American Crocodiles (*Crocodylus acutus*) basking in Belize, with the individual in the foreground displaying a red plastic tag on the tail for identification. The tail-spot patterns are unique among individuals of this species. The following article shows how these patterns can be collected passively during field observations, as well as during capture surveys. © Miriam Boucher

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A tail of two crocs: coding tail-spot patterns for individual identification of American (*Crocodylus acutus*) and Morelet's (*Crocodylus moreletii*) crocodiles

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Abstract: The marking of wildlife is an effective tool for the conservation and management of many species. A range of marking techniques is used in crocodylian management and conservation, and primarily involves the alteration of caudal scutes and the application of tags. Here we present the methods and application for two natural pattern identification techniques, which are used concurrently with research and monitoring of the American Crocodile (*Crocodylus acutus*) and Morelet's Crocodile (*Crocodylus moreletii*) in Belize. We collected and analyzed 547 photographs of observed and captured crocodiles, and identified individuals by coding the spot patterns on the lateral portion of the tail. We investigated the efficacy of an established spot pattern coding protocol for crocodylians, and modified the original coding procedure by integrating vertical caudal scutes and irregular scale groups. We generated a total of 191 tail codes for 105 individual crocodiles (*C. moreletii*, *n* = 27; *C. acutus*, *n* = 78). The established methodology demonstrated an 84% success rate in differentiating individuals, whereas our new method showed 99% effectiveness in differentiating individuals and species. Using the spot pattern protocols, we identified no individuals with fully repeated codes (both tail sides). This project demonstrates that tail-spot patterns are distinctive, and consequently the coding of spot patterns is an effective way to passively identify individuals across the species. The proposed techniques are a cost-effective and simple tool that can be used by managers and communities to facilitate long-term demographic monitoring, and also can serve to encourage active participation in crocodile conservation via citizen science.

Key Words: Conservation management, individual identification, mark-recapture, population monitoring

Resumen: El marcado de individuos de la vida Silvestre es una técnica efectiva para la conservación y manejo de muchas especies. Existen varias técnicas utilizadas para el marcado de cocodrilianos, pero principalmente se aplican las técnicas basadas en las escamas caudales y la aplicación de *tags*. En este studio, presentamos dos métodos de patrones naturales de identificación, utilizados corrientemente en las investigaciones y el monitoreo de Cocodrilo Americano (*Crocodylus acutus*) y Cocodrilo de Pantano (*Crocodyous moreletii*) en Belice. Recogimos y analizamos 547 fotográfias de cocodrilos observados y capturados, e identificamos individuos por codificaciones en las patrones de manchas en la parte lateral de la cola. Asimismo, investigamos la eficacia de un protocolo establecido a partir de un patrón de codificación de manchas para cocodrilianos y modificamos el procedimiento de codificación original con la integración de escamas caudales verticales y grupos de escamas irregulares. Generamos un total de 191 códigos para 105 cocodrilos individuales (*C. moreletii*, *n* = 27; *C. acutus*, *n* = 78). La metodologia existente demostró un éxito del 84% en la diferenciación de individuos, mientras que nuestro nuevo método demostró un 99% de efectividad en la diferenciación de individuos y especies. El empleo de este protocolo de los patrones de manchas, no se identificaron individuos con códigos repetidos (ambos lados de cola). Este estudio demuestra que las patrones de mancha en la cola son distintivos, y en consecuencia, la codificación de patrones de manchas es una manera eficaz de identificar individuos pasivamente entre las especies. Las técnicas propuestas son simple y económicas, pueden ser utilizadas por cualquier persona para facilitar el monitoreo demográfico a largo plazo, y también podría estimular la participación activa en la conservación de cocodrilos a travez de los pobladores locales.

