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Characteristics of sun bear chest marks and their patterns of individual variation

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Abstract: Animal coloration is widely involved in a variety of social interactions, and mammals can convey information to conspecifics by visual signals, such as colored or contrasting body marks. The sun bear (*Helarctos malayanus*) has a vibrant and unusual chest mark. Here, we describe the characteristics of sun bear chest marks and their patterns of individual variation by (1) sex, (2) time, and (3) some biochemistry values related to fur pigmentation. Sun bear pictures were taken from 2009 to 2018 at the Bornean Sun Bear Conservation Centre and Free the Bears sanctuary. We hypothesize that chest marks may serve in conspecific communication and, thus, we mainly expect that (a) these marks allow for sexual recognition and, thus, they should show remarkable differences by sex; (b) marks do not change over time because their consistency allows for easier intraspecific recognition; and (c) patterns of variation may be dependent on the age and/or physical condition of an individual. The most common shapes of sun bear chest marks ($n = 63$ M and 108 F) were U (M = 60.3%, F = 57.4%) and V (M = 31.8%, F = 32.4%) shapes. We did not detect differences in shape patterns by sex and, over the years, chest mark shape never changed for the same bear ($n = 49$ individuals, 16 M and 33 F). The number of dark dots in chest marks showed large amounts of individual variation (mean $\pm$ SD = 37.7 $\pm$ 26.8 dots; range = 1–143), and the quantity of dark dots increased with bear age. The complexity of sun bear chest marks might be related to the existence of complex interactions among individuals of the same species, which may allow for recognition and evaluation of their individual characteristics, such as age and health. Experimental approaches are needed to understand the potential functions of sun bear chest marks.

Key words: fur coloration, *Helarctos malayanus,* individual recognition, morphology, pelage, social recognition, sun bear, visual signaling

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Animal coloration, such as colored and contrasting body marks, is involved in a variety of social interactions (Espmark et al. 2000, Penteriani and Delgado 2017, Pérez-Rodríguez et al. 2017). Mammals use elaborate signaling to communicate with conspecifics in different contexts and for a variety of reasons, such as social interactions (e.g., warning displays), mate choice and intra-sexual competition (e.g., territoriality; Bradbury and Vehrencamp 2011). Colored and contrasting body marks are produced, among other elements, by specialized pigment cells (Rosenthal and Ryan 2000), and factors triggering their evolution include the perceptual system of individuals targeted by the signal, the nature

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Fig. 1. Sun bear (*Helarctos malayanus*) with the typical yellowish to orange chest mark (photo: Chiew Lin May, Bornean Sun Bear Conservation Centre). Photos of sun bears were obtained from the Bornean Sun Bear Conservation Centre (2009–2018; BSBCC; https://www.bsbcc.org.my/) in Sabah, Malaysian Borneo.

of the conveyed information, and the properties of the environment in which the signal is generated. That is, if visibility of color patterns depends on the background in which they are seen, species living in dark conditions (e.g., forests) may evolve bright and contrasting colorations to enhance visual display (Marchetti 1993).

Many species of terrestrial mammals have contrasting dark and light patches of fur and these patches may function as signals of social hierarchy or physical condition (Caro 2009). Patches on the face, neck, and chest are most likely viewed at closer range by conspecifics and, thus, may be involved in intraspecific communication. However, the possibility that clearly contrasting color patterns might have a visual signaling function has frequently been overlooked (Penteriani and Delgado 2017).

Although only 8 species of bears are extant in the family Ursidae, the adults of 5 of them regularly exhibit fur markings, such as chest patches (i.e., sun bears [*Helarctos malayanus*], sloth bears [*Melursus ursinus*], and Asiatic black bears [*Ursus thibetanus*]) and facial markings (i.e., Andean bears [*Tremarctos ornatus*]), or, as is the case for the giant panda (*Ailuropoda melanoleuca*), striking body coloration (Penteriani and Melletti 2020). However, except for the giant panda (Caro et al. 2017a), there are no studies that describe these patterns of fur markings or try to understand their significance. The sun bear has a vibrant chest mark, which is highly variable in shape, extent, and color, ranging from pale whitish to dark orange and occasionally speckled (Scotson et al. 2020; Fig. 1). For this study, we used the long-term database of individual sun bears housed in 2 rescue centers, in Malaysian Borneo and Cambodia, to explore the characteristics of sun bear chest marks, including sexual dimorphism, and individual variation through time and according to health status. If sun bear chest marks serve in conspecific communication, we would expect that (a) these marks allow for sexual recognition and, thus, they should show remarkable differences by sex; (b) marks do not change over time because their consistency allows for easier intraspecific recognition; and (c) patterns of variation may be dependent on the age and/or physical condition of an individual (i.e., chest marks might be an honest signal of individual status).

