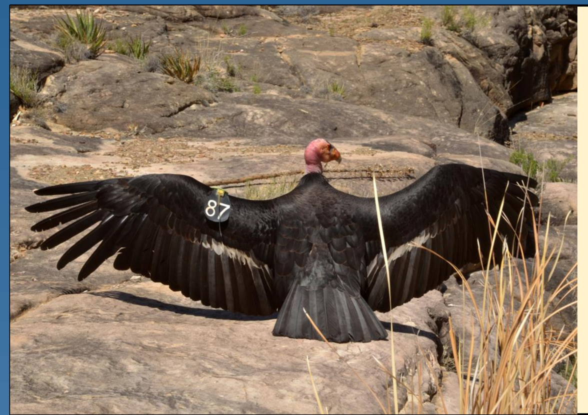

Photo: NPS/Michael Quinn

Skeletal ontogeny in the California condor (*Gymnogyps californianus*)

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Photo: Courtesy of Smithsonian Institution Archives.

Introduction

- Paleontologists and zooarchaeologists need to distinguish bones of adult-sized immature birds from full adults to help characterize paleo-habitats and seasonality of archaeological site occupation.
- Avian biologists are interested in comparing growth patterns between the wing and leg bones of birds to understand how skeletal maturity relates to a chick's behavior and development.
- **We studied postcranial bone growth and the maturation of bone surface textures in the skeleton of the endangered California condor** (*Gymnogyps californianus*), the largest soaring bird in North America with a wingspan of 9-10 ft[1,2].
- The California condor is endangered because of range contraction and excessive mortality, mainly due to lead poisoning [1,2,4]. The California Condor Recovery Program[4] is working to save the species via captive breeding and release.
- The National Museum of Natural History recently acquired a series of carcasses from this program. Unlike most museum specimens, these birds are of known age at death. Previous studies on skeletal ontogeny of birds have used museum specimens of unknown ages but known ontogenetic stages (chick, fledging, juvenile, sub-adult, adult)[3,5,6].

Questions

- Do the growth patterns of the wing and the leg bones differ?
- At what age can we no longer distinguish bones of a hatch-year bird from an adult?
- How does skeletal maturity relate to milestones in the bird's development?

Methods

Linear measurements

- We measured the bone length, between defined anatomical landmarks, for the coracoid, humerus, ulna, carpometacarpus, first phalanx of the major digit, femur, tibiotarsus, and tarsometatarsus in 42 specimens of known age. Measurements were taken with digital calipers, or a ruler for bones over 300mm.
- Data were graphed with the ggplot2 package in RStudio.

Texture observations

- 13 specimens were selected, ranging in age from 9 to 5124 days old, as a representative growth series (Fig.1).
- Textures of the sternum, the synsacrum, and the bones measured were studied in this series.
- Preliminary observations were made to determine areas of late maturity in each bone. These areas were then observed under a dissecting microscope.
- Textures observed were categorized with brief word descriptions and microscope images taken with a Zeiss Axiocam attached to a Zeiss Stereo Discovery V12. After describing each bone in the growth series using these categories as a guide, we identified the age at which each bone can no longer be distinguished from bones of after hatch-year adults.

Results

Growth series

Figure 1. Growth series of the humerus (left) and the femur (right). Ages in days (from left to right) are: 9, 47, 65, 80, 128, 136, 184, 212, 246, 533, 864, 2094, 5124. Scale bars = 5cm.