Palabras Claves: El manejo y conservación, identificación individuo, marcado-recaptura, monitoreo de la población

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INTRODUCTION

Wildlife management and conservation relies on the ability to effectively monitor animal populations. Of the methods used to assess and monitor wildlife populations, mark-capture methodology remains a staple for the collection of direct quantitative data on population dynamics (Twigg, 1975; Krebs, 1989; Powell and Proulx, 2003; Skalski and Robson, 2012). Advances in technology have led to new methods for marking individuals, which include genetic mark-capture, visual detection through game cameras, telemetry and satellite tracking, and implanted tags (Fuller, 1987; Fancy et al., 1988; Bailey et al., 1998; Pearse et al., 2001; Miller et al., 2005; Aarts et al., 2008; Heard et al., 2009). Despite the increased use of these techniques in wildlife management and conservation, they are not easily implemented in areas deficient in resources (Kellert, 1985). Although terrestrial biodiversity is rich in tropical and subtropical regions, human and technological resources for wildlife management in many areas remain limited (Barrett et al., 2001; Janzen, 2004; Brooks et al., 2006; Bradshaw et al., 2009). Consequently, the lack of resources for assessing wildlife populations in developing nations, especially where funding for management programs might be restricted, presents a challenge. Obviously, technologically advanced methods for assessing wildlife populations can be advantageous, and limited resources can be circumvented through the application of simple and cost-effective marking techniques, particularly for large predators that are difficult to capture and handle.

Crocodylians are long-lived, large bodied predators that are keystone species in their respective habitats, and offer a variety of ecosystem services that benefit both ecological and human communities (Nifong and Silliman, 2013). Population survey methods generally involve nocturnal point counts that use light reflected from the internal ocular structures to locate individuals (Webb et al., 1987). This method, however, has shown inherent levels of error from possible failed or repeat detections (Webb et al., 1987). Advances in modeling and statistical techniques can mitigate some of these errors, but challenges persist for observing or recapturing marked individuals, particularly during the day.

Individual crocodylians often are marked by clipping their caudal scutes and by the use of toe tags (Bustard and Choudhury, 1981; Chabreck, 1963; Webb et al., 1989; Jennings et al., 1991; Soberon et al., 1996; Platt et al., 2002; Richardson et al., 2002; Elsey et al., 2004). Plastic tags also can be affixed to the tail scutes to create a more effective visual identifier. Tail tags have been used to monitor *Gavialis gangeticus* (Lang and Whitaker, 2010), *Crocodylus niloticus* (Swanepoel, 1996; Calverley and Downs, 2014), and *C. porosus* (Bayliss, 1987). At a distance, the physical alterations can be difficult to discern, and tags might not last for the life of the animal (Bayliss et al., 1986; Swanepoel, 1996). Similarly, the lifespan and effectiveness of the tracking equipment and data loggers are reduced when utilized on crocodylians (Franklin et al., 2009).

An alternative to the physical marking of individuals is the use of their natural spot patterns on the lateral portions of the tail. These patterns have been noted not to change over the life of the crocodylian, and can be applied to accurately distinguish individuals (Nair et al., 2012; Bouwman and Cronje, 2016). Spot pattern comparisons have been used to discern *G. gangeticus* (Singh and Bustard, 1976; Nair, 2010; Nair et al., 2012), and the coding of natural spot patterns has been used to create unique individual identification codes for *C. niloticus* (Swanepoel, 1996; Bouwman and Cronje, 2016). Despite previous successes in identifying individuals through their natural spot patterns, this technique has not been applied on *C. acutus* and *C. moreletii*. Here, we applied an established spot pattern identification technique, and modified this technique to create a new methodology for assessing the effectiveness of spot pattern coding in the visual identification and monitoring of these species in Belize.

MATERIAL AND METHODS

Study Area

Belize is a small Central American country that measures approximately 23,000 km^2 (Day, 1996) located south of Mexico and east of Guatemala, and bordered to the east by the Caribbean Sea (Fig. 1). We conducted our study on crocodiles in five areas of the country: Ambergris Caye, Caye Caulker, Placencia Lagoon, Rio Hondo River, and Chiquibul National Park (Fig. 1).

Ambergris Caye is an extension of the Mexican Yucatan peninsula. Development is centered in the town of San Pedro, and undeveloped areas largely consist of littoral forest, mangrove swamp, and shallow lagoons. We collected *Crocodylus acutus* tail patterns from crocodiles captured throughout the island, but found the majority of individuals in close proximity to San Pedro.

Caye Caulker is an offshore island located 8 km south of Ambergris Caye. A deep channel divides the island; the area south of the channel is highly developed, and that to the north is relatively undeveloped but contains sporadic settlements. We collected tail patterns from *C. acutus* captured at various localities throughout the island.

