

Relative size and nose color predict age in Andean bears, but their facial markings do not reflect kinship

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Using photos of captive Andean bears of known age and pedigree, and photos of wild Andean bear cubs < 6 months old, we evaluated the degree to which visual information may be used to estimate bears' ages and assess their kinship. We demonstrate that the ages of Andean bear cubs ≤ 6 months old may be estimated from their size relative to their mothers with an average error of $< 0.01 \pm 13.2$ days (SD; $n = 14$), and that ages of adults ≥ 10 years old may be estimated from the proportion of their nose that is pink with an average error of $< 0.01 \pm 3.5$ years ($n = 41$). We also show that similarity among the bears' natural markings, as perceived by humans, is not associated with pedigree kinship among the bears ($R^2 < 0.001$, $N = 1,043$, $p = 0.499$). Thus, researchers may use photos of wild Andean bears to estimate the ages of young cubs and older adults, but not to infer their kinship. Given that camera trap photos are one of the most readily available sources of information on large cryptic mammals, we suggest that similar methods be tested for use in other poorly understood species.

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19 **INTRODUCTION**

20

21 The Andean bear (*Tremarctos ornatus*, FG Cuvier) is vulnerable to extinction (Goldstein et al. 2008)
22 but we know little of its ecology (Garshelis 2004), demography, and genetic structuring (Viteri &
23 Waits 2009), making it difficult to plan for its conservation. To facilitate research in support of Andean
24 bear conservation we've assessed whether we can estimate the ages and assess the kinship of individual
25 Andean bears. Because conservation success may be improved through engagement of local people
26 (Byers 1999; Danielsen et al. 2007; Peyton 1989), and because local people may have knowledge and
27 skills beneficial to scientific research (Sharma, Jhala & Sawarkar 2005; Stander et al. 1997; Zuercher,
28 Gipson & Stewart 2003), we've focused on methods that rely on a minimum of technology.

29 Individual appearance may provide information not only on identity (e.g., Van Horn et al. 2014) but
30 also on age and even kinship, in species as disparate as giraffe (*Giraffa camelopardalis*; Berry &
31 Bercovitch 2012; Foster 1966) and lions (*Panthera leo*; Whitman et al. 2004). Age in other bears has
32 been inferred, with some error, by morphological measurements and dental cementum annuli (Bridges,
33 Olfenbittel & Vaughan 2002; Christensen-Dalsgaard et al. 2010; Costello et al. 2004; Marks &
34 Erickson 1966; McLaughlin et al. 1990; Medill et al. 2009; Mundy & Fuller 1964; Stoneberg & Jonkel
35 1966; Willey 1974), but noninvasive methods of age estimation have not been developed for bears. It
36 appears that the markings of Andean bears may change subtly over an individual's lifetime, but such
37 changes are not predictable enough to allow age estimation (Van Horn et al. 2014). Because the size of
38 offspring relative to their mothers may predict their age (e.g., Jongejan, Arcese & Sinclair 1991), we
39 evaluated whether such data predicted the ages of young Andean bear cubs. In addition, because nose
40 color is a reliable indicator of age in another carnivore (Whitman et al. 2004), we examined the degree
41 to which the nose color of Andean bears reflected their age. Genetic analysis would provide strong
42 evidence of kinship (e.g., Woods et al. 1999) and genetic tools are being developed for Andean bears

43 (e.g., Viteri & Waits 2009), but collection of genetic samples is not always feasible in the humid
44 tropical forests and grasslands where most Andean bears are thought to live (Goldstein et al. 2008).
45 Aside from genetic data, kinship may be inferred from similarity of appearance among individuals in
46 some species (Alvergne et al. 2009; Bateson, Lotwick & Scott 1980; Caro & Durant 1991; Jarman et al.
47 1989; Mills et al. 2000; Parr et al. 2000; Pokorny & de Waal 2009; Vokey et al. 2004), but not in others
48 (Kelly 2001). The inheritance of markings among bears is poorly understood (Higashide, Miura &
49 Miguchi 2012) and there is some evidence that patterns in markings of Andean bears are not obviously
50 heritable (Eck 1969), so the link between kinship and similarity in markings among Andean bears is
51 uncertain, at best. We therefore assessed whether this link is informative.