Growth in length

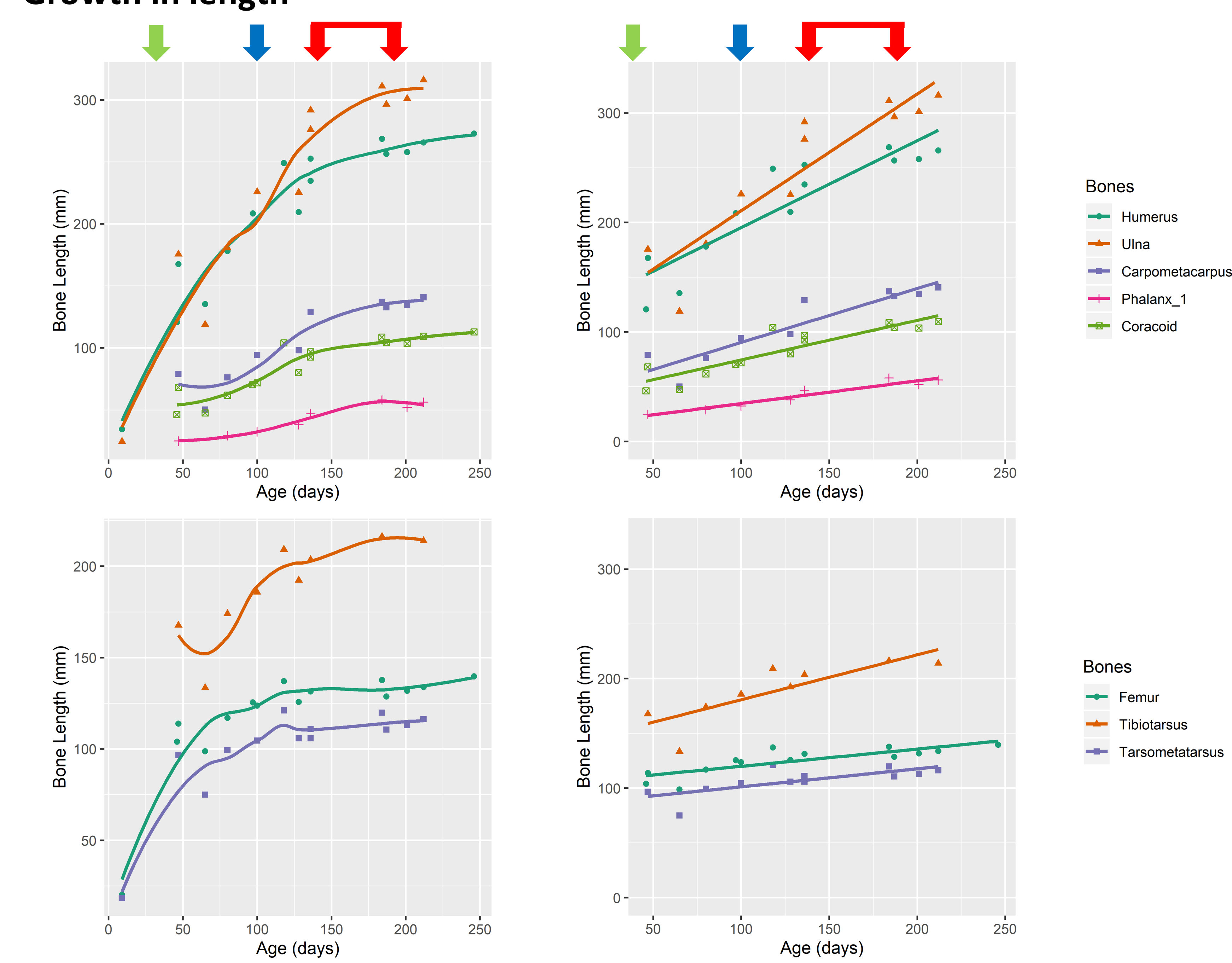

Figure 2. Postcranial bone lengths in hatch-year birds. Top left and bottom left show growth trajectory, with a Loess line. Last data point is an individual near mean adult size. Top right and bottom right show the roughly linear period of growth, with linear regressions. Slopes of linear regressions are: humerus = 0.795, ulna = 1.066, carpometacarpus = 0.492, first phalanx = 0.207, coracoid = 0.361, femur = 0.157, tibiotarsus = 0.41, and tarsometatarsus = 0.164. Colored arrows indicate ages of developmental milestones.

Developmental milestones (in days)