We collected tail patterns from both *C. moreletii* and *C. acutus* captured around Placencia Lagoon in Stann Creek District. We also sampled *C. moreletii* from Raspaculo and Macal River branches within Chiquibul National Park, Belize's largest national park located in Cayo District, and Four Mile Lagoon off the Rio Hondo River in Corozal District.

Capture Methods

We captured crocodiles from September 2014 to September of 2016, in association with ongoing behavioral research and population surveys, and resident collaborators and management agencies have continued to collect data. The West Virginia University Animal Care and Use Committee (Protocol # 15-0703) and the Belize Forest Department (BFD) approved our capture protocol prior to fieldwork, and we acquired research permits from the BFD prior to initiating any visual identification or tagging (Ref. No. CD/60/3/15(45)). We captured and restrained the crocodiles by using the conventional techniques detailed in Webb and Messel (1977), such as hand-capture (total length [TL] < 1.2 m), noose, or treble hook (TL > 1.2 m). We collected morphometric measurements and performed a health assessment on the captured crocodiles, following the protocols of Webb and Messel (1978) and Sánchez-Herrera et al. (2011). Lastly, we applied visual tags to adult *Crocodylus acutus* at Ambergris, Caye Caulker, and the Placencia Lagoon study sites, and photographed the tail patterns on all individuals.

Tail Pattern Collection and Coding

We collected photographs of the lateral portions of the tail of crocodiles during processing and passive observations. We organized the photographs by date and recorded the relevant metadata of location, species, approximate size, and sex (if known). In analyzing the tail-spot patterns, we used two marking systems to record the presence of distinct markings on the lateral caudal scales, to generate a code representative of the observed pattern and to determine the efficacy of these methods for crocodiles in Belize. With the first system, hereinafter referred to as the numeric code, we followed the protocol of Swanepoel (1996) to assign a numeric value for the presence or absence of dark markings on the caudal scales. With the second coding method, hereinafter referred to as the additive code, we adapted this novel method by using Swanepoel's numeric code system, and integrating the dark vertical scutes and irregular scales groups.

Fig. 1. Map of Belize, located on the Caribbean side of Central America. The letters indicate the study areas, as follows: (A) Ambergris Caye; (B) Caye Caulker; (C) Placencia Lagoon; (D) Chiquibul National Park; and (E) Rio Hondo and Four Mile Lagoon.

Numeric Code (= Swanepoel's system)

We determined the tail patterns by working up the body of the animal, beginning at the single row of caudal scutes and counting anteriorly to double scute row 9. We denoted the tail sides with a capital "L" for the left and "R" for right. We counted solid dark markings if they occupied at least 25% of the scale on which they were observed. We did not count markings on the vertical scutes or irregular scales. We counted markings that spanned along multiple scales and across rows separately on each row. After the alphabetic character, we recorded the scute row numbers if dark markings were present. We repeated the scute row number in the code if multiple markings were present, and skipped it if markings were absent (Table 1). We did not record markings on the ventral portion of the tail, since they were not visible from a distance (Fig. 2).

Table 1. Numeric code generation guide. Steps 1–3 are preceded by a capital "L" (left) or "R" (right), denoting tail side. The steps begin at double scute row number 1 and are repeated for scute rows 2–9.

Step		Action
1	(a) Dark markings present (> 25% of scale)	Step 2
	(b) Dark markings absent (or < 25% of scale)	Do not record (skip) scute row number. Step 4
2	(a) > 1 distinct (separate) marking on scute row	Step 3
	(b) Only 1 distinct marking on scute row	Record scute row number in code. Step 4
3	(a) Multiple markings present (< 25%)	Record scute row number in code. Step 4
	(b) Multiple markings present (> 25%)	Record and repeat scute row number for number of distinct markings, e.g., 122345559. Step 4
4	(a) All markings on scute row have been recorded	Move anteriorly on tail to next scute row. Step 1