52

53 **MATERIALS AND METHODS**

54

55 We extracted information from portraits of captive Andean bears of known identity, age, and pedigree
56 that were posted online, and from zoo personnel and field researchers in North America, Europe, and
57 South America (Van Horn et al. 2014). If we did not know the date on which the photograph was taken,
58 we assigned it the midpoint of the time period in which the photo was taken (e.g., photos taken in
59 'July' were assigned the date 15 July).

60

61 **Visual estimation of age through relative body size**

62 To evaluate whether the relative size of young cubs might predict their age, we extracted
63 information from photographs of known-age cubs born in captivity, and from young cubs found in
64 their natal dens in the tropical dry forest of northwest Peru (6°26'S, 79°33'W), where research on
65 Andean bear ecology and behavior has been underway since 2007. We located active natal dens by

66 inferring den entry from the sudden cessation of new telemetry positions and by then searching near
67 the last previous transmitted locations, along with searching similar sites during the same season. We
68 estimated the ages of cubs found in their natal dens from their development when compared to
69 published descriptions of captive cub development (Aquilina 1981; Bloxam 1977; Malzacher & Hall
70 1998; Molloy 1989; Müller 1988; Peel, Price & Karsten 1979; Saporiti 1949; Stancer 1990). We later
71 opportunistically collected photos of some of these same wild cubs and their mothers with camera traps
72 set during a long-term study. Within photos we measured the size of cubs, relative to the size of their
73 mothers, for wild-born and captive-born cubs that were < 180 days old. We chose this age period
74 because the growth of bear cubs within the first 6 months of life often appears linear (Bartareau et al.
75 2012; Blanchard 1987; Bridges et al. 2002; Bridges, Vaughan & Fox 2011; Kingsley 1979; McRoberts,
76 Brooks & Rogers 1998) and because growth among older cubs might be influenced by factors other
77 than age (e.g., variation in food availability). To avoid potentially confounding variation that might be
78 introduced by variation in litter size we also excluded data from twin litters. We estimated the relative
79 sizes of cubs by taking the mean of three repeated measures of the same fixed post-cranial
80 measurement (e.g., length of lower hindlimb, shoulder height) of cubs and their mothers when they
81 were the same distance from the camera, as determined by visual landmarks in the photographs (n =
82 14). We constructed candidate predictive models of relative cub size from cub age (69 - 180 days), cub
83 provenance (captive-born or wild-born), cub identity (4 captive-born, 3 wild-born), and the interaction
84 between cub identity and age. We then used an information theoretic approach (Burnham & Anderson
85 2002) to compare the candidate models using AIC_c as the key criterion for model selection, and we
86 used R^2 and p to assess the effectiveness of the 'best' model for describing a cub's relative size.

87

88 **Visual estimation of age through nose color**

89 To investigate the relationship between the color of a bear's nose and its age (years) we first
90 screened photos of captive Andean bears to exclude photos that did not show the entire nose, photos
91 that did not appear in focus when magnified to 2 – 4X, and photos from which there were < 1000
92 pixels in the image of the nose. To avoid non-independence between photos we excluded multiple
93 photos of the same bear that were taken within 365 days, and we renamed the 76 remaining photos
94 from 58 bears (32M, 26F), aged 0.3 – 31.4 years, with random numbers. We then expressed the color
95 of a bear's nose as the proportion of the area of the nose that was pink ('proportion pink') by taking the
96 mean of **three independent estimates** of the proportional area of pink in each photo, excluding the
97 nostrils (which were often shaded), and being alert for the presence of pink scar tissue. We had
98 longitudinal series of photos from 10 bears (7M, 3F) that provided 12 pairwise within-individual
99 comparisons of the change in nose color over time; the average annual change in the proportion pink
100 was 0.02 ± 0.02 , which lent credence to the use of proportion pink as an indicator of age. Because there
101 were multiple photographs for some but not all bears (**1.31 ± 0.6 photos/bear**), to avoid non-
102 independence of data and to allow for model testing we randomly selected 1 photograph per bear from
103 photographs of bears ≥ 9.9 years old (the minimum age at which we observed pink on the nose) for use
104 in model building and retained the other data in this age range for use in model testing. We then used
105 the proportion pink as the response variable in linear regression analyses with candidate models
106 including age, sex, and the interaction of age and sex. We used AIC_c as the key criterion for model
107 selection, with R^2 and p to assess the effectiveness of the 'best' model for **describing a cub's relative**
108 size. When multiple candidate models were competitive (i.e., $\Delta AIC_c \leq 2$), we used full model
109 averaging (e.g., Lukacs, Burnham & Anderson 2009) to derive the predictive equation including age,
110 sex, and the interaction of age and sex. To assess the fit and putative power of relationships predicting
111 age we then examined the reverse relationships, with age as the response variable, and examined the

