A summary of the cost per body part, sources (both from where and from whom), sales and availability scores of the two focal species are shown in Figure 3 (see also Appendix 2). The most expensive species, according to the five vendors interviewed, was the pangolin (the entire dead animal) sold for spiritual (51 USD) and medicinal purposes (32.3 USD). The most frequently sold of the two species over the last ten years was the python (their heads and as a live animal). For both species, Benin was cited most frequently as the source (by all five vendors), followed by Nigeria (four vendors), Togo (two vendors) and Ghana (one vendor). For both python and pangolin, products were sourced more often directly from hunters, rather than from a middleman, and by "regular customers" rather than locals or tourists buying out of curiosity.

Discussion

Our study confirmed that a wide variety of live wild animals and their derivatives are being sold at the "Marché des Fétiches" in Togo (Figs 5, 6). Interestingly, all of the vendors at this market were from Benin, with some of them having relied on the sale of traditional medicine involving wild animal derivatives for up to 45 years. In terms of specific use, vendors stated that the majority of wildlife was used for spiritual use rather than medical purposes (Fig. 1b). The most-cited purpose for vendor 1 was "fetish object", vendor 2 – "against witchcraft", vendor 3 and 4 – "good luck charm" and vendor 5 – "protection". Anti-venom was also a cited purpose across all the vendors.

Figure 5. A Entrance to the "Marché des Fétiches", Akodessewa, Lomé, Togo **B** African grey parrot (*Psittacus erithacus*) intended for commercial sale **C** West African slender-snouted crocodile (*Mecistops cataphractus*) intended for commercial sale **D** live vulture (Accipitridae sp., cf. *Gypohierax angolensis*, Palm nut vulture) intended for commercial sale, Togo, West Africa. Images **A–D** Neil D'Cruze / World Animal Protection.

Vendors provided a total of 36 different common local names (inferring an estimated 281 species) when asked to confirm the wild animals that they considered to be the most profitable and to have most increased in rarity. Our study reiterates the conservation concerns associated with this type of commercial trade activity in West Africa (Djagoun et al. 2018). According to the IUCN Red List of Threatened Species, a considerable proportion of the wild animals, thought to be sold at this market, are already considered to be threatened (13%; 35 inferred species) or to be declining [(26%; 72 inferred species), Appendix I, Suppl. material 2]. Vendors also referred to an additional 32% species (n = 91) that are not currently listed on the IUCN Red List as threatened,

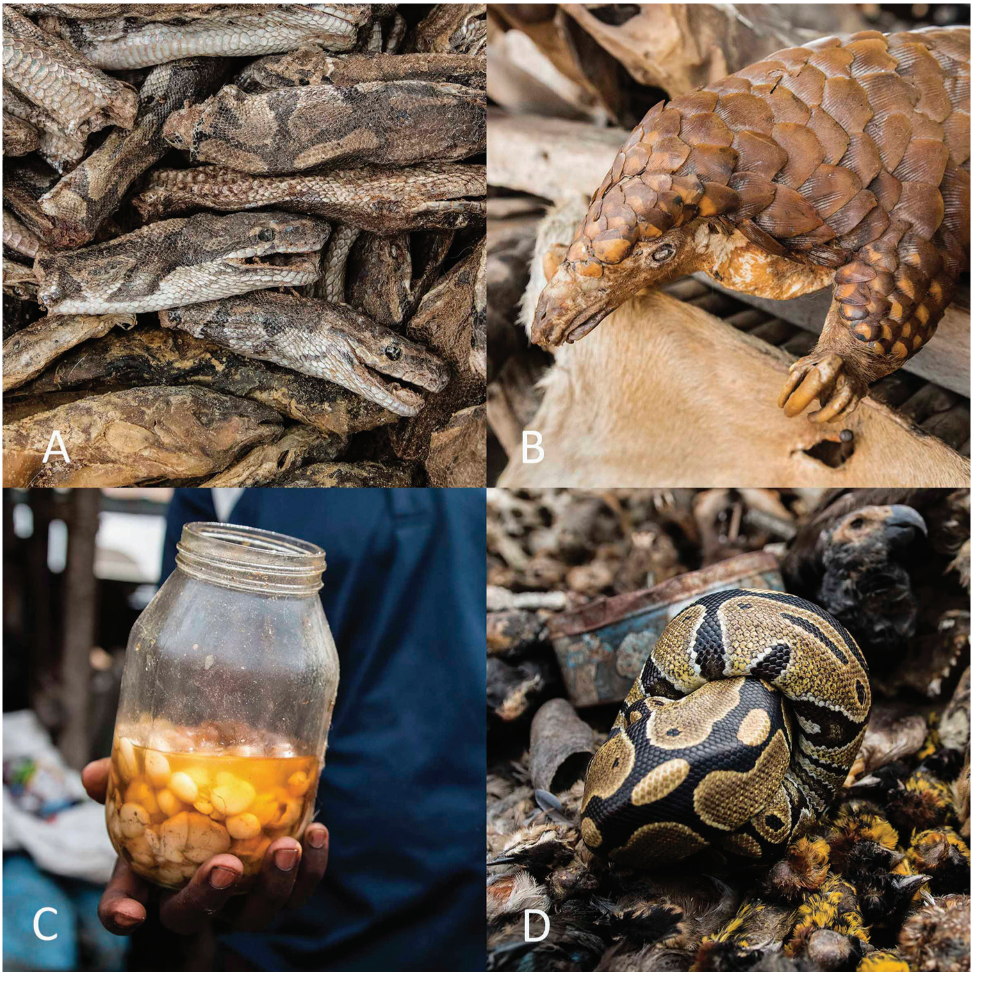

Figure 6. A Ball python heads (*Python regius*) intended for commercial sale **B** pangolin (*Phataginus tricuspis*) intended for commercial sale **C** Ball python fat bodies / oil intended for commercial sale **D** live Ball python intended for commercial sale, Togo, West Africa. Images **A–D** Neil D'Cruze / World Animal Protection.

but have greatly increased in rarity from the vendors' perspective. Whilst this type of traditional use is centuries old, growing human populations, increasing human-mediated pressures and globalisation (Esmail et al. in press) might mean that traditional uses that were perhaps once sustainable, may not necessarily be so in future.

Our findings also draw additional attention to the animal welfare concerns associated with this type of activity. During our visits to the market, we observed stalls with thousands of wild animal derivatives for sale, all of which would have suffered to some degree during capture, potential transport, onward sale and slaughter (Baker et al. 2013). However, it is clear that the potential for wild animal suffering extends beyond slaughter as vendors confirmed that they are also engaged in the commercial sale of a large number of live wild animals. During survey work at this market, researchers observed a number of live animals (including ball pythons, cane rats, chameleons, monitor lizards, crocodiles and vultures) (see Figs 5D, 6D). These animals were kept in poor welfare conditions (e.g. small barren dirty cages, cloth bags and plastic buckets often out of sight from visiting customers) that clearly compromised their health and well-being.

Although this market is promoted as a tourist attraction by domestic and international tour agencies, the legal status regarding this type of commercial trade activity in Togo is unclear, given the existence of a number of different and potentially conflicting pieces of domestic legislation (D'Cruze et al. 2020). For example, Article 61 of the 005 Framework Law on the Environment (2008) requires that hunting is managed in a sustainable manner, which is questionable for many of the species (internationally considered as threatened according to the IUCN Red List of Threatened Species), whose derivatives are being openly sold. However, from an international trade perspective, a considerable proportion of the wild animals sold at this market are currently afforded some level of legal protection (28%; 79 inferred species) via CITES (Appendix I, Suppl. material 2). As such, the purchase of derivatives from any of these CITES-listed species for international export without relevant CITES permits would be illegal. The implications of trade involving the two species identified as being most economically profitable (pangolin and python) are discussed in more detail below.

Pangolins

"Pangolin" was identified as the most commercially viable wild animal derivative by vendors interviewed during our study. Its increased rarity was also suggested by two of the five vendors. This group of African and Asian scaly mammals is considered to be "the most heavily trafficked wild mammal in the world", used predominantly as traditional medicine and food, but also in rituals, art and magic amongst communities across Africa (Soewu and Sodeinde 2015) and Asia (e.g. Mahmood et al. 2012). By collating local-scale studies, Ingram et al. (2018) found that pangolins are hunted and observed at wildlife markets throughout West and Central Africa and that pressure from hunting has increased. Mounting evidence suggests that, as the availability of Asian pangolins declines and international trade flows increase, traders are increasingly supplying the currently more abundant and less expensive African pangolins to meet Asian demand (Challender and Hywood 2012).

All four African species [the "Endangered" White-bellied (*Phataginus tricuspis*) (Pietersen et al. 2019a), the "Vulnerable" Black-bellied (*Phataginus tetradactyla*) (Ingram et al. 2019), the "Endangered" Giant ground (*Smutsia gigantea*) (Nixon et al. 2019) and the "Vulnerable" Temminck's ground pangolin (*Smutsia temminckii*) (Pietersen et al. 2019b)] are currently considered to be threatened with extinction, according to the IUCN Red List (IUCN 2020) and commercial international trade was effectively banned in 2016 (CITES 2016). Clearly, any trade in pangolin parts at the "Marché des Fétiches" represents a potential conservation concern. Although only the white-bellied pangolin is extant in Togo, trade at the "Marché des Fétiches" likely also involves the black-bellied and the giant ground pangolin, given that vendors stated that they also source pangolins from Ghana. In addition, there are a number of animal welfare issues associated with pangolin hunting practices, for example, it can take hours to successfully extricate a pangolin from its burrow or tree den during capture and transport and also concerns remain that a proportion may still be alive when the boiling process begins (D'Cruze et al. 2018).

Pythons

"Python" was identified as the second most commercially viable wild animal derivative by vendors interviewed during our study. Its perceived increased rarity was also stated by one of the five vendors. Two species of python are known to occur in Togo, the Northern African rock python (*Python sebae*) and the Ball python (*Python regius*) (Segniagbeto et al. 2011). Unlike pangolins, commercial international trade in python species from West Africa is largely permitted, given appropriate CITES paperwork is in place. In fact, the Ball python is the most traded CITES listed (Appendix 2) live animal legally exported from Africa (CITES Trade Database 2019) with most specimens intended for onward sale as exotic pets (Auliya and Schmitz 2010; CITES Trade Database 2019). From a domestic trade perspective, the Northern African rock python is used extensively for meat, leather and use in traditional medicine (e.g. Eniang et al. 2008; Fuashi et al. 2019). The use of pythons as traditional medicine has a number of animal welfare implications. Reptiles are recognised in the limited relevant research as being capable of a range of intellectual abilities and states including anxiety, distress, excitement, fear, frustration and pain (Lambert et al. 2019), suggesting that they have the capacity to experience suffering during capture, restraint, transport and subsequent captivity (Baker et al. 2013).

From a conservation perspective, the Northern African rock python has not been evaluated by the IUCN Red List of Threatened Species. However, this species is also not thought to be as widespread as they once were (Areste and Cebrian 2003). Similarly, although the Ball python is currently considered as Least Concern, information regarding the status and impact of commercial trade on wild populations is also lacking (Auliya and Schmitz 2010). Although the majority of live Ball pythons are reported as animals originating from "ranching" operations, there are concerns that current hunting practices to maintain ranch stock target the most vulnerable biological stages (specifically gravid females and neonates) (Auliya and Schmitz 2010; D'Cruze et al. 2020). Additionally, there are concerns that methods used to source wild Ball pythons, such as the digging and destruction of burrows and the improper release of ranched Ball pythons, may also be contributing to an overall reduction in wild populations of this species (Auliya and Schmitz 2010; D'Cruze et al. 2020) and genetic pollution (Auliya et al. 2020). In light of these other conservation pressures, the large-scale sale of pythons as traditional medicine is also of potential conservation concern.

Herbal alternatives

Our study confirms that a proportion of the vendors who sell wildlife derivatives at the "Marché des Fétiches" in Togo also sell plants as traditional medicine (Suppl. material 2). This is perhaps unsurprising given that other studies in other locations (e.g. South Africa; Williams 2007) have found that the majority of traditional medicines are of botanical origin. In fact, while there is a rich history of research focused on the use of traditional medicinal plants for more than 200 years, research focused on wildlife as traditional medicine in Africa arguably only commenced in the 1980s (Williams and Whiting 2016). However, it appears that studies, focused on the potential use of plants as a humane and sustainable alternative to the use of threatened wildlife species, are largely lacking. Moorhouse et al. (2020) found that plant-based alternatives are likely to be a viable and preferred option for consumers of wildlife as traditional Asian medicine in China, given that they are listed within existing pharmacopoeia and provided by practitioners that do not challenge the existing Chinese belief system. Although the use of botanical-based traditional medicine does not involve animal welfare concerns, it is important to note that careful steps should be taken to ensure that conservation concerns are not transferred to target plant species in West Africa.

Limitations

Establishing the impact of traditional medicine on wildlife is notoriously difficult (Williams and Whiting 2016). In particular, caution is always required in interpreting data derived from interviewees when trade involves some element of illegality and/or unsustainability (e.g. Newton et al. 2008; D'Cruze et al. 2018). For example, given the potentially sensitive nature of the information asked for in our surveys, interviewees might have been reluctant to be honest about the magnitude of their activities or may have unintentionally underestimated sales due to poor memory recall. Conversely, interviewees may have exaggerated the extent of their trade activities, knowingly or unknowingly. As such, there is a risk that the data underestimate or overestimate the impact on wildlife in Togo. With regards to the impact of wildlife trade activity on wild animal populations, it should be noted that there are a number of other causative factors (including those that are legal, political, epidemiological and environmental in nature) that can also affect the availability of a particular species at a given point in time. However, our aim was not to assess the extent of impact, rather we sought to identify those species that might potentially be at risk, to better understand what they might be used for (by consumers) and to gain preliminary insights into the prescription and sale of plant-based alternatives (by vendors).

A full inventory of the wild animal species being sold at the "Marché des Fétiches" was beyond the scope of this study. Similarly, although vendors provided samples upon request, it was not possible to identify any of the local plant species from the dried specimens available. As such, we acknowledge that our use of local names to infer the species sold by vendors does not provide a complete taxonomic account. Furthermore, our use of local names likely means that, in some cases, vendors may be referring to only one particular species that is not threatened by extinction or vice versa. However, taxonomic inventories, based on direct observation, also have their limitations when considering the impact of traditional medicine on wildlife. For example, many traders sell individual bones or pieces of skin, making it impossible to determine how many individual animals are being traded in a particular market (Williams and Whiting 2016). In addition, traders are sometimes willing to use animals recovered dead from the wild rather than those killed specifically for use as traditional medicine (Williams and Whiting 2016). Despite the limitations of an interview-based approach, involving a relatively small number of vendors, we believe that our findings represent valuable information that can be used to help provide information for future efforts to protect wildlife in Togo.

Recommendations

The use of wild animals as traditional medicine involves multiple overlapping anthropological, ecological and behavioural aspects with a complexity that should not be underestimated (Williams and Whiting 2016). Although it is important to acknowledge an individual's reliance (World Health Organization 2002) or preference for traditional medicine (Whiting et al. 2011), the potential negative impacts of species exploitation on their conservation and welfare (Lambert et al. 2019) should also not be ignored, as ultimately the health and welfare of wildlife and people are inextricably linked and dependent on each other (Slorach 2013; OIE 2019). In particular, trade in live wild animals and their derivatives at markets that lack proper biosecurity have been specifically cited as a transmission mechanism of growing concern in recent decades (Can et al. 2019).

In addition to increased clarity regarding the domestic legislation and associated penalties (e.g. D'Cruze et al. 2020), increased research effort, focusing on the impacts of traditional medicine on both individual and wild animal populations, is required. We recommend that those wild animals already considered threatened by extinction (31 inferred species, including pangolin) and those with populations already thought to be in decline (65 inferred species) should be made a priority. However, we would also like to highlight that non-threatened wild animals, stated to have increased in rarity (70 inferred species), specifically those that are also considered to be highly profitable (such as python), should also not be overlooked in this regard.

During our survey, vendors stated that the majority of derivatives were used for spiritual use rather than medical purposes, with the most frequently cited benefit of using animals being to acquire "protection" (Fig. 1b). Furthermore detailed discussion with a larger sample size of vendors and an in-depth thematic analysis of content could be carried out to substantiate this finding and to explore potential nuances in relation to, for example, different product types and pricing. In addition, although not a focus of our research, future studies should look to collect data on how these derivatives are prepared and utilised. Clearly, additional research, focused on the socio-economic and societal pressures responsible for this type of consumer demand (including studies focused on consumer attitude and behaviour), is required and could be used to provide information for future initiatives aimed at minimising any negative impacts on people and wildlife. Given that a number of plant-based alternatives exist within the traditional medicine culture in West Africa, we also recommend additional research that could relieve pressure from over-exploited wildlife. For example, molecular studies could aid future taxonomic identification of plant species being sold as traditional medicine and weight-based price comparisons of plant-based alternatives with wildlife derivatives, could prove particularly useful in this regard. However, although such initiatives would not incur animal welfare costs, they would need to carefully ensure that conservation costs were not unintentionally transferred to these plant species. More research focused on the taxonomy, conservation status and uses of the plant-based products being sold in Togo is recommended in this regard.