Methods

Sample collection

Photos of sun bears were obtained from (1) the Bornean Sun Bear Conservation Centre (BSBCC; https://www.bsbcc.org.my/) in Sabah, Malaysian Borneo; and (2) the Free the Bears sanctuary (https://freethebears.org/) located inside the Phnom Tamao Wildlife Rescue Centre, Cambodia. At the BSBCC, photos of 54 sun bears (20 M and 34 F) were taken during the period 2009–2018, from the bear's arrival at the center and subsequently at each annual health check until its release or death (mean no. of years per bear = 4.9 ± 2.2, range = 2–10 yr, n = 49 individuals; for 6 of the 54 individuals only 1 photo was available). In the Free the Bears sanctuary, individual photos of 117 sun bears (43 M and 74 F) were taken during the period 2017–2019 (1 photo/individual only). For both the BSBCC and Free the Bears sanctuary, the photos always included the chest mark of the bear and an ample portion of the body around it (Fig. 2).

Biochemistry values

Biochemistry values were only available for the BSBCC sun bears. We took into account 4 parameters (i.e., 2 biochemistry values related to renal function [urea, creatinine]) and 2 for liver function (i.e., aspartate aminotransferase [AST] and alanine aminotransferase [ALT]). We chose the biochemical values that indicate hepatic and renal functioning because one of the clinical signs derived from pathology of these organs is hyperpigmentation (Faye and Bengoumi 2018). Urea is a product resulting from the degradation of proteins carried out by the liver and is filtered by the kidneys, and an increase in its value may be caused by, among other things, renal pathology (Attur Shanmugam et al. 2008). For example, the appearance of darker hair color can coincide with a progressive increase in blood urea, a characteristic feature

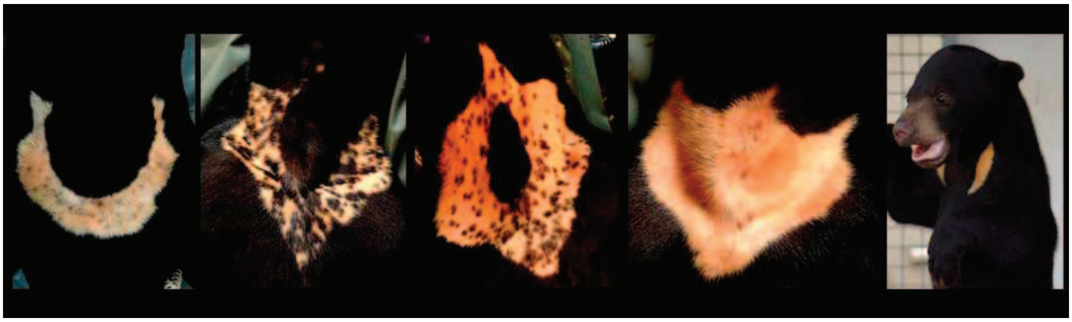

Fig. 2. The 5 categories of sun bear (*Helarctos malayanus*) chest mark shapes (from left to right): U, V, O, half circle, and noncontiguous shape. Photos of V, O, and half circle shapes sun bears were obtained from the Bornean Sun Bear Conservation Centre (2009–2018; BSBCC; https://www.bsbcc.org.my/) in Sabah, Malaysian Borneo. Photos of U and non-contiguous shapes were obtained from the Free the Bears sanctuary (2017–2019; https://freethebears.org/) located inside the Phnom Tamao Wildlife Rescue Centre, Cambodia.

of progressive renal failure coinciding with the advanced age of an individual or the presence of chronic pathology (Faye and Bengoumi 2018). Creatinine is a waste product that is eliminated by the kidneys and an elevated blood count could indicate a low filtering capacity of this organ. On the other hand, both of the indicative factors of hepatic state help us to understand whether the elevations in renal values are a consequence of multi-systemic pathology, even though renal values can also increase progressively with the age of the animal (Attur Shanmugam et al. 2008).