Walking: 21-42 Jumping: ~100 Fledging: 140-180

Surface textures

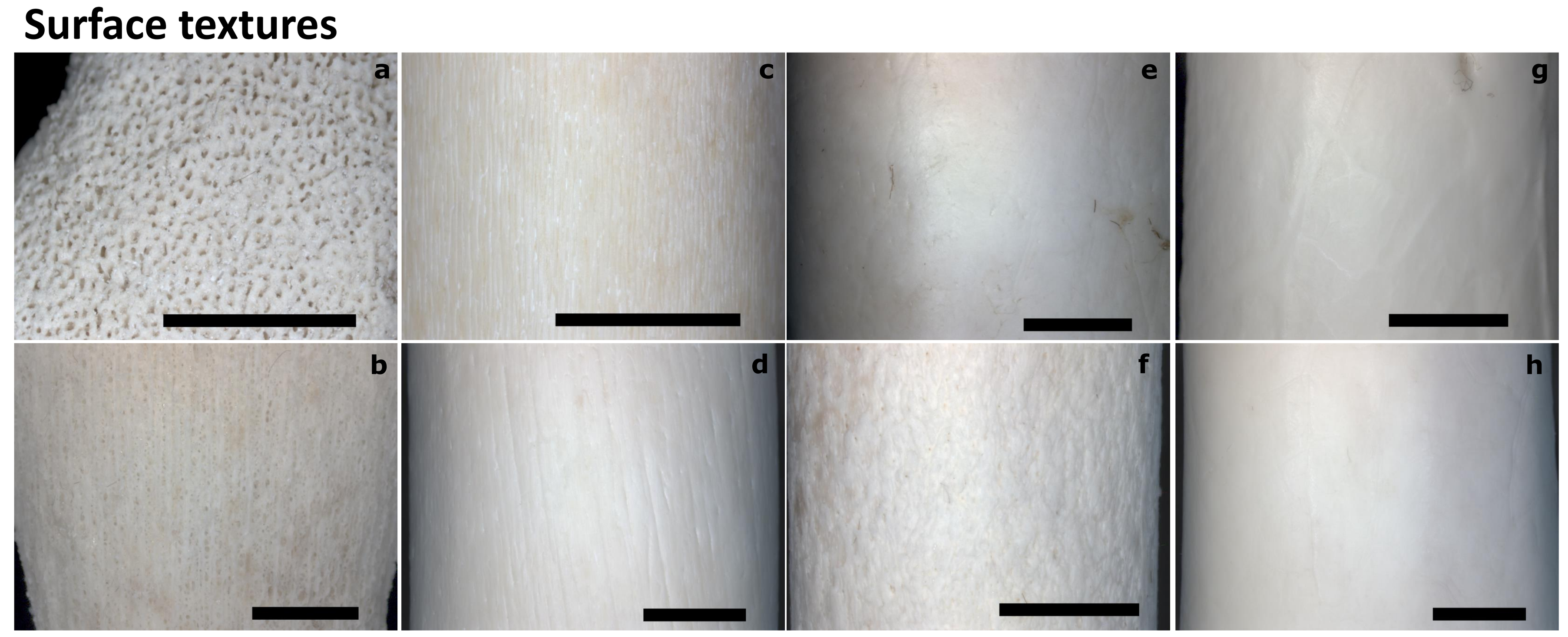

Figure 3. Pictorial guide to surface textures. (a) porous, (b) webbed, (c) striated, (d) dispersed striations and dimples, (e) dimpled, (f) "muscular", (g) rugose, (h) smooth. Scale bars = 5mm.

Results (continued)

- The humerus and the ulna have the highest growth rates (Fig. 2). During the period observed, bones of the wing have higher growth rates than bones of the leg, except for the tibiotarsus.
- Adult texture can be described, in general for all bones, as rugose (g) or smooth (h), with scattered dimples (e). Faint and dispersed striations may be present. Muscular (f) texture is present in sites of muscle attachment. See Figure 3.
- The coracoid, humerus, synsacrum, and femur attain this texture between 212 and 246 days. By this time, bones are full adult size.
- The sternum is the last bone studied to reach adult texture. The carina (keel) is porous (a) at 533 days and smooth by 864 days.
- Skeletal maturity as it relates to developmental milestones
  - Walking: Long bones growing with webbed (b) to striated (c) textures in shaft. Coracoid porous (a) to webbed (b). Sternum not ossified.
  - Jumping: Femur and tarsometatarsus near adult size but exhibit webbed (b) to striated (c) textures in the shaft like other long bones and coracoid. Sternum not ossified or extremely porous (a).
  - Fledging: Femur, tarsometatarsus, carpometacarpus, and first phalanx are adult size; humerus and ulna are near adult size. Bones exhibit dispersed striations(d). Sternum ossified with porous carina.

Discussion

- A hatch-year bird can be identified by the texture of the long bones up to 212 days (8 months). The sternum retains immature texture until over 1.5 years of age.
- The longest bones (humerus and ulna in the wing, tibiotarsus in the leg) have the highest growth rate within that limb during the period studied.
- The femur and tarsometatarsus have low growth rates yet appear to reach adult size at a younger age. We infer that the femur and tarsometatarsus grow rapidly during the first 6 weeks after hatching, a period we did not study because of insufficient data.
- It appears that jumping and flying (fledging) behaviors are not performed until the leg (for jumping) and wing (for flying) are at or near adult size, although bone surface textures may not yet be adult.
- We studied individuals that died near the extremes of the range for the fledging period (136 and 184 days), but none that died within it. Our results indicate significant change during this time, including complete fusion of the elements of the carpometacarpus and a change in texture in the sternal plate from porous to smooth.

Acknowledgments and references

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