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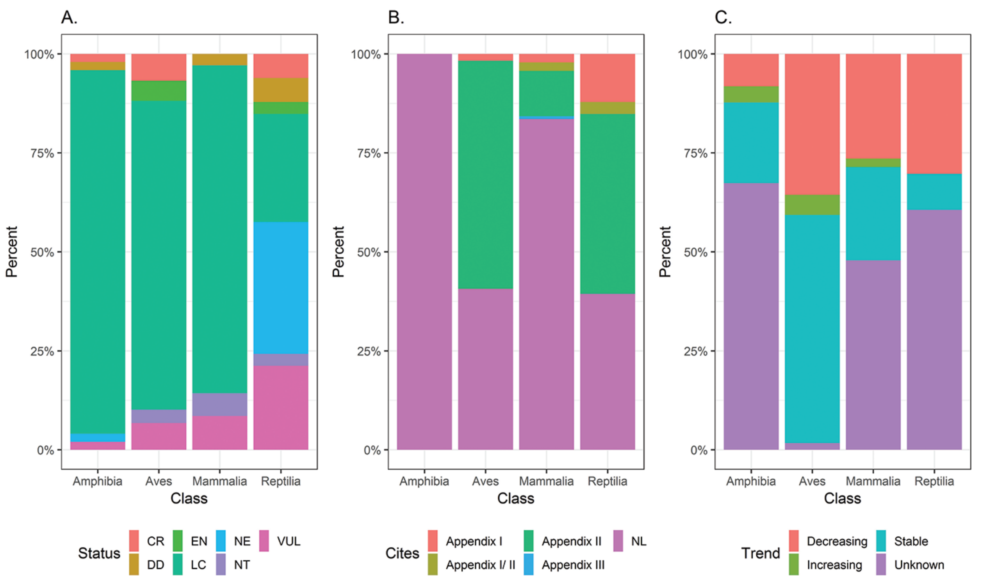
Appendix 1

Proportion of species potentially referred to using common name split by Class and IUCN status (A), by Class and CITES status (B) and Class and population trend (C).



Appendix 2

Summary of respondent questions relating to wildlife derivative sales.

Species	Mean min price per item USD (Range)	Mean max price USD (Range)	Total number of items sold last year (Range)	Most frequent purpose	Body part sold										
					All Parts	Bile	Bones	Feathers	Foot	Head	Live animal	Scales	Skin	Teeth	Toes
Antelope	14.73 (10.2-17)	14.73 (10.2-17)	160	Make drums							X		X		
Baboon	19.55 (2.55-51)	36.55 (2.55-102)		Treat Elephantitus						X			X	X	
Bats	1.70 (0.85-2.55)	1.70 (0.85-2.55)		Heart Conditions	X										
Big Cats	86.98 (1.70-255)	115.32 (1.70-204)		Fetish Objects						X			X		
Cane Rat	7.86 (2.55-13.60)	7.86 (2.55-13.60)	115 35-40	Against Witchcraft	X						X				
Chameleon	2.05 (0.26-4.25)	2.05 (0.26-4.25)	915 (35-600)	Good Luck Charm	X						X				
Cobra	4.76 (3.40-8.50)	4.76 (3.40-8.50)	280 (10-200)	Anti-Venom	X						X				
Crocodile	24.79 (0.85-68)	33.29 0.85-68)	70 (20-50)	Protect against drowning	X					X	X		X		
Eagle	17.85 (2.55-42.50)	17.85 (2.55-42.50)		Memory, treat ear infection, headaches	X			X		X					
Elephant	5.44 (1.70-13.60)	5.44 (1.70-13.60)		Treat Elephantitus					X				X		X
Frogs	0.34	0.34			X										
Hedgehog	4.25 (1.70-8.50)	4.25 (1.70-8.50)	65 (15-50)	Good Luck Charm, Protection, Treat ulcer	X						X				
Hippopotamus	765	765		Protection Against Mermaids						X					
Honey Badger	13.6	13.6	300	Protection							X				
Hyena	119.47 (3.40-340)	119.47 (3.40-3.40)		Protection, Fetish Object, Against Witchcraft						X			X		
Lion	59.88 (1.70-255)	79.33 (1.70-425)		Fetish Objects, Protection			X			X			X	X	
Mice	2.13 (1.70-2.55)	2.13 (1.70-2.55)	15	Against Witchcraft						X					
Monitor Lizard	7.37 (5.10-8.50)	7.37 (5.10-8.50)													
Monkey	7.65 (5.10-10.20)	8.50 (6.80-10.20)	200	Help Memory, Fetish Objects	X						X				
Owl	5.44 (3.40-8.50)	5.44 (3.40-8.50)	50	Against Witchcraft	X						X				
Pangolin	26.88 (0.34-59.50)	26.88 (0.34-59.50)		Protection	X					X	X	X			
Parrot	36.19 (1.70-204)	36.19 (1.70-204)	80 (30-60)	Good Luck Charm	X			X		X	X				
Partridge	5.53 (2.55-8.50)	5.53 (2.55-8.50)		Good Luck Charm, Asthma		X				X					
Pied Crow	13.60	13.60	40	Against Witchcraft							X				
Porcupine															
Python	5.84 (2.55-8.50)	5.84 (2.55-8.50)	130 (10-100)	Protection	X					X	X		X		
Sea Turtle	76.50	76.50		Asthma	X										
Shrew	1.53 (0.51-2.55)	1.53 (0.51-2.55)	40	Love	X						X				
Sparrow Hawk	5.51 (0.34-11.90)	5.51 (0.34-11.90)	20	Protection, Ear Infections				X		X	X				

Species	Mean min price per item USD (Range)	Mean max price USD (Range)	Total number of items sold last year (Range)	Most frequent purpose	Body part sold										
					All Parts	Bile	Bones	Feathers	Foot	Head	Live animal	Scales	Skin	Teeth	Toes
Squirrel	42.50	42.50	150	Help Memory							X				
Tortoise	9.07 (6.80-13.60)	9.07 (6.80-13.60)	70 (25-45)	Treat Knee Pain	X						X				
Turtle	5.53 (4.25-6.80)	5.53 (4.25-6.80)	220 20-200)	Asthma							X				
Viper	3.64 (0.85-8.50)	3.76 (0.85-8.50)	590 (10-500)	Anti-Venom	X					X	X				
Vulture	47.94 (1.70-136)	71.74 (1.70-255)	200 (50-150)	Against Witchcraft, Help Child Birth				X		X	X				
Warthog	425	425		Attract Clients						X					
Weaver Bird	2.55	2.55		Good Luck Charm	X										

Supplementary material 1

Questionnaire

Authors: Neil D'Cruze, Délagnon Assou, Emma Coulthard, John Norrey, David Megson, David W. Macdonald, Lauren A. Harrington, Delphine Ronfot, Gabriel H. Segniagbeto, Mark Auliya

Data type: questionnaire

Link: https://doi.org/10.3897/natureconservation.39.47879.suppl1

Supplementary material 2

Table S1. List of inferred species and their respective scientific names (assigned to each common name provided by questionnaire respondents) based on the documented presence of wild populations in Togo

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Data type: species data

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RESEARCH ARTICLE

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A preliminary assessment of bacteria in "ranched" ball pythons (*Python regius*), Togo, West Africa

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Abstract

Captive reptiles are routinely identified as reservoirs of pathogenic bacteria and reports of reptile-associated infections relating to some species are well documented (e.g., salmonellosis). Currently, relatively little is known about the epidemiology and bacteria of ball pythons. We carried out a survey of ball python farms in Togo, West Africa to assess the presence of any potentially pathogenic bacterial taxa that have been identified in recent scientific literature relating to this species. The presence of bacteria belonging to the genera *Acinetobacter*, *Bacteroides*, *Citrobacter*, *Enterobacter*, *Lysobacter*, *Proteus*, *Pseudomonas*, *Staphylococcus*, and *Tsukamurella* in oral and cloacal samples taken from five individual ball pythons is of potential concern for horizontal transmission given that pathogenic species belonging to these genera have been previously documented. The presence of bacteria belonging to the genera *Clostridium*, *Escherichia*, *Moraxella*, and *Stenotrophomonas* in the oral and rectal samples taken from five mice used to feed ball pythons suggests that they represent a potential reservoir of infection for wild caught ball pythons and their progeny. Furthermore, possible sources of environmental contamination include other captive amphibians, birds, reptiles and mammals, as well as free ranging birds and small mammals. Additional surveillance of ball pythons in the wild and in captivity at python farms in West Africa will shed light on whether or not this type of commercial activity is increasing pathogen exposure and lowering barriers to transmission. Meanwhile, as a precautionary measure, it is recommended that python farms should immediately establish biosecurity and disease surveillance practices to minimize potential horizontal and vertical bacterial transfer.

Keywords

ball python, *Python regius*, reptile, wildlife trade, zoonosis

Introduction

Global demand for reptiles as exotic pets is a relatively recent phenomenon (Mitchell 2009). Their popularity, however, has risen to the extent that they are now thought to represent the second most species-rich vertebrate class (after birds) in the international exotic pet trade (Bush et al. 2014). Reptiles are particularly rife in European and North American markets (Auliya 2003; Jensen et al. 2018), with conservative estimates of c. 0.7 million individuals being kept in the UK and 9.4 million in the USA, respectively (PFMA 2017; APPA 2019).

Global trade in wildlife (whether it legal or illegal) has also been cited as a disease transmission mechanism of growing concern in recent decades (Smith et al. 2009; Can et al. 2019). Specifically, these concerns relate to how pathogens are spread when humans capture wild animals from their natural habitats, transport them by land, sea and air and trade them dead or alive in different parts of a country or the world (e.g., Morens et al. 2004; Karesh et al. 2005; OIE 2017).

Captive reptiles are routinely identified as reservoirs of pathogenic bacteria and reports of reptile-associated infections for some species are well documented, such as salmonellosis (Arena et al. 2012; Bošnjak et al. 2016; Green et al. 2020). Several studies have investigated and highlighted the potential for horizontal and vertical transfer of disease at commercial captive breeding operations [e.g., Green iguanas (*Iguana iguana*) (Mitchell et al. 1999; Mitchell and Shane 2000) and Green sea turtles (*Chelonia mydas*) (Warwick et al. 2013)]. In some scenarios reptile-associated infections can spread to humans who have had direct or indirect contact with pet snakes and feeder rodents (used as reptile food) before their illnesses occurred [e.g., Canada in late 2019; (Government of Canada 2019)].

The ball python (*Python regius*), a species native to western and central Africa, is being exported in relatively large numbers [1,657,814 live individuals since 1978 (Convention on International Trade in Endangered Species of Wild Fauna and Flora [CITES] Trade Database; https://trade.cites.org)]. In fact, it is the single most traded CITES listed species (currently under CITES Appendix II) that is legally exported alive from Africa (D'Cruze et al. 2020). Much of this international trade can be traced back to a number of python "farms" that are in operation across West Africa, most notably in Benin, Ghana and Togo (Robinson et al. 2015).

Since c. 1996, these python farms have been engaged in "ranching" (UNEP 2019), which refers to *rearing, in a controlled environment, snakes taken as eggs or juveniles from the wild, where they would otherwise have had a low probability of surviving to adulthood* (CITES 2019), and releasing a proportion back into the wild (Ineich 2006). Additionally, gravid females are also collected, and after laying their eggs in captivity are released back into the wild (Ineich 2006).

Recent studies have confirmed that the wild capture of ball pythons (for the export of specimens as "ranched" individuals the CITES source code "R" is used) often involves the removal of snakes from rodent burrows and live transport in sacks filled with other reptiles (D'Cruze et al. 2020). Once at farms, the snakes are reportedly housed separately, but they can also be housed at times in overcrowded enclosures in rooms that are filled with many other reptile species (D'Cruze et al. 2020). Mature ball pythons are typically fed live mice that are sourced from breeders or housed, or even bred, on site at farms.

Despite the international scope, large scale, and national wild release component of ball python "ranching" in Togo, there has been no current research focused on the epidemiology of this commercial trade activity. Therefore, we aimed to carry out an initial review, using amplicon sequence variants (ASVs) methods, to determine the presence of any potentially pathogenic genera of bacteria present in ball pythons and the live mice used as their food. We hope our findings will inform biosecurity surveillance practices to minimize potential horizontal and vertical transfer of zoonotic diseases.

Methods

Literature review

We conducted a systematic review of the scientific literature featured in PubMed, Scopus and Web of Science, from 2009–2019 to identify bacteria that are known to have affected the well-being of ball pythons. The following search terms were used (disease, pathogen, bacteria, bacterial). Each search term was employed with the Boolean operator "AND", with three additional terms (ball python, royal python, *Python regius*).

Laboratory analysis

A total of 20 dry swab samples were taken from five snakes and five mice at a python farm in Togo in September 2019 (Fig. 1, Suppl. material 1). Two swab samples were taken from each animal, one each from oral (both snake and mice), cloacal (snakes only) and rectal (mice only) orifices. Swabs were immediately transferred into 2 ml screwcap microcentrifuge tubes containing approximately 600 µl of DNA/RNA Shield and stored at -20 °C until transport to the UK.

Prior to DNA extraction, samples (swab and reagent) were transferred into a fresh 2 ml screwcap microcentrifuge bead-beating tube, containing approximately 0.06 g of 0.1 mm glass-silica beads (Thistle Scientific, Glasgow), and vortexed twice for 30 seconds. The swabs were then discarded and the supernatant/liquid portion of the sample transferred to a 1.5 ml tube containing 274 µl polyethylene glycol (6000) and 141 µl 5M sodium chloride and incubated at 5 °C for 15–45 minutes. DNA was extracted using a modified phenol-chloroform method (Rogers et al. 2013) with reduced reagent volumes (200 µl each of molecular biology grade water, phenol, phenol-chloroform and ammonium-acetate: isopropanol compared to the 500 µl used previously). DNA pellets were suspended in 10 µl of molecular biology grade water and stored at -20 °C.

For PCR, 16S rRNA gene amplicons were generated following the Illumina two-step protocol (Illumina 2019) using primers designed by Caporaso et al. (2012) for the first step PCR and Nextera XT Index primers (Illumina, USA) for the second step. PCR conditions are shown in Appendix I. Amplicon clean-up was performed using AMPure XP beads (Beckman Coulter, UK), and normalised using a 96-well Sequal-Prep Normalisation Plate (Thermo Fisher Scientific, USA). Amplicons were sequenced using a 300-cycle MiSeq Reagent Micro Kit v2 (Illumina, USA) with a read length of 2 × 150 bp – on the MiSeq platform.

Sequence quality of the top six samples was visually assessed within R (R Core Team 2019) using the DADA2 R package (Callahan et al. 2016), which was used for taxonomic assignment in combination with the Genome Taxonomy Database (GTDB) (Parks et al. 2018; Chaumeil et al. 2019) using 1 × 150 bp forward read sequences. Raw reads were processed in accordance with the DADA2 Pipeline Tutorial (1.12) (Callahan 2019). In addition to using the standard filtering parameters for trimming, an extra step was added to ensure only amplicons of the expected length were included (i.e., with a minimum length of 148 and a maximum length of 151 bp). The resultant ASV and taxonomy csv files were combined to make a single database, which was further trimmed in Excel (Microsoft, USA). Prior to the assignment of presumptive genus-level classification for the ASVs, NA values for taxonomic levels at family level and above were removed. NA values at the genus level were kept and included as part of the 'other' genus category. Species level assignment was not possible due to the short length of the targeted 16S rRNA region, which may be indistinguishable among species and / or strains (Bulman et al. 2018; Osawa et al. 2015).

Bacterial genera that had been reported in the published scientific literature were identified using the search function within Excel. The assigned identity was confirmed using nucleotide BLAST searches against the 16S rRNA sequences (Bacteria and Archaea) coupled with megablast (highly similar sequences). Sequence read values for each genus were combined to create a stacked bar chart. No cut-off values for reads per sample were applied. The overall relative abundance for some genera were calculated by converting the number of reads for ASVs that have been assigned to a particular genus to a percentage relative to the total number of reads (derived using ASVs assigned genera in addition to the 'other' category).

Results

The literature review identified 29 different species of bacteria across 26 genera that have negatively impacted the health of ball pythons [according to 15 scientific papers published between 2017 and 2019 (Table 1, Fig. 1, Suppl. material 1)]. Sequencing the microbiota of snake and mouse samples collected from the python farm in Togo provided presumptive identification of 13 (50%) of these 26 genera. One of the samples (Mouse Oral 1) did not contain amplifiable DNA and hence was not successfully sequenced. (Table 1, Fig. 1). Searches with BLAST resulted in a query cover range of 94 – 100% and percentage identity range of 89 – 100% (Suppl. material 1).

In terms of overall abundance, 85% of ASVs were assigned to genera of bacteria that were not identified as being of zoonotic concern by the literature review (Table 1, Fig. 1, Suppl. material 1). However, all but one of the samples (95%) contained at least one assigned genus of potential zoonotic concern (Table 1, Fig. 1). Between zero to six of the literature-identified genera were assigned within each sample (mean of two) (Supp. Mat. I). The relative abundance of the literature-identified genera ranged between 0–35% of isolates per sample (mean of 13%) (Suppl. material 1).