112 distribution of the relevant residuals. When possible we tested the ability of equations to predict the
113 ages of bears in images that had not been used to describe the relationship between age and nose color.

114

115 **Similarity of markings and kinship**

116 To assess humans' ability to visually evaluate kinship among Andean bears, as part of a larger
117 study we created an online survey and sought volunteer participation by colleagues, peers, personal
118 contacts, and a solicitation in the International Bear News (Paisley et al. 2010; Van Horn et al. 2014).
119 We asked participants to rate the similarity of 11 pairs of images of bears whose kinship was unknown
120 to them; the average pedigree r-values across these pairs of images was 0.32 ± 0.23 . Participants were
121 asked to rate the similarity of the markings of bears in these images as 1 of 5 categories: exactly the
122 same, similar, slightly different, extremely different, and unable to determine. Participants ($n = 109$) in
123 the online survey rated the similarity of, on average, 9.6 ± 1.7 of 11 pairs of images. We used logistic
124 regression to examine the strength of the relationship between the perceived visual similarity of
125 markings and the pedigree r-values of the bears in the images.

126 Unless otherwise noted all quantities are expressed as $\bar{x} \pm SD$, and statistical significance refers to
127 two-tailed $p = 0.05$. Statistical analyses were conducted in JMP 10.0.2 (SAS Institute Inc., Cary, NC.).
128 Human subjects research was ruled exempt from IRB Review by the Research Compliance Office of
129 Miami University (project 01632e) and animal research was approved by the IACUC committee of San
130 Diego Zoo Global (#10-023).

131

132 **RESULTS**

133

134 **Visual estimation of age through relative body size**

135 The model which described cub relative size from only an intercept and cub age in days ($R^2 = 0.835$,
136 $DF = 13$, $p < 0.001$) fit the data better than all other models (i.e., $\Delta AICc > 4$): $\text{relative size} = 0.123 +$
137 $0.003 * (\text{age in days})$. This model would not perform well for much younger and older cubs, as it
138 predicts that newborn cubs are 12.3% of their mother's size and that cubs would be the same size as
139 their mothers when only 313 days old, but from 2 - 6 months in age there appears to be a linear
140 relationship between cub age and relative size (Fig. 1). The reverse relationship is $(\text{age in days}) = -$
141 $15.263 + 293.26 * (\text{relative size})$, from which the average residual was $1.32 \times 10^{-14} \pm 13.2$ days.