Chest mark patterns

We described the characteristics of chest marks by 4 parameters and using different data sets. By using data pooled from both sanctuaries ($n = 171$ individuals, 63 M and 108 F), we described the shape of the chest mark, divided into 5 categories (i.e., U, V, O, half circle, and noncontiguous shapes [Fig. 2]). We separated U and V shapes on the basis of their downward-facing edges, if smoothed or jagged, respectively. We also investigated individual consistency of chest mark shape through time and individual variation of the dark dots that frequently appear in chest marks (Fig. 3) using the Borneo data set ($n = 49$ individuals, 16 M and 33 F). We calculated frequency of dark dots using the ImageJ MultiPoint Tool (https://imagej.nih.gov/ij/) as the total number of dots inside the chest mark of the same individual in the years that it was checked.

Statistical analyses

First, to explore possible variation in chest mark shape by sex for the 2 most common shapes (i.e., U and V shapes [see Results]), we built a generalized linear model including chest mark shape as the binomial response variable, and sex and year as explanatory variables. Then, we analyzed potential relationships between individual variation of the number of dark dots inside the chest mark and (1) sex, (2) year (as a surrogate of age), and (3) the 4 biochemistry values (i.e., urea, creatinine, AST, and ALT) by building a linear mixed model including the individual as a random factor (measures of the same individual were taken over the years). Urea and AST were correlated ($r > 0.8$) with creatinine and ALT, respectively, so we removed urea and AST from the models. We standardized all variables using a z-score transformation with a mean of 0 and a standard deviation of 1. We compared all possible candidate models (including the null model) and performed model selection based on Akaike's Information Criterion corrected for small sample size (AIC_c; Burnham and Anderson 2002). We considered models with values of $\Delta AIC_c < 2$ as equally competitive. We then employed multi-model averaging on the whole set of models to extract coefficients of each explanatory variable (Burnham and Anderson 2002). We performed all analysis in Program R 3.5.1 statistical software (R Core Team 2013), using the packages lme4 (Bates and Sarkar 2007) and MuMIn (Barton 2018).

Results

The most common shapes of sun bear chest marks ($n = 63$ M and 108 F) were U (M = 60.3%, F = 57.4%) and V (M = 31.8%, F = 32.4%) shapes, followed by the other 3 shape categories (Fig. 4). We did not detect any differences in shape patterns by sex (Table 1). Over the years, chest mark shape never changed for the same

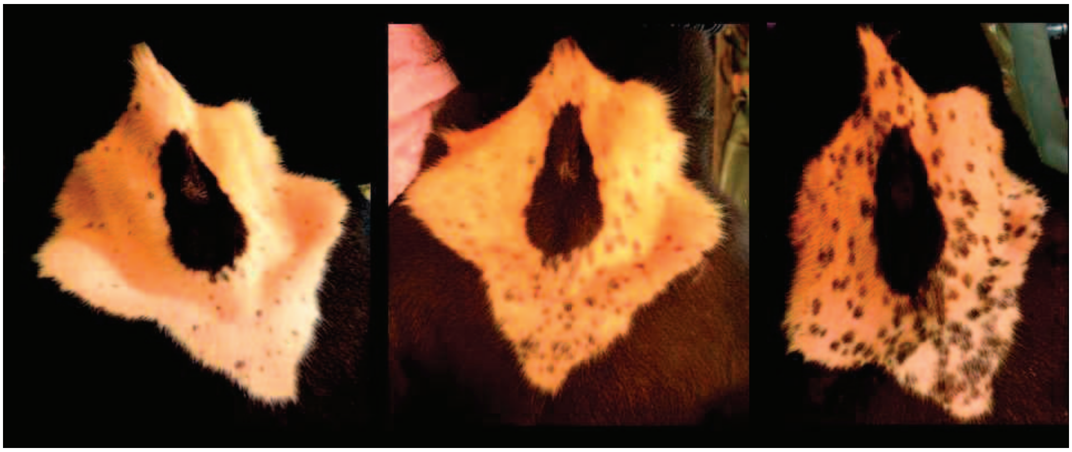

Fig. 3. An example of the yearly increase in dark dots in the chest mark of the same individual sun bear (*Helarctos malayanus*). From left to right: 2016, 2017, and 2018 dot patterns. Photos of sun bears were obtained from the Bornean Sun Bear Conservation Centre (2009–2018; BSBCC; https://www.bsbcc.org.my/) in Sabah, Malaysian Borneo.

bear ($n = 49$ individuals, 16 M and 33 F), showing its individual persistence over time.