Of the literature-identified genera, *Lysobacter* was the most prevalent among the genera-assigned ASVs, although it was only associated with snake samples. *Lysobacter* assigned ASVs also accounted for just over 10% with regards to the overall relative abundance of ASVs. Furthermore, these ASVs were present within eight out of the 19 samples (Fig. 1, Suppl. material 1). The second most abundant genus was *Bacteroides*, which accounted for 2% of the overall relative abundance of ASVs. *Bacteroides* assigned ASVs were present in each of the four sample types (snake oral, snake cloacal, mouse oral and mouse rectal), although relative abundance was greatest in the mouse rectal sample set (Fig. 1; Suppl. material 1).

Discussion

The purpose of this study was to evaluate the presence of any potentially pathogenic bacterial taxa in ball pythons and the live mice used as their food at a commercial python farm that could impact negatively on the health of these snakes and/or those keeping them. The target facility reportedly releases all previously gravid females, and approximately 20% of their hatchlings, back into the wild and exports the remainder internationally for use as exotic pets (primarily to the USA). Of particular interest was relating the epidemiology of infection to potential vertical and horizontal transmission.

This study reported 13 different genera of bacteria, which include species that are known pathogens of ball pythons. The assignment of ASVs to *Acinetobacter*, *Bacteroides*, *Citrobacter*, *Enterobacter*, *Lysobacter*, *Proteus*, *Pseudomonas*, *Staphylococcus*, and *Tsukamurella* in the oral and cloacal samples taken from ball pythons is of potential concern for vertical and horizontal transmission, given that recent scientific literature reports pathogenic species belonging to these genera (Fig. 1, Table 1).

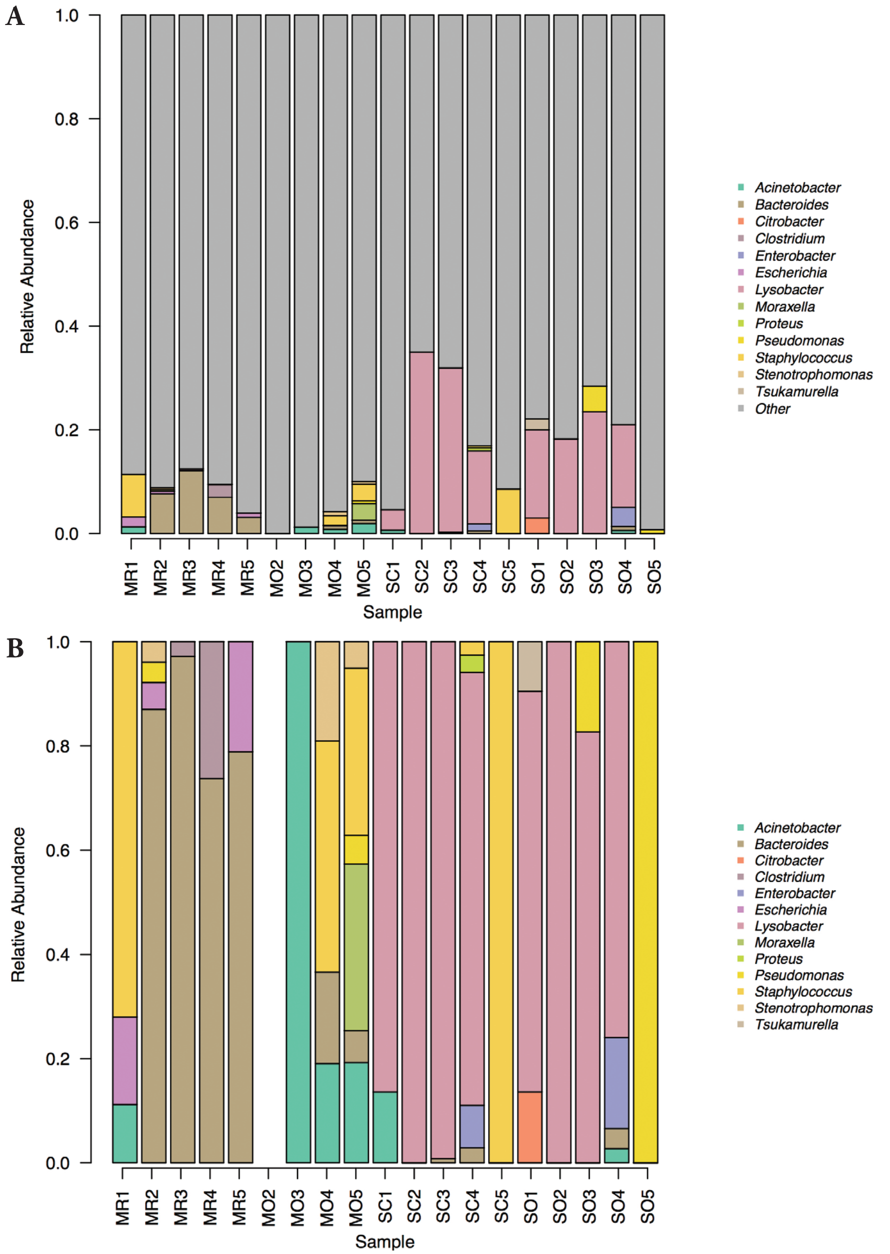

Figure 1. A Relative abundance of bacteria genera identified in samples taken from mice and ball pythons (*Python regius*) at a python farm in Togo. Genera containing potential pathogens of known zoonotic concern to ball pythons (as reported in the scientific literature) are highlighted in colour. The majority of reads (shown in grey) were assigned to "other" least concern groups, which consisted of ASVs that were either assigned to non-target genera or no genus. Samples were from swabs of: MR – mouse rectal; MO – mouse oral, SC – snake cloacal; and SO – snake oral. **B** Relative abundance of bacteria genera of known zoonotic concern to ball pythons (*Python regius*) (as reported in the scientific literature) identified in samples taken from mice and snakes at a python farm in Togo. Samples were from swabs of: MR – mouse rectal; MO – mouse oral, SC – snake cloacal; and SO – snake oral. No bacterial genera of zoonotic concern were identified from sample MO2.

Table 1. List of potentially pathogenic bacteria from ball pythons (*Python regius*) (see Methods).

Genera	Species	References
Acinetobacter	*Acinetobacter calcoaceticus*, *Acinetobacter lwoffii*	Dipineto et al. 2014; Zancoli et al. 2015
Aeromonas	*Aeromonas hydrophila*, *Aeromonas veronii*	Dipineto et al. 2014; Zancoli et al. 2015
Anaplasma	*Anaplasma phagocytophilum*	Nowak et al. 2010
Bacteroides	*Bacteroides* spp.	Dipineto et al. 2014
Bordetella	*Bordetella hinzii*	Schmidt et al. 2013
Chlamydophila	*Chlamydophila* spp.	Hoon-Hanks et al. 2018
Citrobacter	*Citrobacter freundii*	Dipineto et al. 2014; Zancoli et al. 2015; Schmidt et al. 2013
Clostridium	*Clostridium* spp.	Dipineto et al. 2014
Elizabethkingia	*Elizabethkingia meningoseptica*	Schmidt et al. 2013
Enterobacter	*Enterobacter cloacae*	Dipineto et al. 2014; Schmidt et al. 2013
Enterococcus	*Enterococcus pallens*	Zancoli et al. 2015
Escherichia	*Escherichia coli*	Moss et al. 2007; Dipineto et al. 2014; Larsen et al. 2011
Klebsiella	*Klebsiella* spp., *Klebsiella oxytoca*, *Klebsiella pneumoniae*	Bardi et al. 2019; Schmidt et al. 2013; White et al. 2011
Leptospira	*Leptospira grippotyphosa*	Ajayi et al. 2017
Lysobacter	*Lysobacter pythonis*	Busse et al. 2019
Moraxella	*Moraxella osloensis*	Zancoli et al. 2015
Morganella	*Morganella morganii*	Dipineto et al. 2014; White et al. 2011
Mycoplasma	*Mycoplasma* spp.	Hoon-Hanks et al. 2018
Proteus	*Proteus vulgaris*, *Proteus* spp.	Dipineto et al. 2014; Schmidt et al. 2013
Providencia	*Providencia rettgeri*	Myers et al. 2009
Pseudomonas	*Pseudomonas aeruginosa*, *Pseudomonas fluorescens*, *Pseudomonas japonica*, *Pseudomonas* spp.	Bardi et al. 2019; Zancoli et al. 2015; Sala et al. 2019; Dipineto et al. 2014; Schmidt et al. 2013; White et al. 2011
Salmonella	*Salmonella enterica*, *Salmonella paratyphi* B, *Salmonella* spp., *Salmonella* Muenchen	Moss et al. 2007; Krishnasamy et al. 2018; Dipineto et al. 2014; Schmidt et al. 2013; White et al. 2011
Serratia	*Serratia plymuthica*	Zancoli et al. 2015
Staphylococcus	*Staphylococcus* spp., *Staphylococcus warneri*	Dipineto et al. 2014; Zancoli et al. 2015; White et al. 2011; Schmidt et al. 2013
Stenotrophomonas	*Stenotrophomonas maltophilia*	Zancoli et al. 2015; Schmidt et al. 2013; Klinger et al. 2018
Tsukamurella	*Tsukamurella paurometabola*	Zancoli et al. 2015

The relatively high frequency of ASVs assigned to the genus *Lysobacter* – 80% (*n* = 8) of oral and cloacal samples from ball pythons – is consistent with a recent report of isolates from the trachea of a ball python suffering from respiratory tract infection [*Lysobacter pythonis* sp. nov. (Busse et al. 2019)]. *Lysobacter* spp. have been described as "ubiquitous inhabitants of soil and water" (Christensen and Cook 1978) making the soil from the dens of wild caught pythons a potential source of infection.

The absence of ASVs assigned to the genera *Citrobacter*, *Enterobacter*, *Lysobacter*, *Proteus*, and *Tsukamurella* in the oral and rectal samples taken from mice used to feed ball pythons suggests that their diet was not a source of infection in this commercial operation, at least on the days of sampling, for these particular genera. Nonetheless, a much larger sample of mice is needed to determine the true bacterial status of the rodents that are typically used to feed "ranched" ball pythons when in captivity.

The presence of ASVs assigned to the genera *Clostridium*, *Escherichia*, *Moraxella*, and *Stenotrophomonas* in the oral and rectal samples taken from mice used to feed ball pythons suggests that these mice represent a potential reservoir of infection, for these particular genera, that could impact negatively on the health of wild caught ball pythons (i.e., gravid females) and their progeny. Other potential sources of environmental contamination include other captive amphibians, birds, reptiles and mammals that are traded by python farms (cf. Bell et al. 2004), as well as free ranging birds and small mammals (including rodents), which were observed on the farm.

Ball python production systems in West Africa have the potential to encourage disease transmission and the evolution of increased pathogen virulence. Python farms that practice the "ranching" of ball pythons operate at high stocking densities and with poor hygiene measures, where animals are sourced from geographically and ecologically diverse areas with minimal quarantine. These practices can increase pathogen exposure and lower barriers to transmission (Stenglein et al. 2014).

Furthermore, the ball python is the most traded CITES-listed live wild animal currently being exported from Africa, with more than 963,334 snakes exported from Togo alone between 1978 and 2017 (D'Cruze et al. 2020). Commercial breeders in importing countries (predominantly the USA and countries of the EU) also operate at high stocking densities and commonly attend trade shows, where animals from different sources are juxtaposed (Stenglein et al. 2014).

Limitations

The present study was restricted to 20 samples taken from five snakes and five mice at one of the seven python farms currently operating in Togo. Furthermore, it reports only on assigned bacterial genera identified as possessing pathogenic species that are known to have affected ball pythons (as reported by recent scientific literature); thus, this study is not a comprehensive or exhaustive list of genera that may contain zoonotic pathogens. Only 15% of the ASVs in our samples were assigned to genera of concern (as reported in the literature), while other potentially pathogenic genera may be present and could be identified by further analysis.

Species level identification could not be achieved with the samples in this preliminary assessment due to the short length of the targeted 16S rRNA region, which may be indistinguishable among species and/or strains (a low level taxonomic rank used at the intraspecific level) (Bulman et al. 2018; Osawa et al. 2015). Future studies could overcome this limitation and improve taxonomic resolution by using more sensitive techniques, such as quantitative polymerase chain reaction (qPCR) with species-specific primers (Osawa et al. 2015).

Similarly, the present study did not distinguish between pathogenic and non-pathogenic ASVs. This is an important distinction, since the same species of bacteria can act as a harmless commensal, as well as a dangerous pathogen (e.g., *Escherichia coli*) (Proença et al. 2017). To overcome this limitation, future studies should adopt a highly targeted and individual approach per species [e.g., as taken by Delannoy et al. (2017) who detected pathogenic strains of *Escherichia coli* using a qPCR assay that target the

K1 capsule]. Similar analyses should also look to target other pathogen types (e.g., viruses) in "ranched" ball pythons and other wild animal species held in captivity at python farms.

We recognize that the present study represents a preliminary evaluation that should be treated as an initial indicator of both the bacteria present in commercial python farms in West Africa and their potential involvement in zoonotic disease. However, given the international scope, large scale, and national wild release component of the "ranching" process that currently underpins commercial trade of live ball pythons, we believe that these initial findings provide an important insight into the potential for vertical and horizontal bacterial transmission and highlight the need for further research.

Recommendations

Additional surveillance of ball pythons, both in the wild and in captivity at python farms in West Africa, will shed light on whether this type of commercial activity increases pathogen exposure and lowers barriers to transmission. However, in light of other management concerns (Auliya et al. 2020; D'Cruze et al. 2020), and as a precautionary measure, it is strongly advised that farms maintaining reptiles and other wildlife adjust to standard hygiene and quarantine measures, (e.g., biosecurity and disease surveillance practices [cf. Woodford 2000]) to minimize horizontal and vertical transfer.

Biosecurity measures should also be applied to snakes that are being released back into the wild as part of the "ranching" system in Togo. Theoretically, when they are properly released within an area of its indigenous range, this type of wild population "reinforcement" can improve the conservation status of the focal species (IUCN/SSC 2013). However, the IUCN/SSC (2013) recommends effective monitoring as an essential activity, and that reinforcement efforts should include the assessment of disease, welfare conditions, and mortality to maximise positive conservation outcomes.

Biosecurity surveillance practices should extend to importing countries. Such initiatives should also aim to inform those who trade and own ball python of the potential risks associated with zoonotic infection. Providing an appropriate environment and adequate nutrition for ball pythons is also important for maintaining their health. Washing of hands after handling ball pythons is strongly recommended (Centers for Disease Control and Prevention 2018) and they are inappropriate pets for immunocompromised owners and in households with young children (Centers for Disease Control and Prevention 2018).

Conclusion

This survey represents the first investigation into the epidemiology of bacterial genera at a commercial ball python farm in West Africa. This study was developed through the opportunity to collect samples during a broader official scientific review. It is recommended that further research should be carried out at python farms in Benin, Ghana and Togo. These studies should look to fully assess the species diversity, relative abundance, and pathogenic status of any bacteria (and other types of pathogen such as viruses) present in "ranched" ball pythons and the rodents that are used to feed them.

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Appendix I

PCR conditions for amplicon preparation using the Illumina two-step protocol.

Step 1 Thermocycler conditions			
Stage	**Temperature (°C)**	**Duration**	**Cycles**
Initial Denaturation	98	3 min	1
Denaturation	95	30 s	×25
Annealing	59	30 s	
Extension	72	30 s	
Final Extension	72	5 min	1
Step 2 Thermocycler conditions			
Stage	**Temperature (°C)**	**Duration**	**Cycles**
Initial Denaturation	98	30 s	1
Denaturation	98	10 s	×10
Annealing	62	20 s	
Extension	72	30 s	
Final Extension	72	2 min	1

Supplementary material 1

Genera of bacteria identified in swab samples of mice and ball pythons (*Python regius*)

Authors: Neil D'Cruze, Jodie Bates, Délagnon Assou, Delphine Ronfot, Emma Coulthard, Gabriel Hoinsoudé Segniagbeto, Mark Auliya, David Megson, Jennifer Rowntree

Data type: Excel sheet

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Stimulating collective action to preserve High Nature Value farming in post-transitional settings. A comparative analysis of three Slovenian social-ecological systems

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Abstract
The main research challenge of this paper is to gain a better understanding of collective action to preserve High Nature Value (HNV) farming in the specific setting of post-transitional EU Member States of Central and Eastern Europe, which we explore using Slovenia as a model country. We apply the Social-ecological Systems (SES) framework and combine participatory and action research in considering different options for stimulating collective action of local actors in three social-ecological systems in Slovenia. We describe the systems, focussing on first-tier variables, and provide a comparison of their characteristics influencing the readiness to engage in collective action. Characteristics of system actors had the greatest influence on outcomes, followed by the social, economic and political setting (macro issues) and governance arrangements. Strong leaders enjoying the community's trust are needed; rules must be transparent and individuals must have a personal interest to engage in cooperation. In a post-transitional setting, overcoming the issue of lack of trust is a limiting factor when attempting to stimulate collective action.