142

143 **Visual estimation of age through nose color**

144 No pink was seen on the nose in 26 photos of 20 bears (10M, 10F), of which all but one (96.1%) were
145 < 10 years old; the youngest age at which we saw pink on the nose was 9.9 years ($n = 50$ photos; Fig.
146 2). Nearly all of the 52 photos of bears > 9.5 years old (96.2%) showed some pink on the nose. The
147 linear model, built upon data from 41 photos of 41 bears (23M, 18F), which best fit the data predicted
148 the proportion pink from only age ($R^2 = 0.554$, $DF = 39$, $p < 0.001$) but there were two other
149 competitive models (i.e., $\Delta AICc > 2$): the model that also included sex, and the model that included sex
150 and the interaction of sex and age. We therefore used model averaging to derive the equation
151 $(\text{proportion pink}) = -0.257 + 0.022 * (\text{age in years}) + 0.0006 * (\text{age in years}) * (z)$ where $z = 0$ if male or z
152 $= 1$ if female. However, in practice it will not always be possible to determine the sex of a bear from
153 camera trap photos. The best predictive model for bears of unknown sex predicted the $(\text{proportion}$
154 $\text{pink}) = -0.254 + 0.022 * (\text{age in years})$. In reverse, this relationship predicted $(\text{age in years}) = 15.055 +$
155 $25.129 * (\text{proportion pink})$ with an average residual of $2.99 \times 10^{-15} \pm 3.46$ years. Testing this model with
156 the 7 independent data points (6M, 1F) yielded an average error of -1.62 ± 2.3 years. Using the 23
157 points from males in the model-building data set, we found that for males $(\text{proportion pink}) = -0.156 +$

158 $0.018*(\text{age in years})$ ($R^2 = 0.335$, $DF = 22$, $p = 0.004$). The reverse of this relationship predicted age
159 (in years) of males as $15.482 + 10.698*(\text{proportion pink})$ with an average residual of $2.39 \times 10^{-15} \pm 3.2$
160 years. Testing this model with the 6 independent data points from males produced an average error of -
161 2.43 ± 2.7 years. Using the 18 points from females in the model-building data set, we found that among
162 females the $(\text{proportion pink}) = -0.33 + 0.0245*(\text{age in years})$ ($R^2 = 0.703$, $DF = 17$, $p < 0.001$). The
163 reverse relationship predicted for females that $(\text{age in years}) = 15.435 + 28.644*(\text{proportion pink})$ with
164 an average residual of $-1.28 \times 10^{-15} \pm 3.7$ years. With only 1 independent data point from a female we
165 cannot further assess the errors in age estimation that result from this model.

166

167 **Similarity of markings and kinship**

168 Markings of Andean bears vary greatly even among full siblings (e.g., Fig. 3). The average pedigree r-
169 values across pairs of test images was between the kinship levels of half-siblings and full-siblings, yet
170 the average similarity rating given to these paired images by participants was 3.38 ± 0.85 , between
171 'slightly different' (i.e., '3') and 'extremely different' (i.e., '4'). There was not a meaningful
172 relationship between the pedigree r-values of bears and similarity rankings of their photos ($R^2 < 0.001$,
173 $N = 1,043$, $p = 0.499$), demonstrating that perceived similarity among paired images did not reflect
174 pedigree kinship among the bears.

175

176 **DISCUSSION**

177

178 For the first several months after young Andean bears are independent of their natal dens, the relative
179 size of cubs can be used to predict their age and then estimate their birthdates. At present the only data
180 on birthdates of Andean bears come from captivity (e.g., Spady, Lindberg & Durrant 2007) and from 1

181 den in Ecuador (Castellanos 2010), so the estimation of any additional birthdates of wild cubs should
182 offer important insights into Andean bear reproductive ecology. Interestingly, because the provenance
183 of young cubs had no impact on their relative growth, relative growth of young cubs should be stable
184 across habitats, allowing the use of this relationship to predict ages and estimate birthdates across the
185 species' range. Given that a similar method of age estimation is effective in a phylogenetically distant
186 species (Jongejan et al. 1991), we think the relative size of dependent offspring may be a useful way
187 for investigators to visually estimate the ages and birthdates of progeny in many other species.