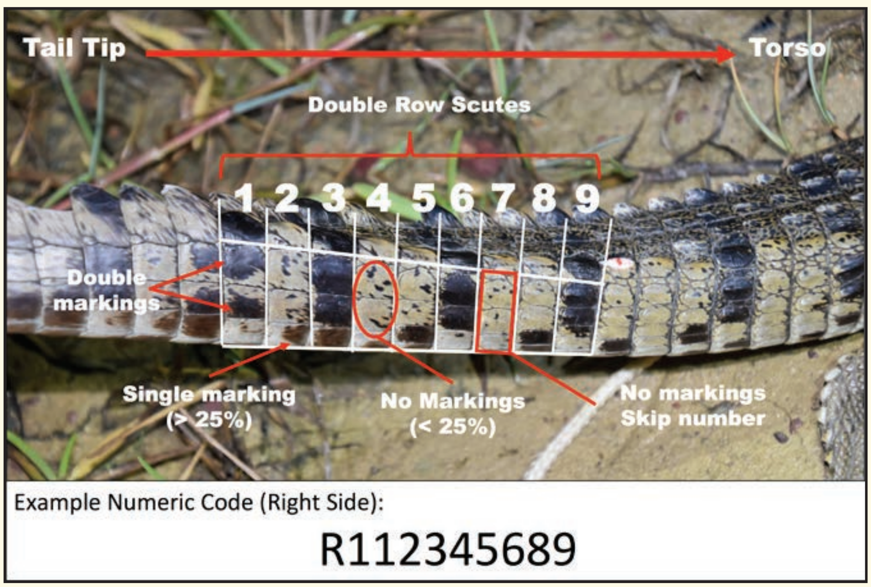

Fig. 2. An example of the numeric tail-spot code generated for a juvenile *Crocodylus acutus*. The scutes with markings are recorded, and the rows that lack markings are skipped. The pattern is determined by working up the tail toward the torso of the animal. © Miriam Boucher

Additive Code (= Boucher et al. system)

Although the numeric code is a simple and effective way to create distinct identifiers for crocodiles, it might not account for individual variation. Thus, we created the additive code to incorporate markings on the vertical scutes and irregular scale groups, to assist in distinguishing the two sympatric species in Belize (Table 2). We integrated the vertical tail scutes from double rows 1–9 where, at least 90% of the total area contained dark markings. We recorded dark upright scutes in the code with a capital "B" placed before the scute row number on which they occurred. If the scute row was not present in the numeric code, we recorded the upright scute character in parentheses. We recorded the vertical scute character in parentheses followed by the row number on which it occurred, e.g., L124B5(B8)9, when the numeric code had multiple missing scute row numbers.

Table 2. Additive code generation guide. Steps 1–10 are preceded by a capital "L" (left) or "R" (right), denoting tail side. Steps begin at double scute row number 1, and are repeated for scute rows 2–10.

Step		Action
1	(a) Dark markings present (> 25% of scale)	Step 2
	(b) Dark markings absent (or < 25% of scale)	Step 4
2	(a) > 1 distinct (separate) marking on scute row	Step 3
	(b) Only 1 distinct marking on scute row	Step 4
3	(a) Multiple markings (> 25%) present	Record and repeat scute row number for number of distinct markings. Step 4
	(b) Multiple markings (< 25%) present	Record scute row number in code. Step 4
4	(a) Vertical scute > 90% darkly marked	Step 5
	(b) Vertical scute < 90% darkly marked	Step 7
5	(a) Irregular scale (IS) group present	Step7
	(b) IS group absent	Step 6
6	(a) Scute row number present in code	Record "B" before scute row number, e.g., 6B789. Step 11
	(b) Scute row number absent in code	Record "B" in parentheses before scute row number, e.g., 6(B)89. Step 11
7	(a) IS group present between rows 9 and 10	Step 8
	(b) IS group absent between rows 9 and 10	Step 9
8	(a) Scute row 9 present in code	Record "i" at end of code, e.g., 6789i. Step 11
	(b) Scute row 9 absent in code	Record "i" in [ ] at end of code e.g., 678[i] or before "B" if present, e.g., 678(B)[i]; Step 11
9	(a) Both scute row numbers present in code	Record "i" between rows, e.g., 67i89 or before "B" if present, e.g., 67Bi89; Step 11
	(b) Both scute row numbers absent in code	Step 10
10	(a) One scute row number present in code	Record "i" in parentheses between where scute rows occur, e.g., 67(i)9, or before "B" if present, e.g., 67(Bi)9. Step 11
	(b) Both scute row numbers absent in code	Record "i" in parentheses between scute row numbers, e.g., 6(7i8)9 or before "B" if present, e.g., 6(7Bi8)9. Step 11
11	(a) All markings on scute row have been recorded	Move forward on tail to next scute row. Step 1