Keywords
Social-ecological systems, Post-transitional setting, HNV farming, Conservation, Resource management

Introduction

Traditional European extensive agricultural systems are not only a source of food and fibre and farmers' incomes, but also the main reason for the historical development of species-rich semi-natural habitats and cultural landscapes considered to be public goods (Cooper et al. 2009). A substantial proportion of European biodiversity (including domesticated plants and animals) depends on extensive High Nature Value (HNV) farming systems, a concept introduced in the 1990s to describe farming systems associated with high biodiversity and mostly with low chemical inputs and stocking densities (Hoogeveen et al. 2004). These farming systems, which tend to be labour-intensive but create low incomes from the market (O'Rourke and Kramm 2012), are being abandoned across Europe due to either intensification of production or farm abandonment (European Union 2018; Díaz et al. 2016; McGinlay et al. 2017; Sutcliffe et al. 2015; Ustaoglu and Collier 2018). Consequently, there are strong Europe-wide trends of declining farmland biodiversity (European Union 2018; European Commission 2019), farmland abandonment, overgrowth (Perpiña Castillo et al. 2018) resulting in loss of production potential, and depopulation (ESPON 2017). Therefore, the question arises as to how farmers as land managers can be incentivised to continue managing their land in a way that preserves environmental and social benefits, such as farmland biodiversity, cultural landscapes and rural vitality (Dwyer et al. 2018). This paper builds on previous research demonstrating the potential of doing this through improved market valorisation of products stemming from marginal production systems through collective action of smallholders, which helps to reduce transaction costs through resource-pooling (e.g. Kruijssen et al. 2009, Gruère et al. 2009).

Being resource management systems, HNV farming (and agricultural systems in general) can be conceptualised as social-ecological systems (SES) (Ostrom 2007, 2009; McGinnis and Ostrom 2014). This means that we consider them to be an inseparable combination of social and ecological elements. They consist of the human system, i.e. people and their interactions, and the natural system or ecosystem. The main advantage of the SES framework in analysing resource management systems is that it takes into account both of these sub-systems and their interactions. It thus examines systems' building blocks in order to understand how institutions and people co-produce outcomes in terms of appropriation and governance of natural resources (Schoon and Van der Leeuw 2015). It builds on empirical work on managing common pool resources, as well as research on institutions and collective action (Partelow 2018); although today the framework is viewed more as a diagnostic tool for assessing the sustainability of systems (Ostrom 2009), the aspect of collective action for sustainable resource management remains very relevant.

The basic framework organises SESs into four basic interacting entities or subsystems: **resource units** extracted by **resource users** from a **resource system**. Resource users determine the maintenance of the resource system according to a certain **governance system** (rules and procedures) and in the context of ecological systems and broader socio-political-economic settings. The processes of extraction and maintenance represent the most important forms of interactions and outcomes and are located at the centre of the framework (Cumming 2014; McGinnis and Ostrom 2014). One of the framework's advantages is its flexibility; it has been expanded and applied to numerous different situations in assessing the sustainability of SESs (Partelow 2018). One such expansion of the framework is the conceptualisation of agricultural and forestry systems as not only extractors of biomass, but as systems in which human action and natural processes interact to jointly provide environmental and social services (Dwyer et al. 2018); this application draws on the concepts of ecosystem services (Costanza et al. 1997; Daily 1997) and public goods (Samuelson 1954; Musgrave 1959). It is this conceptualisation that is used in the present paper, applied to HNV farming systems, in which farmers are seen not merely as resource users but as actors interacting with the ecological system to provide certain services that would otherwise not exist, i.e. agricultural landscapes, biodiversity specific to these landscapes and rural vitality.

Post-transitional EU member states have retained relatively large species-rich areas (Sutcliffe et al. 2015; ESPON 2017). Although the threats of future abandonment or intensification are highly likely in these countries, literature on managing common resources and on stimulating collective action here is scarce, as opposed to the rich practical and scientific experience in Western Europe (Sandberg et al. 2013; Mike and Megyesi 2018). However, previous research has shown that trust, social capital and readiness to cooperate (preconditions for collective action) are generally low in post-communist countries, regardless of whether they belonged to the Soviet bloc or the 'softer' more market-orientated "socialism" (Estrin 1991; Uvalić 2018) of (ex-)Yugoslavia (e.g. Swain 2000; Murray 2005; Sapsford and Abbott 2006; Lawrence 2008; Scrieciu 2011). In prior research, promoting the sustainable management of biodiversity (specifically in protected areas) in post-communist countries through markets has been explored and shown to be challenging (Otto and Chobotova 2013). However, the potential for stimulating collective action and commercial cooperation is less explored (Scrieciu 2011), although it is particularly pertinent for the same farm structure that is the most relevant for HNV farming (i.e. predominantly low-input, labour-intensive subsistence farming). The main research challenge of this paper is to gain a better understanding of collective action to preserve HNV farming in the specific setting of post-transitional EU Member States of Central and Eastern Europe, taking Slovenia, a former socialist EU Member State with a high proportion of HNV farmland (ARSO 2008), as a model case. Our research question, which asks which are the main factors influencing the willingness and ability of local actors to engage in this kind of collective action, is approached by considering different options for stimulating it in three social-ecological systems in this country.

As many inhabitants of traditional farming landscapes are poor (Fischer et al. 2012) and extensive HNV farming practices are largely being abandoned due to their low profitability (O'Rourke and Kramm 2012), our research explored the possibility of stimulating collective action to engage in a form of improved market valorisation of value-added products from protected areas (in the present case, Landscape parks as defined by the Slovenian Nature Conservation Act, and Natura 2000 areas) and the area of the wider communities in which they are embedded, in order to improve local livelihoods and thus hopefully detract from abandonment or intensification. Namely, previous research shows that it is possible to add value to existing products stemming from HNV farming by better communicating to consumers their provenance, which is becoming increasingly relevant in light of changing consumer preferences (e.g. World Bank 2007; Jarvis et al. 2011; Scrieciu 2011). This potential, if appropriately harnessed, could have wide-ranging implications for the numerous small, semi-subsistence farms in the European Union in general and the Central and Eastern European countries (CEEC) in particular – in 2010, farms smaller than 5 ha represented 67% of all holdings in the EU-27 and this amounted to 78% of farms in New Member States (Davidova et al. 2013).

The paper is organised as follows. Following a description of the methods of analysis, we provide an analytical description of the main elements of each SES, applying the modified framework developed by Dwyer et al. (2018). This is followed by the results of our attempt at stimulating collective action towards improving the valorisation of the products stemming from these systems and a comparison of findings from all three systems. We then discuss our findings against the backdrop of previous research and finish with some concluding thoughts.

Methods

The study combined participatory (Cornwall and Jewkes 1995) and action (McIntyre 2007) research, meaning that the research group was actively engaged in attempting to affect the trajectories of the social-ecological systems (Ostrom 2007, 2009; McGinnis and Ostrom 2014). The research mainly took place in the period 9/2015–7/2016, with some information gathered in follow-up interviews in 2018 (for total number and structure of people engaged, see Table 1). Authors conducted coding manually and independently, with regular checking of the coding process to limit potential inconsistencies.

In selecting the cases, we sought areas that are typical cases of HNV farming systems that contain important habitats under the European Union's Natura 2000 (N2K) network and are currently socially (depopulation, low incomes and educational levels) and/or ecologically (habitat degradation, biodiversity loss) threatened. The three cases were selected to be rounded (geographically, administratively or socially) social-ecological systems, representative of HNV farming systems in different geographical areas and of different sizes and to represent different levels of agricultural management intensity (CS1 – low intensity; CS2 – medium intensity; CS3 – high intensity) and different levels of familiarity with nature conservation in the form of Landscape parks (CS1 – 28 years; CS2 – 13 years; CS3 – not established). Thus, CS1 (Solčavsko) covered agri-forestry in low-intensity systems in a sub-alpine region; CS2 (Goričko) covered medium-intensity subsistence farming in a hilly region; and CS3 (Središče) covered high-intensity farming in river lowlands, adjacent to a riparian forest. Despite the fact that the concept of High Nature Value farming has been around since the

Table 1. Description of focus groups and interviews and their attendants/interviewees. Source: authors.

Case study	Solčavsko (CS1)	Goričko (CS2)	Središče (CS3)
N° focus groups	6	2	1
Total number[a] of focus group participants	47	26	13
Other meetings	8	2	4
N° interviews[b]	26	14	13
Farmers	13	14	9
Entrepreneurs	7		2(1)
Extension officers	3		
Municipality officials	3		1
NGO representatives	(2)		1(4)
Other	(2)		

[a]attendants of multiple focus groups only listed once
[b]some interviewees belonged to several categories; numbers in parentheses indicate that the interviewee has already been listed in another category

1990s, indicators and monitoring methods are still not fully developed (Lomba et al. 2014, Keenleyside et al. 2014). The only national assessment of HNV farming in Slovenia known to the authors was quite broad-brushed, based on Corine Land Cover and national land use data and estimated 60–80% of utilised agricultural area (UAA) in Slovenia as HNV farmland (ARSO 2008). Since we could not rely exclusively on this assessment, we used the Natura 2000 classification and association with Landscape Parks (defined by the Nature Conservation Act as "area(s) of high quality and long-lasting interconnection of man and nature of great ecological, biological or landscape value") as indirect indicators that they are indeed associated with high biodiversity, as both systems rely on using expert conservation guidelines and indicator species to merit classification as Natura area/Landscape Park.

We deliberately sought out partners seeking help in stimulating collective action for improved market valorisation in concrete cases – regional developers in CS1, a Landscape Park director in CS2 and a national NGO in CS3. We looked for partners whom we knew to have a good knowledge of local dynamics, as well as a stance that sought to reconcile nature-related considerations with social ones.

The research approach consisted of two parts (see Fig. 2). In the first part, we described the social-ecological systems (Fig. 1), focussing on first-tier variables: actors, resource system, resources (environmental and social services), governance (rules and institutions) and broader macro issues – social, economic and political setting (Table 3). The action situation in our cases is associated with the attempt to stimulate collective action for improved market valorisation (Table 4) and was the focus of the second, action-based part of our research. In describing the variables, we took a broad-brush approach, as the aim of analysis was not to describe every detail, but to understand the functioning of the systems as a whole. Specifically, the focus in this analysis was more on the human aspects of the system than on the physical quantification of resource extraction and service provision, as our aim was to explore the factors influencing the ability and willingness of the systems' actors (mainly land managers, but depending on

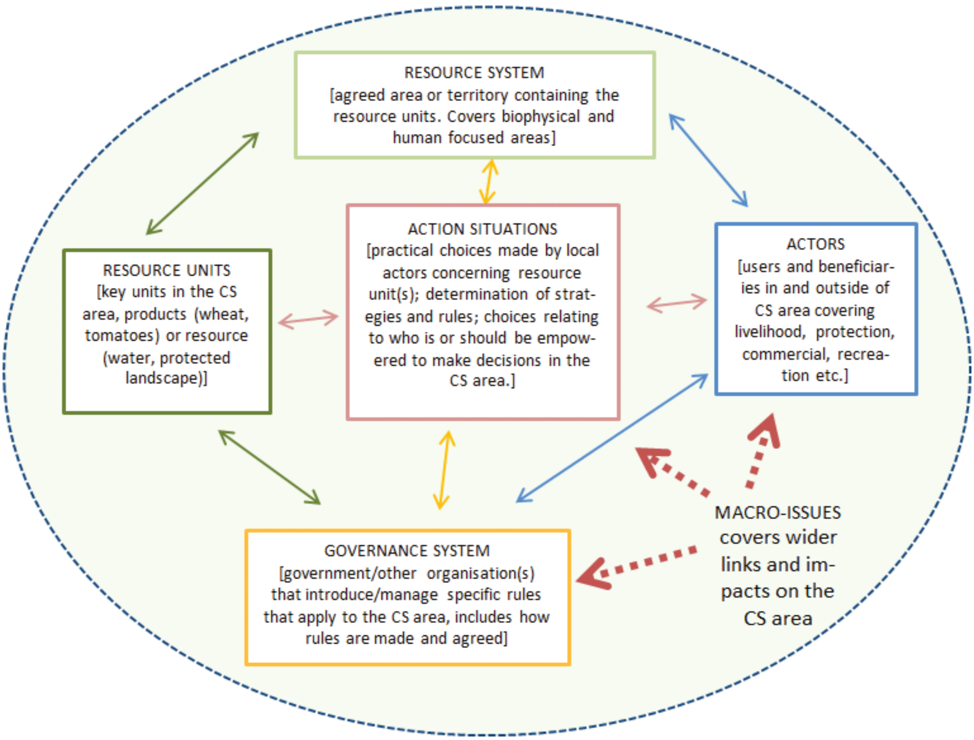

Figure 1. The SES diagram. Source: PEGASUS project, based on McGinnis and Ostrom, 2014.

the specific context in each case study area; see next section) to engage in collective action. Qualitative methods of analysis are preferable to quantitative ones in cases when understanding of human behaviour is sought, as it allows for the understanding of context and processes (Maxwell 2012), while the relative level of abstraction of the SES framework, which organises elements of systems into variables, still allows for some level of comparison between systems (Partelow 2018).

The first part of the research was conducted in several steps:

- Initial screening of scientific and grey literature, statistical data and web pages on the case study areas for information on their demographic, economic, geographical, biodiversity-related and agricultural production characteristics, as well as historical development.
- Preparation of preliminary textual descriptions of the basic elements of each SES that were then distilled into tables briefly describing each system's first-tier variables as listed above.
- Verification at meetings with one or several key informants for each case, whom we knew, based on prior experience (e.g. through preceding project collaboration or the persons' prominence in certain fields), to be knowledgeable regarding the respective systems. These gatekeepers helped us to improve the descrip-

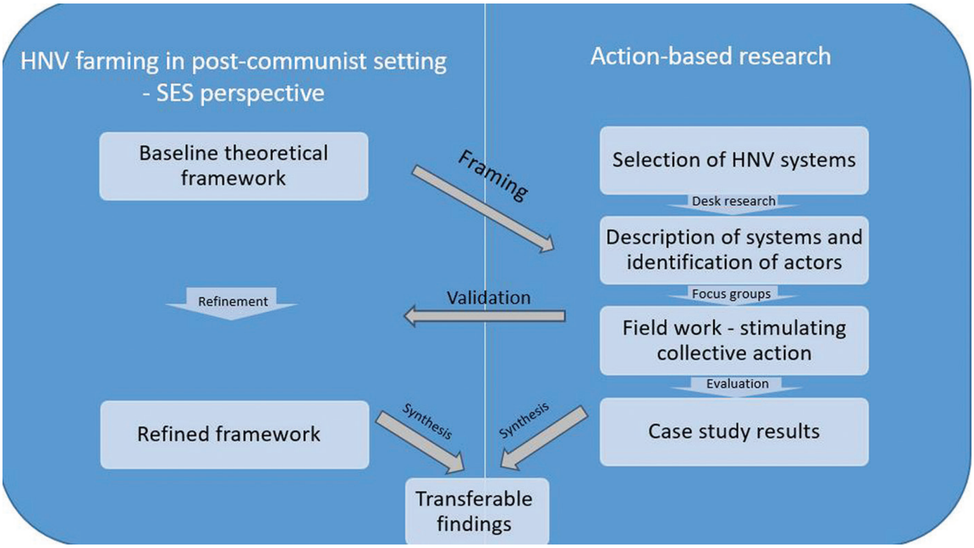

Figure 2. Depiction of the workflow of the research.

tions by providing additional information and to assemble a list of the main actors (land managers who are local opinion leaders, municipality officials, tourist operators, advisory service officials, business owners, NGOs – local associations and other locally prominent persons) in each case study who were then invited to participate in a focus group meeting.

- Presentation of the descriptions of each SES and its main elements to focus group participants and gathering of further feedback at meetings. Subsequently, we discussed with each group the possibility of stimulating local collective action that could, in their view, contribute most to improving the valorisation of their products, while preserving HNV farming.

In the second part of the study, we prepared questionnaires for each case, based on the findings of focus groups, and conducted a total of 53 semi-structured interviews with actors (farmers, entrepreneurs, representatives of local non-governmental organisations and advisory services, municipal officials). In these interviews, we checked the readiness for, attitudes towards and obstacles to collective action, whose specific nature differed in each case. The lists of persons to be interviewed were provided by the local gatekeepers, based on their familiarity with their economic activity and willingness to cooperate. Based on the interviews, our research group prepared a proposal for action, which was presented back and discussed in the broader community at a public final event in each case. Based on any new information provided, our own observations and internal discussions, we revised the SES description as needed. Each addition or elimination was discussed and agreed amongst the authors of this paper.

The success of the initiatives to achieve collective action served as an indirect indicator of the sustainability of the three systems. We used a simple three-step scale to assess this success:

1. Unsuccessful: no interest to engage in collective action was found in the community;
2. Partly successful: some interest was stated or demonstrated, but there was no follow-through;
3. Successful: interest was clearly demonstrated and followed by action, whether by building on existing initiatives or initiated by our research.

Description of social-ecological systems

Table 2 provides an overview of the basic ecological and socio-economic characteristics of the three case studies and of Slovenia as a whole.

CS1: 'Solčavsko' – agri-forestry in sub-alpine Slovenia

This case study investigated agriculture and forestry in the Upper Savinja Valley, in the municipalities Solčava and Luče. The entire area is hilly or mountainous. A total of 80% of the territory is forested and forestry is the main source of income for many farms (Mavsar 2005), supplemented by farming (mostly animal husbandry) and agri-tourism. Traditional farming practices (extensive grazing and harvesting) on large family farms and restrictive forestry policy (ZGS 2012) created a characteristic HNV landscape with

Table 2. Selected socio-economic and ecological indicators for each case study and Slovenia as a whole. Source: SURS (2018); MKGP-RKG (2018); http://www.natura2000.si/index.php?id=45.