188 Nose color provides a clear noninvasive indicator of whether an Andean bear is older or younger
189 than 10 years: if any of the nose is pink the bear is almost certainly > 10 years old, and vice versa.
190 Older Andean bears also show grizzling on their faces (Van Horn et al. 2014). Using the proportion
191 pink of the bear's nose, and whatever information is available about a bear's sex, we can estimate the
192 age of a wild Andean bear to $\pm 3 - 4$ years. These estimates are less precise than age estimates for some
193 other bear species (e.g., Christensen-Dalsgaard et al. 2010; Costello et al. 2004) but those estimates
194 require capture and handling of the bear, while measuring nose color does not. It may not be easy to
195 obtain many suitable photos of the noses of free-ranging bears without the use of lures and relatively
196 complex configurations of camera traps, but two of us (RVH, RDA) have done so. We do not know if
197 nose color changes in a predictable manner in other bears and in other carnivores, although we have
198 seen photos of some cats (e.g., *Leopardus pardalis*, *Puma concolor*) showing variation in their nose
199 color. We therefore suggest that nose color may provide valuable information on age structure in other
200 carnivores.

201 Our data indicate that it is not possible to infer kinship among Andean bears based on the
202 perceived similarity of their markings. This is consistent with Eck's (1969) hypothesis that patterns in
203 markings are not heritable and this affirms that genetic tools (e.g., Viteri & Waits 2009) are needed to
204 infer kinship among wild Andean bears.

205 Although the methods we describe cannot replace long-term research on known individuals, we
206 believe that they will facilitate the collection of data and enhance the value of camera trapping efforts
207 for the conservation of Andean bears. In addition, we believe the examination of the relationships
208 among relative size, nose color, sex, and age among known-age individuals of other species may
209 produce similarly useful methods across more taxa.

210

211 **ACKNOWLEDGEMENTS**

212

213 We thank the Smithsonian's National Zoo and the following for the use of their photographs in Figure
214 3: Daniel Reidel ('Billie Jean', 'Chaska', and 'Nicole'), Tracey Barnes ('Bernardo' and 'Curt'), and
215 Valerie Abbott ('Nikki'). We thank Drs. Peter Arcese and Ron Swaisgood for their intellectual
216 contributions. We thank the volunteer participants in the online survey, which was made possible by
217 Yuri Nataniel Daza (Universidad de San Simon). The following zoological gardens and individuals
218 shared photographs of captive Andean bears for use in the online survey: Antwerp Zoo (Sander
219 Hofman), Basel Zoo (Dr. Friederike von Houwald), Brookfield Zoo, Cheyenne Mountain Zoo,
220 Cincinnati Zoo, Cleveland Metroparks Zoo, Connecticut's Beardsley Zoo, Dortmund Zoo (Dr. Florian
221 Sicks), Durrell Wildlife Conservation Trust (Mark Brayshaw), Gladys Porter Zoo, Houston Zoo, Köln
222 Zoo (Dr. Lydia Kolter), Minnesota Zoo, Oglebay's Good Zoo, Racine Zoo, Reid Park Zoo, Rolling
223 Hills Wildlife Adventure, Salisbury Zoo, San Antonio Zoo, San Diego Global, Smithsonian National
224 Zoo, and Smoky Mountain Zoo. We were able to collect data on wild Andean bears only through the
225 efforts of Javier Vallejos, José Vallejos, and Isai Sanchez. We thank the citizens of the Rio La Leche
226 watershed for permission and support to work on communal land. Governmental permission to conduct

227 field research was granted by the Dirección General Forestal y de Fauna Silvestre as Resolución