The number of dark dots in chest marks, which showed large variation among individuals ($\bar{x} \pm \text{SD} = 37.7 \pm 26.8$ dots; range = 1–143), increased (Table 2): (a) over the years (i.e., the quantity of dark dots increases with bear age [Fig. 5]); and (b) with increasing values of creatinine. Even though sex and ALT were included in the competing models, their effects were not significant (Table 2).

Discussion

The main features of sun bear chest marks are (1) their persistence over time and the similarity in shape patterns between males and females. Thus, and contrary to our expectation, we found no evidence that chest marks function as a signal of sex recognition. And (2), the number of dark dots within the chest mark increases with bear age. The positive relationship of this dot pattern with creatinine values might also confirm the increasing pattern of dottiness with age, as in fact a progressive reduction of renal function due to age is expected (Attur Shanmugam et al. 2008). However, the absence of other clinical signs on the skin (authors' unpublished data), which may be characteristic of renal and hepatic pathologies (i.e., pruritus, dermatitis, or alopecia), allows these pathologies to be ruled out as causing the hair color change (Costello et al. 2006). As a consequence, the highlighted positive

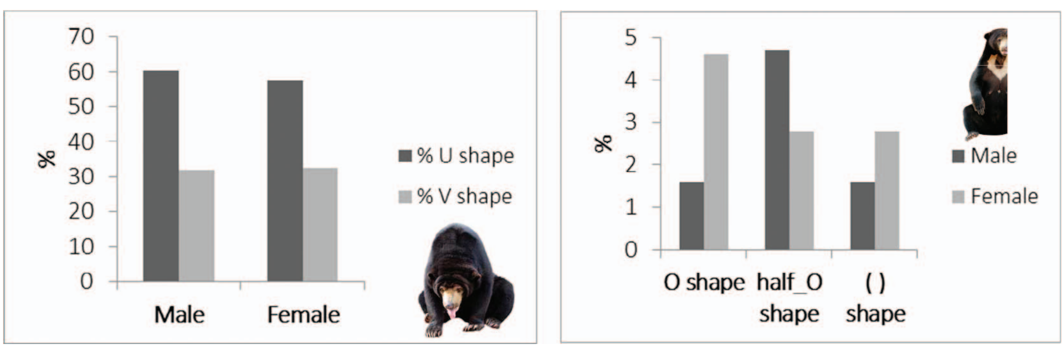

Fig. 4. The recurrence (%) of the different chest mark shapes (U, V, O, half circle, and noncontiguous) of sun bears (*Helarctos malayanus; n* = 63 M and 108 F). The bear photos were downloaded from 123RF ROYALTY FREE STOCK PHOTOS, http://www.123rf.com: ID 24096359, Anan Kaewkhammul.

Table 1. Shape variation in sun bear (*Helarctos malayanus*) chest marks by sex for the 2 most common shapes (i.e., U and V shapes [see Results]). For the explanatory variable, we report the estimate (β), standard error (SE), significance (*P*), confidence interval (CI), and the relative importance value (RIV) obtained from model-averaging on the entire set of models. Sample size was $n = 171$ individuals (63 M and 108 F). Competitive models are ranked from the lowest (best model) to the highest AIC$_c$ value. Only models with ΔAIC$_c$ <2 are shown. Photos of sun bears were obtained from (1) the Bornean Sun Bear Conservation Centre (2009–2018; BSBCC; https://www.bsbcc.org.my/) in Sabah, Malaysian Borneo; and (2) the Free the Bears sanctuary (2017–2019; https://freethebears.org/) located inside the Phnom Tamao Wildlife Rescue Centre, Cambodia.