Irregular caudal scale groups (IS) on the ventral and ventrolateral tail surface are not present on genetically uncompromised *Crocodylus acutus*, but are present in *C. moreletii* or in hybrids between these species (Platt and Rainwater, 2005). As such, inclusion of these irregular scales is beneficial not only for differentiating individuals, but also for the species. We recorded irregular scale groups for rows 1–10 with a lowercase "i" recorded between the scute rows where they occurred (Table 2; Fig. 3). The scale groups must be a true intermediary between the scute rows, and we did not record IS groups if they fully or partially bisected a single scute row. We recorded the IS in alphabetical order, after the character for dark vertical scutes ("B"). If one of the IS scute rows was absent in the numeric code, we recorded the character in parentheses, e.g., L12457(i)9. If both of the IS row numbers were not represented in the code, we recorded the character in parentheses between the respective scute row numbers, e.g., L12456(7i8)9. We recorded irregular scale groups that occurred between rows 9 and 10 as the last character of the code. We recorded the IS in brackets at the end of the code if scute row 9 was absent in the base numeric code, e.g., L124578[i].

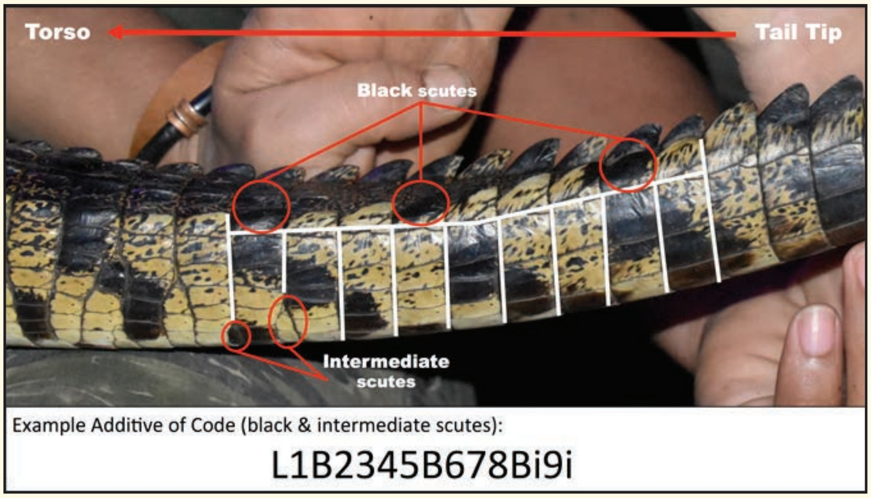

Fig. 3. Left side tail pattern code using the additive method for a juvenile *Crocodylus moreletii.* The black vertical scutes and irregular scale groups (intermediate scutes) are integrated into the code. © Miriam Boucher

Visual Tagging

We implemented the visual tagging of crocodiles in the field by applying plastic tags on a dorsal vertical caudal scute to verify the spot pattern recapture. We acquired round and flexible Perma-Flex self-piercing male and smaller locking female ear tags in bulk from Ear Tags Direct, Inc. (www.eartagsdirect.com). Once the crocodiles were captured, we affixed tags to the number 1 or 2 vertical single row caudal scutes, because this part of the animal’s tail often is visible when individuals are swimming or displaying during social interactions (Fig. 4). Since each tag consists of two halves, we assigned a specific color combination to each tagged individual. We noted the positioning of the male or female tag component on either the left or right side of the tail, as an additional metric for identifying and recording the tag orientation and color of each individual. We did not apply tags to crocodiles measuring < 121 cm (1.2 m) TL, as the size of the tag might interfere with their daily activities. After tagging individuals and recording the data, we released the crocodiles at the point of capture.