	CS1	CS2	CS3	Slovenia
Size [km^2]	213	578	31	20,273
Inhabitants (2018)	1,985	25,899	1,977	2,066,880
Population ratio 2018/2008	0.97	0.95	0.92	1.02
Average age (2018)	43.93	45.18	45.70	43.20
% over 65 y.o. (2018)	19.9	21.5	22.3	19.4
Total farm area [ha]	10,187	30,686	1,623	897,769
Forest [%]	69.8	25.3	22.2	41.6
UAA (2010) [%]	7.1[a]	37.8	37.4	23.4
Permanent grasslands and pasture [%]	96.4[a]	20.7	16.4	58.5
Field plots [%]	0.6[a]	76.1	80.5	35.9
N° Agricultural holdings (2010)	211	3652	191	74455
Average farm size (total farm area) [ha] (2010)	48.1	8.4	8.5	12.0
Utilized agricultural area /farm [ha] (2010)	7.1[a]	6	6.4	6.4
ANC [%]	100	76[a]	23[a]	86.3
N2K[a] [%]	61.5	77.8	50	37.16

[a]estimate; ANC: Area with natural constraints for farming

Table 3. Summary of the main elements of studied SES. Source: authors.

	Solčava	Goričko	Središče
Social, economic, and political settings	Post-transition situation, EU accession, lagging incomes, increasing demand for products with higher value-added	Post-transition situation, EU accession, lagging incomes, increasing demand for products with higher value-added, agricultural intensification, cultural specificity	Post-transition situation, EU accession, lagging incomes, increasing demand for products with higher value-added, agricultural intensification
Resource systems	Alpine forests and agricultural land (grassland) with high biodiversity and cultural value	Hilly agricultural mosaic countryside and forests with nearby hot springs; rich cultural and culinary tradition	Riparian forest and mosaic agricultural landscape, cultural tradition
Governance systems	Forest and agricultural policy; engagement of municipality, local NGOs, invested individuals; park management regime	Agricultural and environmental policy; engagement of Landscape Park management; park management regime, N2K rules	Agricultural, environmental and forest policy; engagement of national NGO and municipality; N2K rules
Resource units (environmental and social services)	High biodiversity in semi-(pasture) and pseudo-natural (forest) habitats, including animal genetic resources; products (food, feed, wood, wool); recreation and public health, rural vitality	High biodiversity in semi-natural habitats, products (food), recreation	High biodiversity in natural (riparian forest) and semi-natural (mosaic agricultural landscape) habitats, rural vitality, products (food), recreation
Actors	Strong local leader, engaged municipality, invested individuals, local NGOs (associations), research group	Park management, engaged municipalities and national extension service officers, research group; low levels of cooperation	Strong local leader, engaged municipality, invested individuals, national NGO and local NGOs (associations), research group; low levels of cooperation

well-preserved biodiversity (many rare or protected plant (e.g. *Taxus baccata*, *Cypripedium calceolus*, *Primula auricula*) and animal (e.g. *Tetrao urogallus*, *Lynx lynx*)) species and stable productive forest ecosystems, the wood of which is considered to have special technical properties due to high altitudes and traditional selective felling practices that take into account (supposed) seasonal and lunar influences (Lipnik et al. 2009).

In the 1970s and 1980s, this area became a mass tourism destination (Anko et al. 2007). Due to the accompanying pollution, some natural values were protected in 1987, including two landscape parks – Logarska Valley (2430 ha) and Robanov kot (1447 ha) that represent a significant proportion of the case study area. A private company uniting landowners in Logarska Valley was granted management rights in 1992 and limited the number of tourists by introducing an entry fee and a relatively strict protection regime. The valley became a well-known destination for nature lovers, and residents of the park and its surroundings prospered through rural tourism and gastronomy.

Traditional HNV farming practices, mainly extensive grazing with cattle and sheep of predominantly autochthonous breeds adapted to the harsh environment (cika cattle and Jezersko-Solčava sheep), are today threatened by trends such as emigration from marginal areas and subsequent overgrowth; subsistence crop farming has already disap-

Table 4. Main elements of action research. Source: authors.

Action situation	Solčava	Goričko	Središče
Current state	overgrowth	rapid overgrowth	agricultural intensification
	farm abandonment	proliferation of invasive alien species	low incomes
	depopulation	abandonment of traditional farming	depopulation
	low value added	depopulation and aging/ intensification and consolidation	no cooperation of producers and other service providers
	low producer cooperation	lack of cooperation, trust and entrepreneurship	
Desired state	Preserved traditional grazing and thus grassland habitats	Improved cooperation amongst farmers and with the park	Preserved mosaic landscape and natural habitats
	Preserved animal genetic resources	Developed coordinated supply of value-added products	Economically and ecologically sustainable exploitation of natural assets through park umbrella brand
	Preserved forest ecosystems	Employment opportunities	
	Improved value-added and consequently rural vitality	Maintained population and consequently land management	
Result	Unsuccessful (agriculture) Successful (forestry)	Partly successful	Successful

peared almost completely. Pastures, especially more remote ones, are preserved largely due to the public payments for the preservation of farming on Less Favoured Areas and related agri-environmental measures under the EU's Common Agricultural Policy. In addition, the traditional, locally adapted breeds are threatened, a decline in their populations only being prevented by agricultural policy measures, the engagement of individuals (also within breeding and related associations) and, more recently, by increasing consumer interest in 'local' and 'traditional' products. Part of the problem is the difficult transport and distance of processing facilities for local produce (milk, beef, lamb), as well as a highly seasonal character of direct sales channels (mainly through tourism and gastronomy), which result in lower and more volatile incomes.

The forest ecosystems are threatened by growing numbers of natural disasters due to climate change, for example widespread damage due to sleet in 2014 and strong winds in 2017, exacerbated by subsequent damage by pests and affecting the species structure. Continued sustainable management requires coordinated replanting efforts and an improved ability to compensate for increased management costs.

CS2: 'Goričko' – Agriculture-based development strategies for areas hit by the economic crisis

In CS2, a hilly agricultural landscape in the northeast of Slovenia was analysed; it included 11 municipalities, most of the territory of which falls under the Goričko Landscape Park established in 2003. It is the second largest protected area in Slovenia, protecting 38 animal species, one plant species and seven habitats identified and protected under the Natura 2000 framework (KPG 2018) and containing an aesthetically and environmentally valuable cultural landscape co-created by traditional subsistence mixed farming. The Park has agricultural holding status and directly manages 40.5 ha of land; its activities are aimed at maintaining the traditional sustainable land use system and the livelihood of small farmers.

The small subsistence mixed farms, which have historically contributed to the creation of the diverse mosaic of biodiversity-rich cultural landscapes, typically bred a small number of cattle and perhaps pigs, and tended to some arable land and grasslands, orchards and vineyards. Most of these farms are uncompetitive nowadays and the landscape is threatened by overgrowth due to the abandonment of traditional farming; conversely, parts where mechanised agriculture is possible are intensifying, giving way to a smaller number of specialised apple producers and dairy farmers, threatening the typical wet and dry grassland habitats. The rapid decline of these habitats (Government of the RS 2015) is exacerbated by the intrusion of invasive plants (especially *Solidago* sp.). As small-scale livestock farming has disappeared, farmers only perform late mowing of grass to receive subsidies. Two challenges are associated with late mowing. First, the acquired biomass is not suitable for animal feed and thus has limited economic potential. Second, late mowing accelerates the growth of invasive plants. Monitoring of bird (*Upupa epops*, *Otus scops* and *Lullula arborea*; Denac et al. 2017) and butterfly (*Euphydryas aurinia*, *Phengaris nausithos* and *Phengaris teleius*; Verovnik 2015; Zakšek et al. 2017) populations show a marked decline in abundance, indicating ineffectiveness of agricultural policy measures. Park conservation activities have been successful in improving butterfly abundance (Verovnik 2015), but long-term effects require systemic action.

The region's economy is underdeveloped in terms of average net earnings and off-farm job availability, and based on agriculture; in some municipalities, over half of the working population is employed in agriculture (SURS 2018). Following the collapse of large manufacturing plants during the transition, the area faces high unemployment, depopulation and aging; many seek employment elsewhere, leaving behind the older, less educated and less proactive. There is no active cooperative in this area and no market organisation; distrust and passivity (Klemenčič 2011) are traditionally strong.

Many individuals and institutions are working to mitigate these trends, including the Park administration, municipalities, agricultural advisory service etc., and the region is eligible for preferential financial assistance from EU and national sources. However, measures have generally failed to stem negative demographic and ecological trends. The Park administration is mistrusted by many farmers, seen as an obstacle to intensification and development. As a result, most refuse to participate in its activities, including joint marketing of products under a collective brand. The public recognises the region as an attractive tourist destination, but green tourism is in its infancy.

CS3: 'Središče' – Nature conservation enabling social security in farming

The third example covers an agricultural landscape (ca. 200 ha) and riparian forest (ca. 230 ha) in the municipality Središče ob Dravi in NE Slovenia. It contains the best preserved lowland river ecosystem of riparian forest in Slovenia, with nationally important populations of a number of animal species (*Charadrius dubius*, *Actitis hypoleucos*, *Alcedo atthis*, *Haliaeetus albicilla*, *Umbra krameri*, *Cobitis taenia*, *Cucujus cinnaberinus*); the area, including some agricultural land, falls under the framework of biodiversity-rich Natura 2000 areas. Recently, there have been indications that the hamster *Cricetus cricetus* has re-appeared; it is the only part of Slovenia with habitats suitable for this species, so an area of approx. 2.5 km^2 was proclaimed as a Natural Asset of national importance in 2004.

The riparian forests in the immediate vicinity of the river are not commercially interesting for intensive logging; they are managed under forest management plans emphasising their nature conservation function. The agricultural landscape is a mosaic of meadows, small fields and hedgerows exposed to annual flooding. Historically, most farmland was grassland, but agricultural policy in the 1960s stimulated conversion to arable land, consolidation and intensification, even in erosion-prone waterfront areas. Despite this risk, these fields are cultivated by farmers receiving CAP direct payments, often participating in the national scheme providing for subsidised crop insurance. Some waterways face eutrophication.

The area is remote and economically very weak. Many farmers are older and not developing any supplementary activities, but try to compete by reducing costs and intensifying production, yet even the largest farms in the region are relatively small and are in an unfavourable economic position. On the other hand, some younger farmers have invested in processing and some offer tourist and leisure services or gastronomic products. Several associations (beekeeping, tourist, equestrian, hunting) are also active but insufficiently coordinated for the development of a comprehensive range of tourist products and services, which is also limited by a lack of accommodation.

Cooperation between farmers and members of value chains is also weak; there is little organised production or coordinated marketing activity. Many farmers traditionally produce pumpkin seeds and sell them to a local oil mill that produces pumpkin oil, a gastronomic speciality, and attracts thousands of visitors annually.

Due to the rich natural (and cultural) heritage, several attempts have been made to establish a Landscape Park. The first, in the 1990s, failed due to unrelated disputes and the non-inclusive nature of the decision-making process, which deterred the locals; the second was at the time of our study. The mayor, in cooperation with a national conservation NGO, renewed the initiative to establish a park, insisting that a condition for its establishment is support by the inhabitants.

Results of action-based research

CS1: Solčavsko

During the focus groups, two sustainability issues emerged as crucial: the decline of traditional extensive pastoralism and a general decline of rural vitality due to low incomes, which are both a consequence of the unattractive economic position of farming and low availability of jobs outside agriculture. The solution can be to develop value-added products. Therefore, our action research investigated the capacity and readiness of land managers to cooperate in two integrated value chains that emerged as crucial during focus group discussions:

1) marketing of local sheep breed products (meat, processed products, wool); specifically, we investigated the possibility of establishing a small local processing facility and collective marketing efforts;
2) cooperation in a project improving the marketing of Mountain Wood by participating in a consortium of producers, processors, designers, certifiers and scientists; its purpose would be to scientifically assess the supposedly special properties of this material, develop products and improve consumer awareness in order to establish an autonomously functioning value chain.

Regarding the first initiative, interviews and a follow-up focus group revealed that breeders have no real interest in increasing production but prefer to sell products individually, either as part of their on-farm tourist offer or in informal markets. They would only market surpluses and are not interested in joining forces to ensure a consistent supply of meat. Some opinion leaders even expressed opposition to the idea. While one of the farmers is planning to invest in a small-scale processing facility, we did not detect any interest in collective action, so this part of the action research was deemed unsuccessful.

The project of improving the valorisation of Mountain Wood was initiated by a former mayor, who is himself a forest owner and employee of the State Forest service and has been working on the market valorisation of Mountain Wood for several years. Based on past experience and collaboration, we invited producers, processors and experts to cooperate in the project; the response was favourable and an intention to cooperate was publicly proclaimed, endorsed by the Ministry of Agriculture, Forestry and Food. The consortium is working on a project application to acquire funding to establish the value chain. We thus judged this part of the research as **successful**, though the long-term success of the initiative remains to be demonstrated.

CS2: Goričko

Within the focus groups with representatives of the municipalities, park and advisory services, the distrust and conservatism of (especially elderly) farmers emerged as a major obstacle to cooperate in initiatives that could improve the valorisation of the preserved landscape. As community relations between farmers were the greatest issue, before pursuing immediate common economic goals, a 'collective' had to be established in the first place. Therefore, our action research mostly took place in workshops and put a stronger emphasis on (younger) farmers and examined their willingness to cooperate, with the idea that an association of young farmers could serve as a nucleus around which economic cooperation and developmental projects could develop. At first, there seemed to be a critical mass present: they demonstrated some readiness and set up an initiative group to form a Rural Youth Association. However, the initial enthusiasm declined within one year; subsequent interviews indicated that the key issue was the lack of a leader, common economic interest (different production orientations, disagreement between conventional and organic farmers) and common identity (different social backgrounds). We therefore assessed the case as **partly successful**.

CS3: Središče ob Dravi

In the third case, our research coincided with an on-going discussion at the municipal level on the establishment of a Landscape Park initiated by the national NGO and endorsed by the mayor, who sees the park as a development opportunity. Therefore, based on the conclusions of the focus group, we investigated the attitudes of farmers and other residents towards its establishment, as well as their willingness to participate in a comprehensive tourist offer within the park as an umbrella brand. Most interviewees were very sympathetic to the Park and only a few large farmers feared the management regime (despite the fact that it would not bring new restrictions on agriculture); they cited negative past experience with the introduction of Natura 2000. While the Municipal Council initially voted against the establishment of the Park (12/2017), it was established on 4/2019 (after the conclusion of the study), so the case can be considered **successful**.

Analysis – Comparison of the Case studies

Our findings indicate that the most important components of the observed SES influencing sustainable trajectories fall into the categories Actors, Macro issues – Social, Economic and Political Setting, and Governance Systems; the systems of natural resources themselves seemed to be less influential, while the private and public goods (resource units) derived from them appear more as a dependent variable. Below, we discuss the major sets of influential variables.

Actors

The characteristics of actors proved to be essential for the results (see also, for example, Olsson et al. 2004; Folke et al. 2005) and can be roughly divided into two groups:

Perception of the situation, personal interest and values

The perception of the system state as critical by opinion leaders greatly influenced whether or not the will and critical mass to cooperate were present in the system.

Thus, in CS1, there was a lack of interest in the collective effort in the marketing of agricultural (i.e. extensive livestock) production as they did not see sufficient benefits for themselves in cooperating. The same is true of farmers' willingness to cooperate in grassland conservation in CS2, where an additional role was played by the dominant view amongst farmers of the interests of agriculture and nature protection as irreconcilable. In addition, the perception of the situation (habitat decline) as critical from the Park management's point of view was not shared by farmers, nor was the Park director perceived by them as an opinion leader.

In CS3, as well, the perception of the Park by large farmers (opinion leaders) as a threat to agriculture was decisive for the initial failure. Over time, the mayor's personal effort, sharing of positive experiences from elsewhere, the activities of our research team and pressure from the wider local community did however manage to gain critical mass to establish the Park.

Moreover, in the case of mountain timber valorisation, the professional and personal engagement of the former mayor was undoubtedly an essential element; nor are the motivations (professional and/or economic) of other members of the consortium (local entrepreneurs, representatives of professional institutions) a negligible factor.

Community relations and socio-economic traits of actors

In CS1, there was a marked contrast between the two initiatives. The failure of the agricultural initiative was partly attributable to the negative previous experience with the failed establishment of a local slaughterhouse and processing facility, which left in its wake cynicism and eroded trust and willingness to cooperate. Conversely, the Wood initiative built upon earlier successes in promoting the material (including the historical importance of forestry as a source of income and even wealth) and even more on the engagement of the former mayor, a respected and trusted member of the community.

The mayor in CS3, too, invested considerable energy in establishing trust and communication with stakeholders and avoiding repetition of past mistakes. This effort was required to overcome the opposing distrust of farmers towards conservation efforts related to the negative experience with Natura 2000.

In CS2, the distrust of farmers towards the Park and its management, which they see as hampering economic development, seems to be insurmountable at the moment. This may be related to the traditional passivity and mistrust present in the region, as well as the lack of an accepted local leader.