Dependent variable	Competing models	df[a]	AIC$_c$[b]	ΔAIC$_c$[c]	Weight	
Chest mark shape	Sex	2	63.50	1.57	0.69	
	Null model	1	65.08	0.00	0.31	
		Model-averaged coefficients and relative importance values				
Dependent variable	**Explanatory variable**	**β**	**SE**	***P***	**CI**	**RIV**
Chest mark shape	Intercept	0.60	0.44	0.18	−0.28–1.47	
	Sex (males)	−0.82	0.76	0.29	−2.47–0.07	0.69

[a]Degrees of freedom.
[b]AIC$_c$ = Akaike Information Criteria corrected for small sample sizes.
[c]ΔAIC = difference in AIC from top-ranking model.

relationship between the amount of dots in the chest mark of sun bears and their age opens the possibility of using this trait as a reliable way to determine age of bears from the number of spots or, at a minimum, their categorization into age groups (e.g., juvenile, adult, and senior individuals).

Sun bears overlap with the range of Asiatic black bear and potentially at the extremes of their ranges with sloth bear; therefore, features that enable species recognition so as to avoid hybridization may be favored (Caro et al. 2017b). However, on the basis of the individual variations of chest marks (i.e., different shapes among individuals

Table 2. Patterns of dark dots in the chest mark of sun bears (*Helarctos malayanus*). The number of dark dots showed a clear increase with increasing age (see also Fig. 3) and creatinine values. For the explanatory variables, we report the estimate (β), standard error (SE), significance (*P*), confidence interval (CI), and the relative importance value (RIV) obtained from model-averaging on the entire set of models. Sample size was $n = 49$ individuals (17 M and 32 F). Competitive models are ranked from the lowest (best model) to the highest AIC$_c$ value. Only models with ΔAIC$_c$ <2 are shown. Photos of sun bears were obtained from (1) the Bornean Sun Bear Conservation Centre (2009–2018; BSBCC; https://www.bsbcc.org.my/) in Sabah, Malaysian Borneo; and (2) the Free the Bears sanctuary (2017–2019; https://freethebears.org/) located inside the Phnom Tamao Wildlife Rescue Centre, Cambodia.

Dependent variable	Competing models	df[a]	AIC$_c$[b]	ΔAIC$_c$[c]	Weight	
Chest mark dots	Sex + year + ALT + creatinine	7	1,070.17	0.00	0.45	
	Sex + year + creatinine	6	1,070.64	0.47	0.35	
		Model-averaged coefficients and relative importance values				
Dependent variable	**Explanatory variable**	**β**	**SE**	***P***	**CI**	**RIV**
	Intercept	32.96	4.24	<2e-16	24.58–41.35	
	Year	1.44	0.56	0.01	0.33–2.55	0.92
Chest mark dots	Creatinine	2.97	0.92	0.001	1.16–4.78	0.99
	ALT[d]	0.87	0.71	0.48	− 0.53–2.27	0.56
	Sex (males)	4.98	7.26	0.49	− 9.26–19.21	0.88

[a]Degrees of freedom.
[b]AIC$_c$ = Akaike Information Criteria corrected for small sample sizes.
[c]ΔAIC = difference in AIC from top-ranking model.
[d]Alanine aminotransferase.

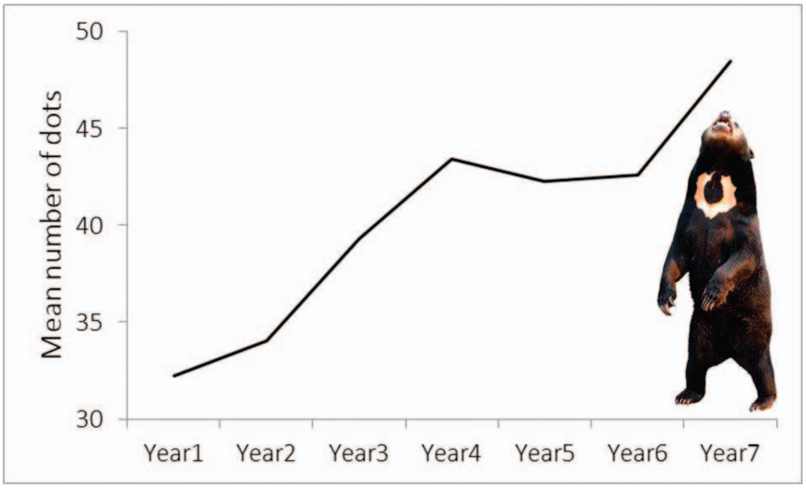

Fig. 5. Example of how the number of dark dots in the chest mark of sun bears (*Helarctos malayanus*) increases with age (raw data plotted; the bear photo was downloaded from 123RF ROYALTY FREE STOCK PHOTOS, http://www.123rf.com: ID 24096359, Anan Kaewkhammul).