Data Analysis

We amalgamated the tail photographs into a single dataset. We relabeled each set of photographs for an individual crocodile according to the species, and to note the location, date, individual, and photograph number in the series. We referenced this media label to link the metadata and tail pattern codes to the associated images. We created a dataset with an entry for each individual crocodile, and recorded the media label, location, date, tail pattern codes, scute row number for black and irregular scales, method of observation (capture or observation), size estimate, and if applicable, scute clip number, visual tag color, and sex. We performed a search query on the data to identify repeated codes. For each duplicate code, we conducted a comparative visual analysis of the photographed tail patterns to determine errors in coding and possible recaptures. We aggregated all recaptures as a single entry per individual, and recorded true duplicates to determine the proportion of distinct pattern codes per coding method. Finally, we compared the proportion of distinct tail pattern codes for the numeric and additive methods, by employing a test of equal proportion with the Yate’s continuity correction at a 95% confidence interval using RStudio version 0.99.902 (RStudio Team, 2015).

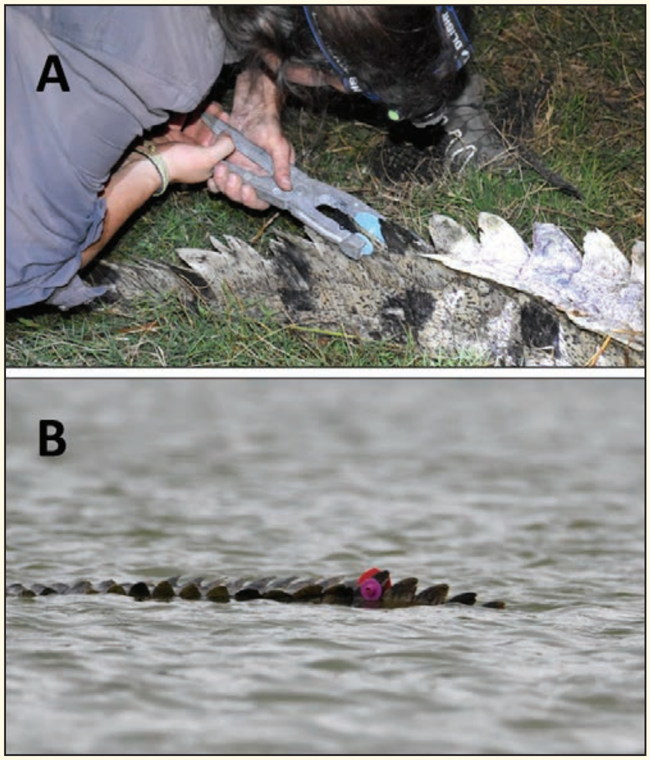

Fig. 4. (A) Application of the visual tail tag on the number 2 single row caudal scute; and (B) a visual recapture of a tagged *Crocodylus acutus* (note the distinct tag orientation and color). © Miriam Boucher

RESULTS

Tail-spot Pattern Coding

Presently, we have analyzed and catalogued 547 photographs from sites on Ambergris Caye, Caye Caulker, Chiquibul National Park, Four Mile Lagoon, and the Placencia Lagoon. We generated 86 full tail patterns, 12 single right side, and 7 single left side patterns for 105 individual crocodiles. Although we found duplicate codes for single tail sides using both techniques, we did not find full pattern (both tail sides) duplicates (Table 3). We reevaluated the photographs for duplicate codes, and found four duplicates (not included in analysis) that we determined to be recaptures. We used distinct individuals that we determined not to be recaptures as a metric for determining the efficacy of the coding method.

Table 3. Tail pattern data by location, species, and completeness of generated patterns (full or partial) obtained in Belize from 2014 to 2016.

Location	Number of Patterns				
	Crocodylus acutus	***Crocodylus moreletii***	**Full**	**Left**	**Right**
Ambergris Caye	43	—	25	7	11
Caye Caulker	23	—	23	—	—
Chiquibul	—	18	18	—	—
Placencia	12	6	17	—	1
Corozal	—	3	3	—	—
Totals	**78**	**27**	**86**	**7**	**12**

The unmodified numeric code generated 83.8% distinctiveness among all the patterns (Table 4). Duplicates occurred between both *Crocodylus moreletii* and *C. acutus* ($n = 1$), within *C. moreletii* ($n = 1$), and within *C. acutus* ($n = 7$) tail patterns. This method did not allow for a complete differentiation between the species by using tail patterns. Additionally, duplicate patterns occurred in the same study areas ($n = 1$), which impede the usefulness of this method in distinguishing individuals in the field. Conversely, the use of the additive code yielded significantly improved results ($\chi^2_{1,105} = 13.67$; $P < 0.001$). The additive code generated 99% distinctiveness among all patterns (Table 4). Since no duplicate codes occurred between *C. moreletii* and *C. acutus*, the code can differentiate the two species. A single duplicate within *C. acutus* resulted from our additive method, but this result was negligible because the two crocodiles were geographically distant and markedly different in size (163 cm and 380 cm TL).