Both in CS3 and in CS2, the low levels of education and low socioeconomic status are related to risk-aversion and resistance to change; this is in contrast with CS1, where the large farm-holders have traditionally been more entrepreneurial and prepared (and able) to invest long-term, but at the same time more individualistic.

The post-transitional context did play a relevant role in all cases. On the one hand, there is a pervasive idea that when something is amiss, 'the state ought to…', indicating a dependence or at least accustomedness to the social state (cf. Scrieciu 2011). On the other hand and perhaps more importantly, the memory of forced collectivisation of property after World War II (though agricultural land itself was not subject to large-scale collectivisation in Slovenia, see Lerman 2001) and the associated phenomenon of free-riding is still raw and seems to continue to be a powerful deterrent to collective action. Crucially for market-based valorisation of public goods stemming from HNV farming, the readiness to cooperate economically and engage in a mutually-dependent activity where trust is a prerequisite, is only in its infancy.

Finally, the role of the research group in cooperation with the gatekeepers should be noted. In CS3, the Mountain Wood initiative, the engagement of agricultural policy and wood science specialists was an important element, and the good reputation that some of the group's members enjoy in the agricultural community contributed towards the readiness of farmers to communicate, especially in CS3.

Macro issues – Social, economic and political settings

Societal change is, in all three cases, the element threatening the system in the first place. Subsistence farming is coming under pressure from economic and political changes that are forcing intensification or farm abandonment (cf. McGinlay et al. 2017). The semi-natural habitats which resulted from traditional sustainable practices are collateral damage of this pressure. It was stated in all three cases by farmers that they would rather receive a 'fair' market price than be dependent on subsidies. Many inhabitants of traditional farming landscapes are financially poor and from their perspective, development is desirable, which threatens biodiversity and cultural heritage (Fischer et al. 2012).

On the other hand, consumer preferences are changing and demand for differentiated, high value-added products is increasing. This represents an opportunity for farmers who are able to adapt by diversifying, but also demands the (collective) development of appropriate market channels, as these areas are remote, isolated from urban markets and demand (cf. Scrieciu 2011).

Demographic trends appear both as an exogenous and endogenous variable. On the one hand, there are general societal trends of population aging and on the other hand, many young people are leaving the sector (and thus the countryside in general) because of lower incomes and poorer general services in rural areas (MAFF 2019), as well as because of the relatively negative societal perception (Černič Istenič 2011) of agriculture in Slovenian society. At the same time, there is a de-urbanisation trend emerging, especially in CS2, where some newcomers are also involved in agriculture. However, due to different value systems, they are mostly less integrated into the local community here.

Governance systems

Agricultural policy, especially the Common EU Agricultural Policy (CAP), has the strongest influence in this category, with significant impact on farmers' production decisions. It is particularly problematic due to inconsistencies in terms of nature conservation signals (Pe'er et al. 2017). On the one hand, farmers receive different payments from the agri-environmental scheme system and, on the other hand, direct payments allow for intensification of production and to some extent stimulate it. While income support contributes to the preservation of farming and supports young entrants, and cross-compliance arguably demands adherence to some basic environmental standards, these payments also cushion famers from market signals (Bureau et al. 2012), inhibiting development and adaptation.

The inadequate substantive design of the measures also has weak effects on the conservation of biodiversity (see, for example, European Court of Auditors 2011, 2017). Examples include poor design of agricultural policy measures for the conservation of butterflies contrasted with more effective locally-adapted measures adopted by the Park in CS2 (Verovnik 2015). The measure for conserving traditional breeds, relevant in CS1, is also inadequate given the declining population; according to interviewees, it is just not attractive to farmers. On the other hand, the Mountain Wood initiative is applying for funding under the CAP's rural development policy (a measure supporting the cooperation between farmers, advisors and researchers).

In terms of influencing outcomes, the aforementioned negative experience of farmers with Natura 2000, perceived as a restriction to farming, is an important factor. On the other hand, it is a condition for eligibility for funding under certain schemes. Nevertheless, it is mostly perceived as an obstacle rather than as an opportunity, especially in CS3 and CS2.

Despite not being formal rules, the rules-in-use regarding the transparency and inclusivity of the decision-making process must be mentioned. Most notably, striving for legitimacy yielded positive results in CS3 and CS1 (wood), while the perception of the Park as imposed in CS2 contributed to farmers' negative attitudes.

In all the observed SESs, the problem of combined property regimes is present (cf. Seixas and Berkes 2003), accompanied by colliding public and private interests. Agricultural intensification (the pursuit of a perfectly legitimate private interest, i.e. higher incomes) directly influences environmental (biodiversity) and social (cultural landscape) public goods. This contrast was most strongly present in CS3, where strong private interests initially prevailed over common ones, as well as over weaker/dispersed private ones.

Resource system

The size of the resource system in itself did not seem to be a crucial variable affecting results. CS1 is a good example of this, as the size of the system in the two initiatives was essentially the same; rather, the success seemed more dependent on other elements listed above, such as community relations and actor traits. Similarly, the intensity of management in itself did not appear to be a critical factor, with the possible exception of CS3, where large farmers were the ones most strongly opposing collective action; however, this again seems more strongly related to their economic dependence than to management intensity as such.

Discussion

Generally, it can be said, based on our research, that there is some awareness amongst farmers from HNV farming systems of the importance of valorising products through markets by turning the fact that they provide a socially-desirable service into a marketable trait – an attribute of value-added. On the other hand, the notion of cooperating to achieve market access more easily is not entertained nearly as much as the one that the state 'ought' to make this value better recognised somehow (preferably through measures like price control or import charges, supposedly a thing of the past in the EU). While they view that the larger collective must recognise the service that they make to it, they do not – ironically – take the individual responsibility that is required for the success of collective action; in many cases, this may simply be attributed to the farmers' relatively high age and low levels of education, but it is also a still-pervasive communist mindset, legacy of the communist period (1945–1990, see also Scrieciu 2011).

Some of the mistrust towards collective action, encountered in our case studies, may also be attributable to the anomalies and controversy occurring during the process of privatisation of socially-owned property (Lorenčič 2016) and which still plagues the Slovenian media space today. By contrast, the relative success of our research group as representatives of a respectable institution in functioning as a cohesive element (granting credibility to the initiatives; cf. Lawrence 2008) suggest the possibility that, in communities where trust is low, external institutional support may be an appropriate interim way of stimulating collective action. This includes policy measures, of which the Rural Development Policy (RDP) measure applied to by the Wood initiative is an apt example.

Our research confirmed the importance of leaders that was found in previous similar studies on community resource management conducted in Western contexts (e.g. Olsson et al. 2004; Folke et al. 2005); interestingly, this issue does not seem to have received as much attention in literature focussing on community-based resource management in the CEEC, with the exception of Mike and Megyesi (2018), who highlight the presence of a leader as an important determinant of success in Common Pool Resource (CPR) management. However, the presence or absence of leaders is a factor that is particularly difficult to influence.

HNV farming ecosystems are complex SESs in which the private and the public intersect. While they can be considered as private resource management systems, there is also a distinctive element of commonality in them, as they collectively provide a number of public goods to society, necessitating collective action to ensure their future sustainable provision. Thus, the problem with which we are faced in managing them is somewhat different from the classical conceptualisation of SESs as (collectively) managed systems of resource abstraction. Dwyer et al.'s (2018) modification of the framework that conceptualises agri-food systems as joint providers of environmental and social services (benefits) has proven its utility in our analysis of such systems.

While HNV farming systems that are declining due to intensification are somewhat more straightforward in that ensuring their sustainability 'only' demands limiting the overuse of resources, systems declining due to abandonment are not 'solved' as easily. Here, the interplay of the social and ecological elements of the systems comes readily to the forefront, as the desired outcomes would not be produced by either subsystem alone. This aspect also confirms the appropriateness of adopting an SES-based approach to analysis.

Admittedly, the definition of a sustainable SES and desirable outcomes is value-laden. It is precisely values that offer themselves as an obvious factor determining system trajectories. In addition to determining our definition of what constitutes a sustainable system (i.e. one that preserves wild and man-made biodiversity, cultural landscapes and sustains rural communities), the internalisation of common values is a precondition for collective action (Wright 2009). Perhaps the transition from communism to capitalism as a transition between value systems (Musek 1997) helps to explain why collective action seems difficult to achieve. We conjecture that, given the facts that Slovenia is amongst the westernmost of the post-communist countries that remained closest to the West-European value circle (ibid.) and was a constituent of (ex-)Yugoslavia with its market socialism (Estrin 1991), its transition should also be easiest; this may mean that other post-communist countries may experience difficulty in achieving sustainable resource management through market-based collective action for even longer. Historical context will, in our view, likely play an important role in the specific developments in each country (cf. Tickle and Clarke 2000; Scrieciu 2011).

Moreover, there is a more current transition between clashing value systems that is particularly visible in agriculture, namely that of farmers adhering to the productivist credo and environmentalists (cf. Burton and Wilson 2006). This is not simply a clash of ideologies; to many farmers, these changing societal values represent a threat to their livelihoods; the natural response of numerous, especially older farmers, is indignation.

Turning to the limitations of our study, the fact that many of the variables described are unmeasurable represented a serious research obstacle. While it is true that the primary intent of our study was not to exactly measure all SES elements, but to understand the system and its interactions, the lack of quantifiable variables makes comparison between the physical elements of different systems difficult. The second drawback of our research is its relatively short time span and definition of the 'success' of the action situation (i.e. stimulating collective action); truly observing the system and its dynamics would undoubtedly require longitudinal research.

Conclusions

Preserving HNV farming plays an important role in conserving biodiversity. This paper attempts to address the gap related to sustainable resource management that exists in the commons literature in the CEEC by exploring ways to motivate land managers to engage in collective action that would enable them to receive remuneration for their provision of public goods through the market.

We used the Social-ecological systems framework to describe the observed systems and approached our comparative analysis in two steps; in the first, we described the systems' main variables, while in the second, we attempted to actively influence their trajectories. This was done in cooperation with local actors. We found that the characteristics of system actors had the greatest influence on outcomes, while wider social, economic and political influences are those that are pushing the systems out of balance in the first place, but are also providing new opportunities.

While we have attempted to provide a cross-case synthesis, it is clear that it is very difficult to construct a single success formula, as every system is different; however, we can conclude that it seems necessary that a strong leader (or leaders) is present who enjoys the community's trust; rules must be transparent and individuals must have a personal interest to engage in cooperation. Considering the post-transitional settings, overcoming the issue of lack of trust was certainly the limiting factor in all cases when attempting to stimulate collective action. Despite increasing amounts of policy support, this rather unfavourable setting is unlikely to be conducive to large-scale shifts towards environmentally-conscious collective market action; rather, what we are more likely to witness in the foreseeable future are individual success stories.

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RESEARCH ARTICLE

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Legacies of past land use challenge grassland recovery – An example from dry grasslands on ancient burial mounds

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Abstract

Due to large-scale agricultural intensification, grasslands are often restricted to habitat islands in human-transformed landscapes. There are approximately half a million ancient burial mounds built by nomadic steppic tribes in the Eurasian steppe and forest steppe zones, which act as habitat islands for dry grassland vegetation. Land use intensification, such as arable farming and afforestation by non-native woody species are amongst the major threats for Eurasian dry grasslands, including grasslands on mounds. After the launch of the Good Agricultural and Environmental Condition framework of the European Union, in Hungary there is a tendency for ceasing crop production and cutting non-native woody plantations, in order to conserve these unique landmarks and restore the historical grassland vegetation on the mounds. In this study, restoration prospects of dry grassland habitats were studied on kurgans formerly covered by croplands and *Robinia pseudoacacia* plantations. Soil and vegetation characteristics were studied in the

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spontaneously recovering grasslands. The following questions were addressed: 1; How does site history affect the spontaneous grassland recovery? 2; Do residual soil nutrients play a role in grassland recovery? In former croplands, excess phosphorus, while in former *Robinia* plantations, excess nitrogen was present in the soil even four years after the land use change and grassland vegetation was in an early or mid-successional stage both on the mounds. The results showed that, without proper management measures, recovery of grassland vegetation is slow on mounds formerly used as cropland or black locust plantation. However, restoration efforts, focused on the restoration of mounds formerly covered by croplands, can be more effective compared to the restoration of mounds formerly covered by forest plantations.

Keywords
cropland, grassland restoration, kurgan, nitrogen, phosphorus, *Robinia pseudoacacia*, soil, steppe

Introduction

In intensively used agricultural landscapes, the remaining natural and semi-natural habitats often occur on small natural features (SNFs). Many of SNFs, such as verges, field margins and midfield islets are physically inappropriate for agricultural utilisation (Lindborg et al. 2014; Jakobsson et al. 2018; Fekete et al. 2019). Other types of SNFs have religious or cultural importance, which prevented their agricultural utilisation (Dudley et al. 2009; Molnár V. et al. 2017; Löki et al. 2019). Amongst them, ancient burial mounds (also called kurgans) of the Eurasian steppe and forest steppe regions are of particular importance (Sudnik-Wójcikowska et al. 2011; Bede et al. 2015; Bede and Csathó 2019; Deák et al. 2016a, 2019; Dembicz et al. 2018). They are earthen mounds of a few metres height, which were constructed from the topsoil layers of the surrounding areas by nomadic steppic tribes several millennia ago, mainly for burial purposes (Dembicz et al. 2016; Lisetskii et al. 2016). The estimated number of these mounds is more than 600,000 in Eurasia and they are typical landscape elements from Hungary to Mongolia (Deák et al. 2016a, 2019). A considerable proportion of these mounds still hold grassland vegetation; hence, mounds are valued as being stepping stones or biodiversity hotspots for grassland specialist plant and animal species even in transformed agricultural landscapes (Bede and Csathó 2019; Tóth et al. 2019; Deák et al. 2020). Despite their cultural importance and steep slopes, many of the mounds have been exposed to ploughing and afforestation works in the past centuries (Deák et al. 2016a, b). Restoration of their former vegetation is an important task for nature conservation (Valkó et al. 2018). Such restoration projects can increase the habitat area of dry grasslands, create stepping stones for grassland specialist species and the restored mounds can be used as demonstration sites for environmental education (Valkó et al. 2018).

The Cross-Compliance system of the European Union Common Agricultural Policy is a progressive initiative that contributes to a more environmental-friendly agriculture. One of its pillars is the Good Agricultural and Environmental Condition framework, which contributes to the development of a long-term and ecologically sustainable agricultural environment (Brady et al. 2009). As there are more than 1600 ancient steppic burial mounds in Hungary (Tóth 2006), that is why they were selected as the landscape elements typical to the country according to the GAEC regulations. Due to this, now there is a tendency for the cessation of crop production on the mounds and sometimes also in a surrounding buffer zone (Rákóczi and Barczi 2014; Tóth et al. 2018). For reconstructing the original vegetation of these important landscape elements, national park directorates and NGOs are increasingly involved in the restoration of grasslands on mounds (Valkó et al. 2018). As part of this initiative, black locust plantations have been cut on many mounds in order to reconstruct the historical landscape and increase the landscape value of the mounds. However, due to limited capacity and financial resources, in most of the cases the abovementioned favourable land use changes on mounds (i.e. cessation of crop production and cutting of non-native plantations) were not followed by any other restoration measures; thus the grasslands are recovering spontaneously. Another challenge is the isolated situation of the mounds: most of them are surrounded by arable fields, therefore, post-restoration management by grazing or mowing is particularly challenging (Deák et al. 2020).

In grassland restoration, spontaneous recovery became increasingly acknowledged (Prach and Řehounková 2008; Török et al. 2011a). In many cases, it is the best option, because it is a natural method, it has low costs and if proper propagule sources of target species are present, successful grassland recovery can be expected (Hedberg and Kotowski 2010; Kiehl et al. 2010). Promising examples of spontaneous grassland recovery were reported from many parts of Central and Eastern Europe, such as the Czech Republic (e.g. Prach and Řehounková 2008; Lencová and Prach 2011, Jírová et al. 2012), Hungary (e.g. Csecserits and Rédei 2001; Csecserits et al. 2011; Török et al. 2011b; Albert et al. 2014) and Romania (e.g. Ruprecht 2005, 2006). However, on isolated sites where propagule sources are limited, vegetation development may stall at a stage dominated by weeds (Prach and Pyšek 2001; Matus et al. 2003).

Here we study two scenarios of grassland recovery: recovery on former croplands and former plantations on mounds. Ploughing and afforestation are responsible for the reduction of grassland area and decline of grassland species richness in many parts of Eurasia (Deák et al. 2016a, b; Biró et al. 2018). Loess grasslands on fertile chernozem soils were the most severely affected by conversion to croplands or plantations (Biró et al. 2018). Amongst plantations, the North-American invasive black locust (*Robinia pseudoacacia* L., Fabaceae) represents a large conservation problem due to its high persistence, excellent vegetative and generative spread, intense evaporation and competition for resources, shading and nutrient accumulation effects, which all lead to the degradation and disappearance of the formerly typical grassland vegetation (Vítková et al. 2017).

The objective was to evaluate the prospects for restoring grasslands in degraded (ploughed and planted with black locust) ancient burial mounds, in order to provide information that will support the development of management plans, restoration and conservation of the local biota. We asked the following questions: 1; How does site history affect the spontaneous grassland recovery? 2; Do residual soil nutrients play a role in grassland recovery? Our final goal was to give recommendations for the restoration of grasslands on variously degraded burial mounds.