228 Directoral No. 0245-2012-AG-DGFFS-DGEFFS.

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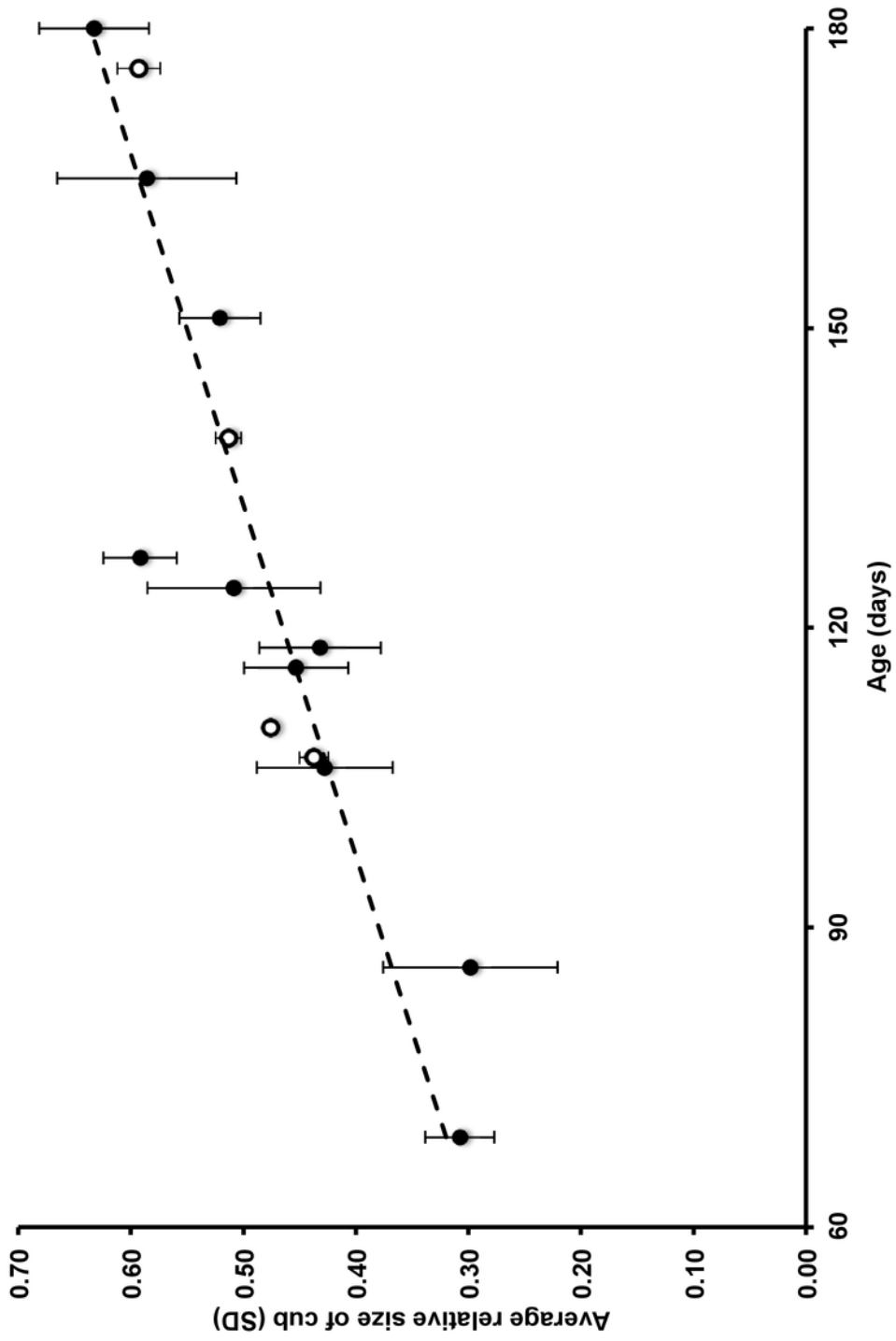
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1

The size of Andean bear cubs in proportion to the size of their mothers, while the cubs were 2-6 months old.