Table 4. Number and percentage of duplicate patterns derived from the numeric and additive coding methods. The additive coding method was superior in identifying individuals through distinct pattern codes.

Code Type	Duplicate pattern pairs N (%)			Percentage of Distinct Codes
	Right	Left	Total Pair	
Numeric	7(7.1)	10(10.8)	17(16.2)	83.8%
Additive	1(1.0)	0(0.0)	1(1.0)	99%

Visual Tagging

We affixed visual tags to 29 *Crocodylus acutus* and 1 hybrid. Tag retention could not be determined in this study, as we were unable to ensure continued visual recapture of the tagged individuals. Nonetheless, we reencountered nine tagged individuals, and confirmed that three tags were present and distinguishable on crocodiles after one year (Fig. 4). Of the nine reencountered individuals, we confirmed the tail-spot patterns and determined their accuracy in the recurring coding of tail patterns.

DISCUSSION

Crocodile management in Belize is under the authority of the Belize Forest Department (BFD). The BFD relies on a network of collaborators across the country to facilitate the management of wildlife species, as well as to mitigate human-wildlife conflicts. All parties involved with the management and conservation of wildlife in Belize face increasing challenges associated with funding projects and conservation initiatives, as well as a general need for increasing the number of personnel. In an effort to provide more cost effective and actionable conservation tools, our aim was to adapt visual identification techniques to complement the management of *Crocodylus acutus* and *C. moreletii* in the country.

Pattern Coding

Tail-spot identification provides an accurate and passive method that involves little training, and does not require expensive specialized equipment. Naturally occurring tail-spot patterns are present on all crocodiles encountered in Belize, and they can be used to generate distinct identifiers. The pattern of the spots can be used to show variation among individuals, and pattern coding creates a way to index and reference their unique patterns. Working with a limited sample size and an open population, we cannot fully validate the methods discussed here, or identify the rate of misidentification. We encourage the testing of our methodology on other species, perhaps on captive individuals with larger sample sizes. Comparable studies of markings on other crocodylian species, however, have not confirmed identical spot patterns in the studied individuals. The probability of identical patterns, which has not been determined for any crocodylian species, likely is extremely small. The results of our study, particularly with captured individuals for which we obtained quality images, did not produce identical patterns. Moreover, we captured and photographed one sub-adult individual in multiple years (2014, 2015, and 2016), and our sets of capture photos generated the same ID code for each year. Our findings support our premise that patterns do not change during the short term, and that similar patterns indicate the same individual.

Patterns can be collected passively through observation or photography, but are best attained through the processing of captured individuals. Although repeated codes may be generated, the size class, sex, and location of individuals can be used to further characterize each crocodile. As with other techniques, spot pattern coding is not without its limitations. Pattern acquisition may be hampered by the ability to accurately observe the lateral portions of the tail. Because crocodiles are amphibious and spend 15–20% of their crepuscular activity fully or partially submerged, pattern acquisition can be challenging (Boucher, 2017). Mark recapture success also might be skewed by singular tail patterns that are observed, but logged as separate individuals, if the two sides cannot be matched and amalgamated into a full pattern. Another consideration is the potential for ontogenetic shifts in patterns as the crocodiles' age. During this study we did not observe ontogenetic changes in the large dark markings used for coding, but the small pigmentation spots on the tail that resemble freckles grow larger as the crocodiles age, and may add more "noise" or distortion to the spot patterns. Our methodology took this into account by designating that coded tail-spots must occupy over 25% of the associated scale, which smaller pigmentation spots do not. A dedicated study tracking development of tail-spots would be beneficial in determining whether crocodylian marking patterns are subject to ontogenetic changes, or whether certain species might undergo ontogenetic pattern shifts.