Material and methods

Study sites

We studied soil and vegetation of six mounds situated in the Hortobágy National Park, EastHungary (Figure 1). Climate conditions are warm temperate, fully humid, with hot summers (Kottek et al. 2006), the calculated annual mean temperature for the area between 1961 and 2010 is 10.7 °C, the average annual precipitation is 544 mm (Lakatos et al. 2013). The area is in the Great Hungarian Plain, dominantly consisting of Pleistocene-Holocene alluvial silt and clay, mixed with aeolian dust. The surface is plain (86–89 m a.s.l.), with nearly negligible elevation differences, being < 1–2 m km^{-2} on average, from which the studied mounds rise 3–6 metres above the surrounding landscape. The mounds were built using soil material collected from the topsoil layer of the neighbouring areas around several thousands of years ago. The mounds are always located on the highest position of the landscape, their surrounding being typically covered by chernozemic soils. The classification status of the soils of these landscapes according to the World Reference Base range from Chernozems over Kastanozems to Phaeozems, depending on the topsoil aggregate quality and the subsoil's carbonate status. The typical natural habitat types in the region are alkaline wetlands in the lowest elevation, alkaline dry grasslands at medium and dry loess

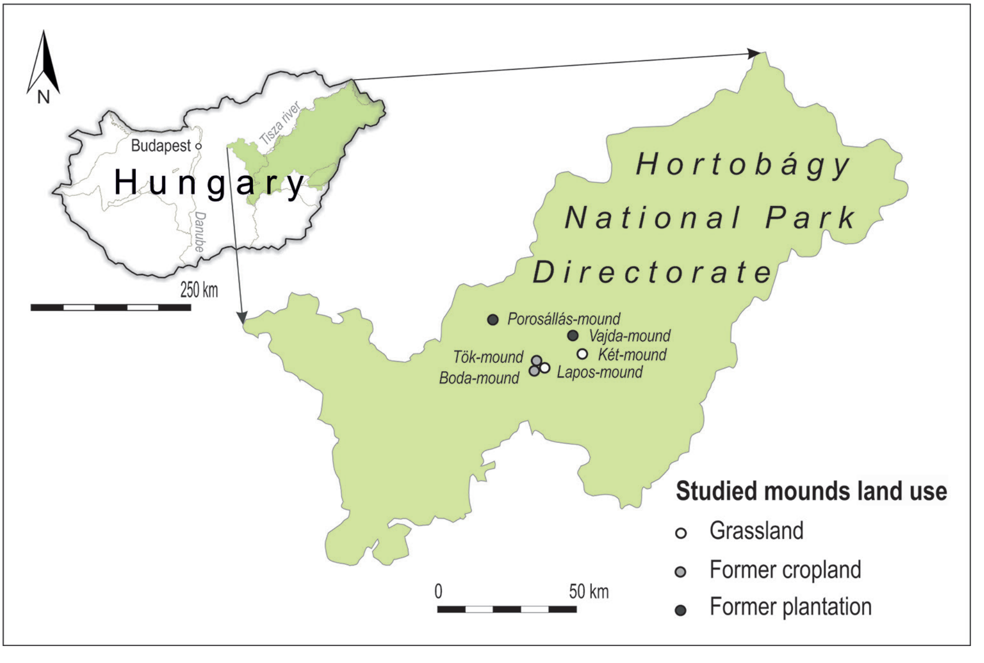

Figure 1. Study area: location of the studied mounds.

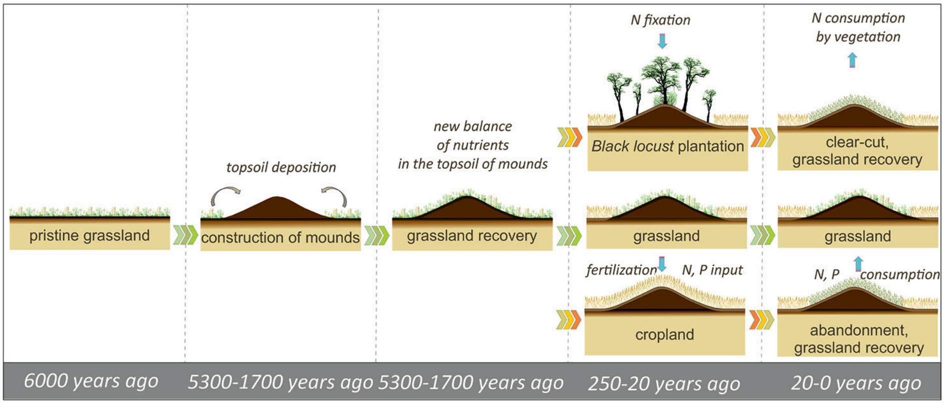

Figure 2. The soil and vegetation development of the studied mounds.

grasslands at the highest-elevated areas (Deák et al. 2014). Besides natural habitats, there are several croplands in the national park, where cereals, alfalfa and maize are the most typical crops. The majority of croplands are managed in an extensive way as farmers manage their lands according to the regulations of agri-environmental schemes, which limit the use of chemicals.

The vegetation of four surveyed mounds was formerly seriously degraded: two mounds (Porosállás- and Vajda-mounds) were formerly covered by black locust (*R. pseudoacacia*) plantations and two mounds were used as arable fields (Boda- and Tök-mounds). According to the oldest available orthophotos, all the two mounds with former croplands were already ploughed and the two mounds with *Robinia* plantations were already afforested in 1961. Based on archive descriptions, we can estimate that afforestation lasted for at least 80 years and crop production for at least 200 years on the studied mounds. Spontaneous grassland recovery started in 2012 in all sites: plantations have been cut and ploughing was stopped. As reference, we selected two mounds (Kettős- and Lapos-mounds) with well-preserved pristine grassland vegetation. Figure 2 shows the land use changes and the related processes of soil and vegetation development in the study sites in the past 6000 years.

Field sampling

Soil conditions were sampled in ten randomly distributed 1 m × 1 m permanent plots on each mound. From each plot, three subsamples were collected with 100 cm^3 stainless steel sampling cylinders, representing the uppermost 5 cm of the soil. First soil sampling was carried out in late June 2014 and it was repeated in late June 2016. On each mound, we designated ten 1 m × 1 m plots (altogether 60 plots), in which we recorded the percentage cover of vascular plant species in June 2016.

Laboratory analyses

Soil subsamples from the same plots and same year were then mixed and, after homogenisation, dried at 40 °C until weight constancy (approximately three days). In the laboratory, pH (H_2O; KCl), plant available nitrogen content and plant available phosphorus content were measured. Soil pH was measured with standard glass electrode in 1:2.5 suspensions prepared with water (pH_{H2O}), and KCl solution (pH_{KCl}), respectively (MSZ-08-0206:1978 2.1). Plant available P was determined after extraction with 0.1 M ammonium-lactate solution buffered with 0.4 M acetic acid at pH 3.7. Plant available NO_3^--N was extracted with 1 M KCl solution. Both N and P content of extracts were determined by spectrophotometric measurements, according the Hungarian standards (MSZ 20135 1999).

Data processing

We calculated cover-weighted scores of Ellenberg ecological indicator values for water (WB), nutrient (NB) and light (LB) adapted to the Hungarian conditions (Borhidi 1995). Based on the social behaviour type (SBT) system of (Borhidi 1995), we categorised the species into two ecological groups, grassland species and weeds. We considered specialists (S), generalists (G) and competitors (C) as grassland species and adventive competitors (AC), ruderal competitors (RC) and weeds (W) as weeds. The SBT system assigns a naturalness value to each category, ranging from -3 (AC) to +6 (S). We calculated the cover-weighted mean naturalness index for each plot, to characterise the overall naturalness.

For visualising the vegetation patterns on the mounds with different site history, we used Detrended Correspondence Analysis (DCA), based on specific cover scores. Soil nitrate and phosphorus content were included as overlay (CANOCO 5; ter Braak and Šmilauer 2012). We performed indicator species analysis to identify species confined to mounds with a certain site history (Dufrêne and Legendre 1997). For the analyses, we used the 'labdsv' package (Roberts 2019) in an R environment (R Core Team 2020).

To explore the effects of 'site history', time since grassland recovery started ('year') and their interaction (explanatory variables) on soil pH ($pH_{(H2O)}$; $pH_{(KCl)}$), soil nitrate and phosphorus content (dependent variables), we used Repeated Measures General Linear Models (RM GLMs) accounting for the normal distribution of the dependent variables (Zuur et al. 2009). Scores of soil variables were log-transformed to approximate them to normal distribution. We used the Greenhouse-Geisser correction for calculating degrees of freedoms and Tukey's test for calculating post-hoc pair-wise comparisons.

We used Generalised Linear Mixed Models (GLMMs) to explore the effects of 'site history' and two soil parameters ('soil nitrate content' and 'soil phosphorus content') (explanatory variables) on the naturalness index, ecological indicator values and the species richness and cover of grassland species and weeds in 2016 (dependent variables). The ID of the 'study sites' was included in the models as a random factor. Scores of naturalness index, ecological indicator values and cover of grassland and weed species were log-transformed to approximate them to normal distribution. Species number of grassland specialists and weeds were fitted using Poisson distribution with a log link. We used Tukey's test for calculating post-hoc pair-wise comparisons. The RM GLMs and GLMMs were calculated using IBM SPSS Statistics v. 22 programme (Armonk, NY: IBM Corp). Significance level was set at $p \leq 0.05$.

Results

Soil characteristics

We did not detect any difference in the soil $pH_{(H2O)}$ and $pH_{(KCl)}$ of the studied mounds (Table 1). The highest values for both $pH_{(H2O)}$ and $pH_{(KCl)}$ were recorded in the former croplands in 2014, but the difference between mounds with different history was not significant (Figure 3). Site history had a significant effect on plant available soil N content (NO_3^-). N content was the highest in former black locust plantations and the lowest in former croplands. Plant available soil P content was affected by time since grassland regeneration started ('year') and 'site history' (Table 1, Figure 3). P content was the highest in former croplands and the lowest in former black locust plantations.

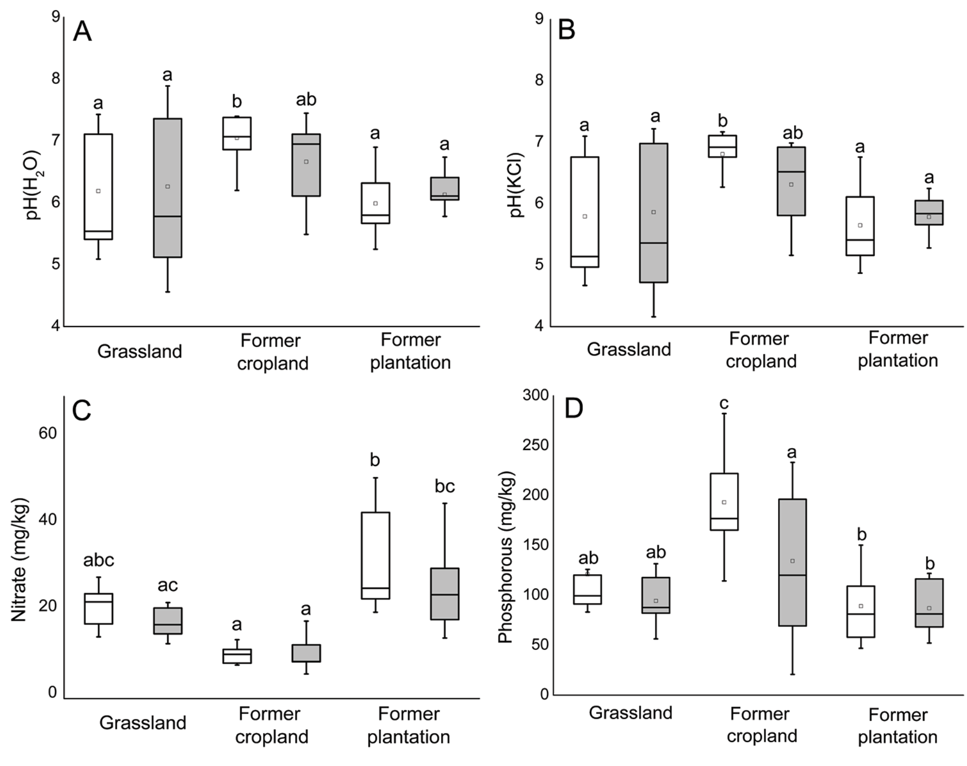

Figure 3. Soil characteristics (A – $pH_{(H2O)}$, B – $pH_{(KCl)}$, C – NO_3^--N content and D – P content (P_2O_5)) measured in the studied mounds (grasslands, former croplands and former plantations). White boxes represent data from 2014, grey boxes represent data from 2016. Different letters indicate significant differences between groups (Tukey test, $p \leq 0.05$).

Table 1. Effects of site history, year and their interaction on soil attributes (RM GLM). Notations: *** p < 0.001; ** p < 0.01; * p < 0.05; n.s.: non-significant.

Parameter	Site history				Year				Site history × Year			
	df_{num}	df_{den}	F	*p*	df_{num}	df_{den}	F	*p*	df_{num}	df_{den}	F	*p*
$pH_{(H2O)}$	2	1.067	2.636	n.s.	1	1	0.425	n.s.	2	1.247	1.426	n.s.
$pH_{(KCl)}$	2	1.088	2.822	n.s.	1	1	1.080	n.s.	2	1.323	1.972	n.s.
NO_3^--N content	2	1.467	37.289	***	1	1	2.190	n.s.	2	1.331	0.138	n.s.
P content (P_2O_5)	2	1.730	10.592	**	1	1	17.590	**	2	1.363	3.120	n.s.

Table 2. Results of indicator species analyses of the vegetation of mounds with different site history. Notations: G – mounds covered by grassland; A – mounds formerly covered by arable land; P – mounds formerly covered by *Robinia* plantation; *** *p* < 0.001; ** *p* < 0.01; * *p* < 0.05.

Species	Site history	Indicator value	p	Frequency
Carex praecox Schreb.	G	0.55	***	11
Koeleria cristata (L.) Pers. em. Borbás ex Domin	G	0.49	***	14
Salvia nemorosa L.	G	0.40	***	8
Festuca pseudovina Hack. ex Wiesb.	G	0.40	**	13
Elymus hispidus (Opiz) Melderis	G	0.35	**	7
Arenaria serpyllifolia L.	G	0.33	*	18
Plantago lanceolata L.	G	0.32	**	8
Bromus hordeaceus L.	G	0.32	*	14
Trifolium retusum L.	G	0.30	**	6
Euphorbia virgata Waldst. et Kit.	G	0.30	***	6
Erodium cicutarium (L.) L'Hér.	G	0.26	*	8
Eryngium campestre L.	G	0.25	*	5
Trifolium striatum L.	G	0.25	**	5
Stipa capillata L.	G	0.20	*	4
Cerastium semidecandrum L.	G	0.20	*	4
Bromus tectorum L.	A	0.84	***	18
Torilis arvensis (Huds.) Link	A	0.49	***	12
Convolvulus arvensis L.	A	0.44	*	34
Alopecurus pratensis L.	A	0.43	***	12
Achillea collina Becker ex Rchb.	A	0.42	**	18
Veronica arvensis Murray	A	0.34	**	8
Geranium molle L.	A	0.26	*	9
Xanthium strumarium L.	A	0.25	**	5
Vicia grandiflora Scop.	A	0.20	*	4
Lolium perenne L.	A	0.20	*	4
Elymus repens (L.) Gould	P	0.65	***	30
Ballota nigra L.	P	0.51	***	14
Bromus sterilis L.	P	0.35	***	7
Silene alba (Mill.) E.H.L. Krause	P	0.28	*	11
Galium aparine L.	P	0.26	*	13
Conium maculatum L.	P	0.20	*	4

Vegetation

We found altogether 92 vascular plant species on the studied mounds. Total species numbers were 64 in the grasslands, 50 in the former croplands and 24 in the former plantations. The vegetation composition of mounds with a different site history was well separated on the DCA ordination (Figure 4). We detected a considerable difference between the vegetation of the two mounds covered by grasslands.

Indicator species of grasslands were *Carex praecox* Schreb., *Koeleria cristata* (L.) Pers., *Salvia nemorosa* L. and *Festuca pseudovina* Hack. ex Wiesb. (Table 2). Typical species of former croplands included *Bromus tectorum* L., *Torilis arvensis* (Huds.) Link, *Convolvulus arvensis* L., *Alopecurus pratensis* L. and *Achillea collina* Becker ex Rchb. Former black locust plantations were characterised by *Elymus repens* (L.) Gould and *Ballota nigra* L. (Table 2).