and patterns of coloration by age), we suggest a different or, at least, complementary function of the sun bear mark, one mostly related to conspecific visual communication. We would expect that the complexity exhibited by sun bear chest marks would not necessarily be maintained if the only, or primary, function was hybridization avoidance. In fact, the highlighted patterns may be better explained by the existence of complex interactions among individuals of the same species, which may allow for individual recognition and evaluation of their characteristics (e.g., age and health). It has previously been suggested that sun bear chest marks do not change for the same bear (Ngoprasert et al. 2010, 2012), and the crescent-shaped chest mark of the Asiatic black bear was found to change only slightly from year to year, making identification of different individuals highly reliable (Higashide et al. 2012). A potential function of the chest mark as a visual signal in conspecific communication may also be supported by recent evidence that sun bears have complex social interactions and social sensitivity as part of their communication system, being able to modify their facial morphology when seen by conspecifics (Taylor et al. 2019). Thus, visual signaling through chest marks may be combined with their ability to communicate using a large repertoire of facial expressions, likely to promote communicative exchanges via visual signals such as mimicking and chest marks.

Moreover, although the function of fur patches is still unclear because of the lack of experimental studies (Caro 2009, Penteriani and Delgado 2017), it has been suggested that body patches might aid visual recognition between conspecifics in the Strepsirrhini (Bearder et al. 2006), a suborder of primates that includes the lemuriform primates. These are cathemeral species (i.e., animals that can exhibit both diurnal and nocturnal activity), whose patterns of light and dark fur might enable them to identify individuals by sight in dark environments. Sun bears are both cathemeral and forest-dwelling species (Scotson et al. 2020), so we suggest that visual recognition through body patches might also have been favored in this bear, similar to that reported for lemurs. The black body of sun bears provides good camouflage in the dark and dense tropical forests and the bright color of the chest patch contrasts greatly with the background. When sun bears sense the presence of another animal around them, they always stand up to get a better view; and, when they raise their head up and lift their nose high, their chest patch becomes visible. Thus, this chest patch might also serve as a warning sign to other animals and that their presence has been noticed by the bear.

Finally, we still consider it important to stress the fact that the results and arguments presented here are based on human vision, and it would be helpful to know the ability of sun bears to resolve chest mark features and at what distances (Caro et al. 2017a). Recent models of large carnivore acuity indicate that their vision is less developed than that of humans and sun bears have relatively small eye diameter, which may suggest that this bear cannot resolve contrasting pelage as well as humans can during the day and not much better than humans under dim light (Caro et al. 2017a). However, only observations of individual interactions in captivity and/or in the wild, as well as experimental manipulations of the chest mark during encounters between individuals of known age, sex, and health (Penteriani et al. 2007, Penteriani and Delgado 2009, Bettega et al. 2013, Chaine et al. 2018), can shed definitive light on the significance of the function of sun bear chest marks. Additionally, it will be crucial to properly interpret the information content of color patterns, which requires a deep understanding of the factors constraining its expression. For this, behavioral tests must be combined with a multidisciplinary approach combining genetics, biochemistry, physiology, and evolutionary developmental biology (Pérez-Rodríguez et al. 2017). The environmental light in which all the photos were taken was heterogeneous, so it was not possible to measure here the color variation in chest marks within and among individuals. Huge variation in colors, from dark orange to whitish (Scotson et al. 2020), necessitates that future studies should address the features and functions of this crucial component of chest marks.

Together with their importance in increasing our understanding of bear communication, fur patterns can also be used in field research to study population density, population trends, and survivorship (Ngoprasert et al. 2010, 2012). Researchers identifying individuals by their chest markings in longitudinal photographic capture–recapture studies should consider, or be aware of, which chest mark features are persistent and which may vary over time.

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