The use of technology can combat some of these pattern acquisition issues through the use of game cameras at basking sites. Game cameras have been used to capture spot pattern information for a variety of terrestrial mammal species (Gerber et al., 2010; Heilbrun et al., 2003; Marnewick et al., 2008; McCain and Childs, 2008). We demonstrated that this technique is feasible in Belize, after an initial trial during which we used two cameras on a field scan interval to capture photos of basking crocodiles. Field cameras also have been used to document nesting behavior in *C. acutus*, as well as to monitor elusive crocodylian species (Charruau and Hénaut, 2012; Chowfin and Leslie, 2014; Mazzotti et al., 2015; Lang and Kumar, 2016). The use of these cameras for pattern acquisition should be pursued further.

Perhaps the greatest resource for acquiring and implementing tail-spot pattern coding is the public. Sightings of crocodiles basking or crossing roads often are reported within communities and to management entities. The growing availability of digital camera technology and mobile devices is allowing the public to capture wildlife images more regularly. With encouragement, the public could become a reliable resource for collecting tail-spot patterns. Much in the way that citizen science has been used to quantify avian species (Sullivan et al., 2009), citizen scientists also could contribute meaningful research on native crocodylian species. Community initiatives to develop passive crocodile identification through tail-spot coding could become an effective approach to expanding population monitoring and engaging communities to actively participate in local management. The identification of individual crocodiles through pattern coding also can be used as a tool to foster greater positive interest in local crocodylians, and to decrease human-crocodile conflicts through increased awareness.

Visual Tagging

Visual tags are a valuable and cost effective complement to conventional marking techniques (i.e., scute clipping) and pattern coding. In this project, we used tags to visually confirm the recapture of crocodiles using tail pattern coding. Despite the benefits of this technique, tail tags are not a permanent marking solution because they might be lost, stained by aquatic vegetation, or degraded by exposure to the elements. The use of tail tags on crocodiles in a more controlled environment would benefit the determination of their retention, and the application of a marine grade protective coating could serve to control environmental staining or degradation. Modifications to make the tags reflective for improving nocturnal visibility also would preclude reencounters with tagged crocodiles during nocturnal eye-shine surveys. Regardless of the limitations, visual tags are an effective means for accurately identifying crocodiles in the field, and for enhancing other marking techniques. In addition to their use here, this method can be applied to an array of other research and management activities. Our observations of tagged crocodiles made short-term population monitoring easier, as we were able to track the presence or absence of individuals and observe their movement patterns. Moreover, the tags allowed us to corroborate observations of sex specific behaviors, and our study of social behavior benefitted greatly because we were able to accurately distinguish the sex of individuals. For example, tagged adult females allowed us to detect previously unrecorded nest sites at several locations on Ambergris Caye. Consequently, this short-term marking technique could benefit future behavioral studies, and allow for cost-effective short-term monitoring of populations.

Tags also can be incorporated into community-based monitoring initiatives. The detection of tags and collection of the associated metadata could be accomplished by non-institutional or research-based entities. Thus, visual tail tagging may become a viable means for encouraging community involvement and developing a positive interest in local crocodylians. Conservation programs that initiate personal connections between communities and wildlife have been successful in fostering positive interactions, in addition to sharing management responsibilities (Decker et al., 2005). Although many incidents go unreported in Belize, conflicts between crocodiles and people appear to be on the rise (M. Boucher, pers. observ.). Community engagement in crocodile conservation is critical for reducing further conflict, as well as for building community partnerships to help manage populations in the future.

The marking techniques we proposed can serve to augment current research, and can be used complement other marking techniques. These techniques are easy to implement and are cost-effective, and make tail pattern coding and tail tagging attractive options for monitoring crocodylian populations. We show that tail-spot pattern coding is an effective tool for characterizing the pattern markings on the lateral portion of the tail in both *Crocodylus acutus* and *C. moreletii*, and the data can be collected through passive observations or from captured individuals. Visual tags also are a short-term solution for distinguishing and observing crocodiles at a distance, and can be used to complement other marking techniques. Although tail-spot pattern coding and visual tagging have their limitations, we conclude that there is considerable potential for their use in crocodylian population monitoring, particularly in areas with limited financial and human resources.

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