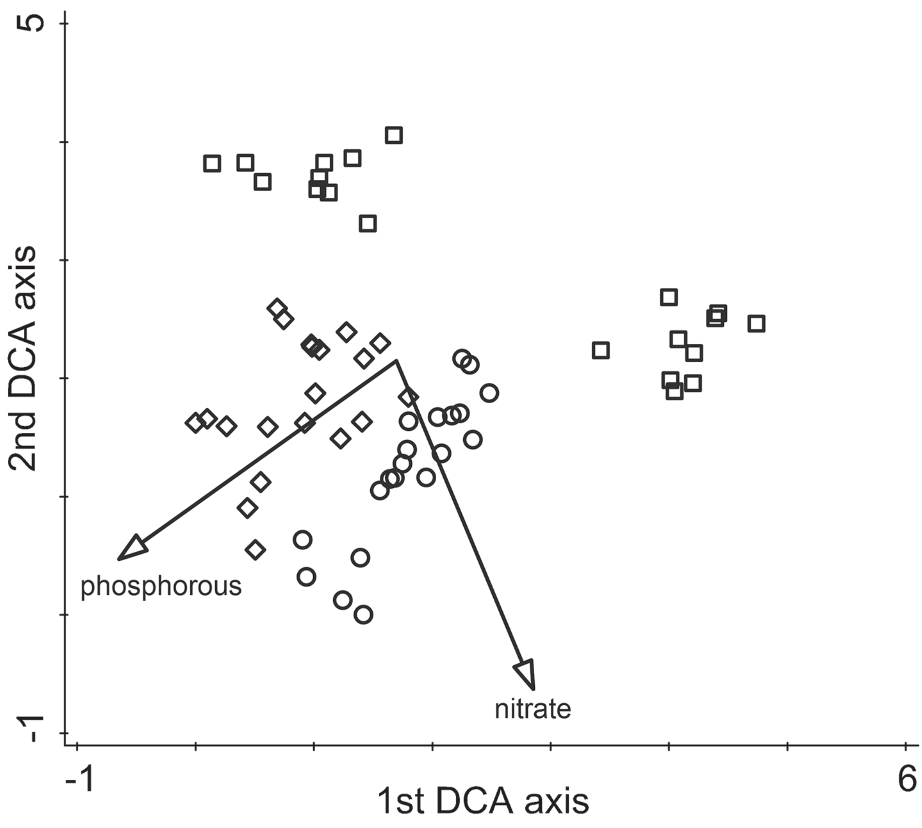

Figure 4. DCA plot of the vegetation of study sites, based on the species composition. Soil nitrate and phosphorus content were included as an overlay. Notations: squares – grasslands; diamonds – former croplands, circles – former plantations. Eigenvalues were 0.753 and 0.548 for the first and second axis, respectively. Cumulative explained variance of the first and the second axis were 12.72% and 21.98%, respectively.

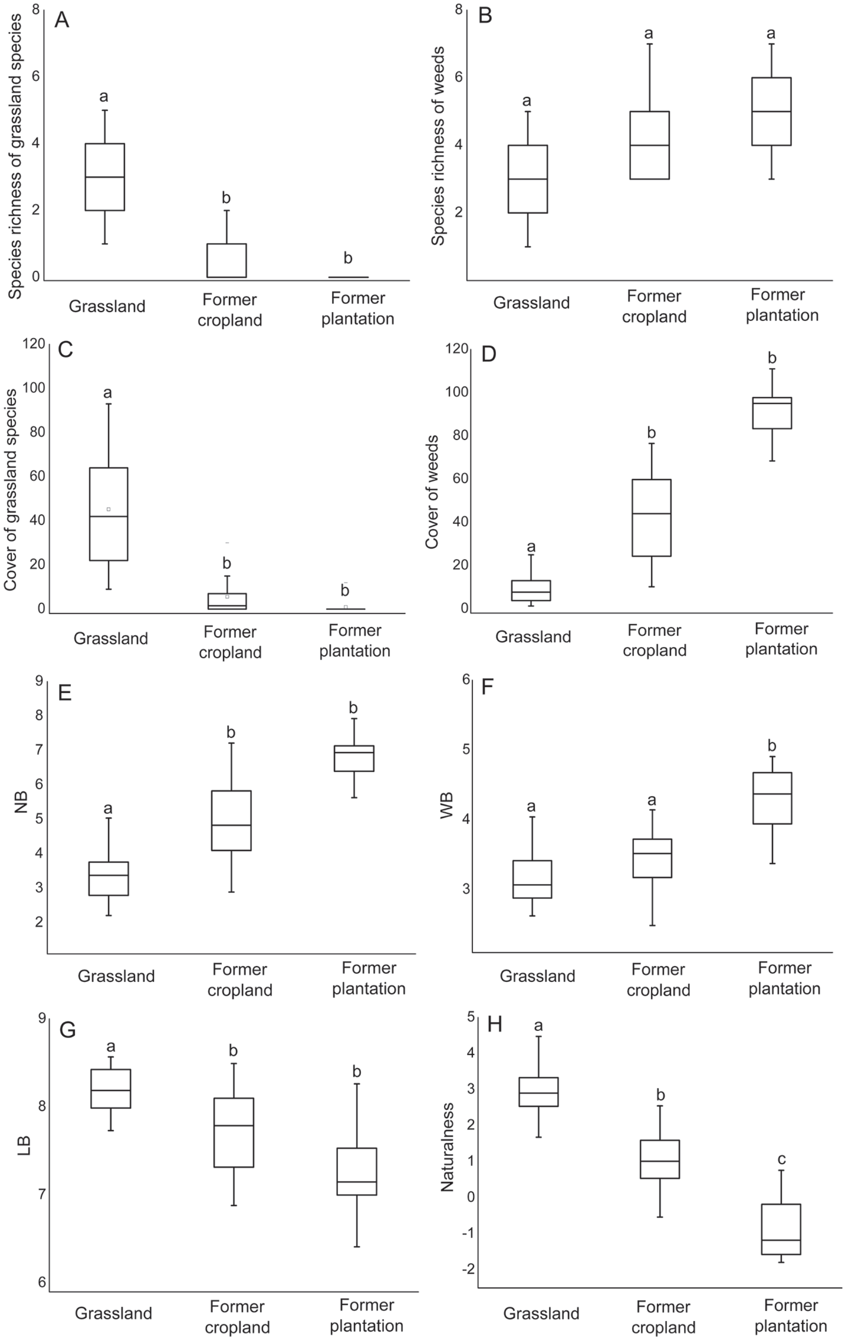

Figure 5. Vegetation characteristics in the studied mounds (grasslands, former croplands and former plantations): **A** species richness of grassland species **B** species richness of weeds **C** cover of grassland species **D** cover of weeds **E** cover-weighted ecological indicator scores for nutrients (NB) **F** cover-weighted ecological indicator scores for water (WB) **G** cover-weighted ecological indicator scores for light (LB) **H** naturalness score. Different letters indicate significant differences between groups (Tukey test, $p \leq 0.05$).

Table 3. Effects of site history, soil nitrate and phosphorus content on the vegetation characteristics of the studied mounds (Generalised Linear Mixed Models). *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; n.s., non-significant. Notations: NB, WB, LB: cover-weighted means of ecological indicator values for nutrients, water and light, respectively.

	Site history		Nitrate		Phosphorus	
	F	p	F	p	F	p
Naturalness	46.35	***	5.15	*	5.40	*
Species richness						
Grassland species	17.59	***	0.19	n.s.	1.80	n.s.
Weeds	1.95	n.s.	0.61	n.s.	0.61	n.s.
Cover						
Grassland species	17.74	***	0.20	n.s.	3.09	n.s.
Weeds	70.27	***	0.03	n.s.	0.01	n.s.
Ecological indicator values						
NB	9.02	***	0.93	n.s.	1.19	n.s.
WB	7.97	***	2.51	n.s.	0.44	n.s.
LB	21.38	***	13.09	***	3.25	n.s.

The re-sprouting ramets of the black locust were only present in the plots of the Vajda-mound and the average cover of black locust was 0.9% in the plots.

Site history significantly affected the naturalness of the vegetation, it was the lowest in former plantations and the highest in grasslands (Table 3, Figure 5). Soil nitrate content decreased the naturalness of the vegetation (coefficient = -0.068; t = -2.324; GLMM), whilst soil phosphorus content increased it (coefficient = 0.010; t = 2.269; GLMM). Both cover and species richness of grassland species were affected by site history; their scores were significantly lower in former plantations and croplands. Cover of weeds was affected by site history; it was the highest in former plantations. Cover-weighted NB, WB and LB scores were affected by site history. Cover-weighted NB scores were higher in former plantations and croplands compared to grasslands. Cover-weighted WB scores were the highest in former plantations. Cover-weighted LB scores were the highest in grasslands.

Discussion

Soil characteristics

We found that pH was highest, close to 7 or even greater, in former cropland in 2014. The likely reason for this is that, in croplands, there was no organic matter accumulation on the surface and the surficial soil layer was constantly mixed with subsoil and the subsoils' carbonate saturation status was always higher in these soils than at the surface. During the study period, pH was not changed significantly in any of the mounds, but a slight increase in former plantation and slight decrease on former cropland could be detected. Soil pH was much more heterogeneous in the grasslands compared to the former croplands and plantations. This supports the findings of the Penksza et al. (2011), Deák et al. (2016a,b) and Lisetskii et al. (2016) who emphasised the role of environmental heterogeneity in driving the plant diversity on steppic burial mounds. Heterogeneity of pH can be an important driver of small-scale plant diversity (Moeslund et al. 2013).

Plant available N content was the lowest in the former cropland and its amount did not change by time since abandonment. This is due to the additive effect of the depletion of soil N stocks by decades-long cultivation and the slow soil N-recovery during secondary succession (Matamala et al. 2008; An et al. 2019). Besides being a limiting factor for the establishment of grassland plant species, limited availability of soil N stocks may also limit the development of the vegetation by suppressing microbial decomposition and soil carbon sequestration (Knops and Tilman 2000). The highest N content was measured in former plantations as a legacy of the former presence of the black locust. By the enhanced nitrogen-fixing of the black locust and the decomposition of its nitrogen-rich leaves, the soil of these former plantations had a high N content (Bolat et al. 2015). Although we detected a slight decrease in soil N content after the plantation had been cut, this difference was not significant. These findings underline the long-term impact of this invasive alien plant on natural ecosystems by increasing the soil N content over a long term.

Plant available P content was the highest in the former croplands in 2014 as result of former P-fertilisation, but after the abandonment, it started to decrease significantly. As P has a low mobility in soils, this decrease can be a result of the P consumption by the vegetation and soil microbes. In the grasslands and former plantations, P content was similarly low, in both cases low pH likely facilitated the mobilisation (Alt et al. 2011), i.e. leaching from topsoil. In former plantations and grassland, there were no temporal changes between the two sampling dates. The high N in the soils of former plantations and the high P availability in the soil of former croplands, should be considered as a relevant regulating factor in subsequent grassland recovery (Alt et al. 2011) and might hinder vegetation recovery for almost a decade (An et al. 2019).

Vegetation changes

We found that, four years after land use change, grassland vegetation was in an early or mid-successional stage, both on the mounds formerly used as cropland and forest plantation. The three vegetation types were clearly separated by their species composition (Figure 4). The recovering grasslands had a few common species with the reference grasslands and were mostly characterised by weed species. The indicator species of the recovering grasslands reflected the different site histories. On mounds, formerly covered by croplands, mostly weeds typical of former arable lands and fallows were present, such as *C. arvensis*, *L. perenne*, *T. arvensis* and *X. strumarium* (Table 3). Mounds, formerly covered by plantations, were characterised by weed species typical of the understorey of black locust plantations, such as *B. nigra*, *B. sterilis* and *G. aparine*. However, some weed and disturbance-tolerant species occurring also in dry grasslands were also present, such as *A. collina*, *V. arvensis* and *V. grandiflora*. The only indicator species on former croplands which is typical of undisturbed grasslands was *A. pratensis*. The latter is a typical competitor species of alkali meadows, but it can also cope with dry habitat conditions, thus, it often can be found in the loess grasslands of the region (Borhidi et al. 2012, Deák et al. 2014). Indicator species of mounds covered by grasslands were mostly species typical to alkali (*F. pseudovina*, *P. lanceolata* and *T. retusum*) and loess grasslands (*C. praecox*, *E. hispidus*, *E. virgata*, *K. cristata* and *S. nemorosa*) (Borhidi et al. 2012, Deák et al. 2014) (Table 3). Only a few weed species such as *B. hordeaceus* and *E. cicutarium* were present, likely due to moderate grazing (Godó et al. 2017).

Species composition of weeds reflected well the site history. Weeds are generally R-strategists and have a dense and persistent seed bank (Török et al. 2012; Melnik et al. 2017). Thus, even several years after the cessation of crop production and cutting of plantations, weed species were able to germinate from the seed bank. Contrarily, the usually K-strategist grassland species generally have a sparse and transient seed bank (Bossuyt and Honnay 2008), thus their seed bank is generally depleted even after a few years of improper management (Valkó et al. 2011). As the studied mounds were used as arable land or black locust plantation for decades, there was no possibility for the grassland species to recover from the seed bank. Another reason for the low proportion of grassland species on the recovering mound vegetation is the lack of dispersal vectors (Deák et al. 2016b). Even though semi-natural grasslands were present near the recovering mounds, the dispersal vectors (the grazing livestock) were missing. As many grassland plant species have a limited dispersal ability and thus a limited dispersal radius, lack of active dispersal vectors can considerably hinder their establishment, even in semi-natural landscapes (Jacquemyn et al. 2010; Auffret 2011). The results regarding the naturalness of the vegetation also suggested that vegetation recovery is at an initial stage even four years after land use change. The naturalness of the recovering vegetation was low in case of both former croplands and plantations (Figure 5). However, it is shown by the results of the GLMM that the vegetation recovery was more successful on former croplands compared to former plantations (Table 2). The proportion of species typical of natural habitats was significantly higher on mounds formerly covered by cropland than on mounds formerly covered by black locust plantation.

The reason for the low success of vegetation recovery on former plantations is the legacy of the former woody vegetation and forestry practices. For establishing a forest plantation, more drastic soil works are needed compared to arable use. Even though the soil works are not so frequent, such as in the case of arable use, they can affect the soil structure in deeper layers. Thus, it affects the chemical properties of the soil in a more intense way; furthermore, deep ploughing transports the seed bank of grassland species to such deep layers (even 1 m deep) from where they are not able to germinate and re-establish. Due to the shading effect of woody vegetation, a milder micro-climate is present in the understorey of the woody habitats (Tölgyesi et al. 2020), which affects their species composition. It could still be observed by the low cover-weighted cover of

LB and high WB scores of the vegetation. Another detrimental effect of black locust on dry grassland species is that, due to its nitrogen fixation, it considerably increases the nitrate content of the soil (Figure 3; and see also Cierjacks et al. 2013; Vítková et al. 2017). The increased residual nitrate content could even be observed four years after eliminating black locust trees (Table 1) and it had a considerable effect on the vegetation by decreasing the naturalness index (Table 3). The high nitrate content generally favours species adapted to ruderal habitats (low naturalness index) and suppresses stress-tolerant species adapted to dystrophic soil (Jentsch and Beyschlag 2003; Albert et al. 2014). Black locust is a species that can re-sprout very effectively after disturbance (Vítková et al. 2017). Under the studied climatic and edaphic conditions, only very few re-sprouting ramets were observed three years after the removal of *Robinia*. However, regular monitoring is needed to detect the abundance of black locust ramets and apply follow-up management, if necessary.

Conclusions

Our results suggest that the legacy of a former intensive land use (i.e. cropland and plantation) is more complex than the effect of excess soil nutrients. Even though former croplands were characterised by excess P and former plantations by excess N (Figure 3), the reasons for differences in vegetation characteristics are likely more complex. The long-lasting various disturbance regimes (fertilisation, herbicide application, tillage) typical for croplands, shading and altered microclimate typical for plantations and the deep cultivation typical for both, are the most likely legacies that hamper or slow down the grassland recovery in the studied habitats.

We found that, without proper management measures, recovery of grassland vegetation is slow on mounds formerly used as cropland or black locust plantation. This is in line with the findings of Török et al. (2011b), who found that a significant decrease in the proportion of the weeds can be expected approximately 10 years after cessation of croplands in the studied region. Our results suggest that arable use transformed the habitat conditions in a more moderate way than the establishment of plantations. Thus, restoration efforts, focused on the restoration of mounds formerly covered by arable lands, can be more effective compared to the restoration of mounds formerly covered by forest plantations. From a practitioner point, it should also be noted that costs associated with the elimination of woody vegetation is high. Especially if we take into account that, in many countries (like in Hungary), a high penalty (ca. 11000 euros per hectare) should be paid in case of elimination of a forest parcel (regardless of whether it is a native forest or an invasive plantation) or, alternatively, another forest of the same area has to be established elsewhere.

Even though spontaneous regeneration of grassland habitats can be a good solution in nature conservation practice, it might be risky as the vegetation development is often unpredictable. The outcome of spontaneous succession is highly dependent on initial site conditions, including land use intensity, landscape context, climatic and edaphic factors. Spontaneous recovery is often unpredictable also due to the founder effect, i.e. that the vegetation composition of late successional phases strongly depends on the initial plant assemblages (Grime 1998). As in case of spontaneous succession, where the initial plant establishment processes have a random pattern, the outcome of the succession can be unfavourable from a nature conservation view or even can stack in a weed dominated phase (Deák et al. 2015; Albert et al. 2014). In case of spontaneously recovering former arable lands and forest plantations, the dense seed bank of the weed species might shift the vegetation development to undesirable pathways. In case of former plantations, resprouting of woody vegetation might also occur (Cierjacks et al. 2013). Thus, continuous monitoring of the spontaneously recovering vegetation is recommended. In case of unfavourable vegetation changes, further measures might be necessary, such as seed sowing of good competitor grassland species (Valkó et al. 2018).

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