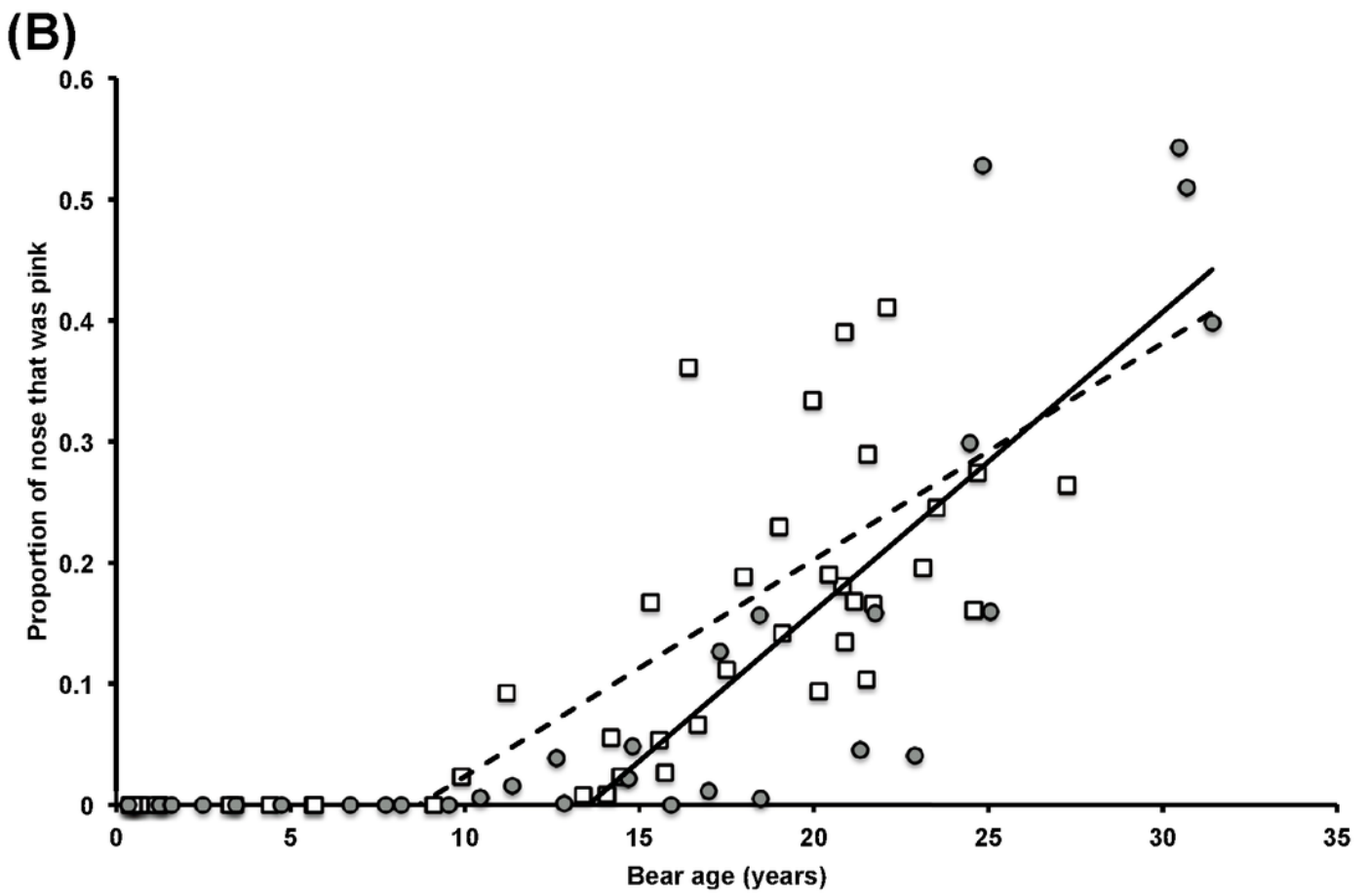
The dashed line illustrates the linear regression of average relative size in response to age in days among 4 captive-born (open circles) and 3 wild-born (filled circles) cubs.



2

The proportion pink of an Andean bear's nose across age in (A) a male Andean bear ('Tommy', studbook #264), aged 2, 17, and 23 years, and (B) in 76 photos of 58 captive-born Andean bears (32M, 26F).

The trendlines show the relationships between the proportion pink and age in males (open square, dashed line) and females (filled circle, solid line).



3

A photographic pedigree of captive-born Andean bears.

Squares represent males and circles represent females in this pedigree of male 'Nikki' (studbook #415, 19.3 years old), his mate 'Billie Jean' (studbook #748, 7.4 years old), and their four offspring: the littermates 'Bernardo' (studbook #837, 1.2 years old) and 'Chaska' (studbook #838, 3.3 years old), and the littermates 'Curt' (studbook #860, 2.0 years old) and 'Nicole' (studbook #861, 1.3 years old).

