Ma e a ca M de f A e d c a B e G Ga c . - ed G

Ja e L. Ha a d,[1]* S a de e M. He ,[2] J C. Ba ,[3] a d S ee a L. L [2]

[1]Biology Department, Andrews University, Berrien Springs, Michigan 49104
[2]Department of Mathematics, Andrews University, Berrien Springs, Michigan 49104
[3]Physical Therapy Department, Andrews University, Berrien Springs, Michigan 49104

ABSTRACT De el me f l c m ac i i . P c - cial i e a d . I bi d , h de el me lead diffe e f c i f hi dlimb a d f elimb . The eme - ge ce f alki g a d i g a e diffe e c m le beha i a e l eek af e ha chi g ide a i e e i g ca e d i a imal de el me . We mea - ed he dia h eal le g h a d mid haf diame e f h ee i g b e (h me , l a, a d ca me aca) a d h ee leg b e (fem , ibi a , a d a me a- a) f 79 j e ile (age 0 42 da) a d 13 ad l gla c - i ged g l (Larus glaucescens), a emi ec - cial ecie . F m a i e f i e al e a i e ma hema i- cal m de , e ed i f ma i - he e ic c i e ia de e mi e he be m del) f le g h a d diame e f each b e a a f c i f age; ha , e de e mi ed he m del) ha b ai ed he be ade ff be ee he mi imi ed m f a ed e id a a d he mbe f a ame e ed he m del. The Ja chek a d H lli g III m de be de c ibed b e g h, i h a lea e f he e m de ielding a R^2 0.94 f e e dime i e ce a me a a diame e (R^2 = 0.87). We ed he be g h m de c c acc a e all me ic c m a f he b e . Ea l ma imal ab l e g h a e cha ac e i e he h me , fem , a d a me a a , b e ha a me ad l - e - f c i ela i el ea l d i g j e ile de el - me . Leg b e le g h e hibi m e a id b le a - ai ed ela i e g h ha i g b e le g h . Wi g b e diame e a e i i iall malle ha leg b e diam- e e , al h gh h ela i hi f e e ed b edgi g. Wi g b e a d he fem a ach ad l le g h b edg- i g b c i e i c ea e i diame e a edgi g; he ibi a a d a me a a a ach b h ad l le g h a d diame e b edgi g. I h , he a e f b e g h i h emi ec cial ecie e ec he cha gi g beha i al eed f he de el i g ga f m.
J. M h l. 000:000 000, 2008.

dic ed b e i e (le g h diame e) i a chick f age t, a d K,
a, b, c, > 0 a e a ame e be e ima ed f m da a. K he
a m ic (ad l) b e i e, b a, b, c

$$
{}_0F_1\ v; z \quad \sum_{j\ 0}^{\infty} \left(\frac{z^j}{j!\ \ {}^{j}_{k\ 0}\ v\quad k} \right.
$$

$$
1 \quad \frac{z}{v} \quad \frac{z^2}{2!v\ v\quad 1} \quad \frac{z^3}{3!v\ v\quad 1\ \ v\quad 2} \qquad 13
$$

ῆ he ca᾽e, ela i e g h a e᾽ ide m e ea᾽ able be ee -b e g h c m a ῆ ᾽. A ela i e g h a e ῆ de e mi ed b di idi g he ab᾽ l e g h a e b he c e ᾽i e f he b e, ha ῆ (df/dt)/f(t). The ela i e g h a e ῆ he g h a e e cm f b e, a d ha᾽ i᾽ f cm/da /cm, ha ῆ, 1/da . Th ᾽, if b e᾽ ha e he᾽ame ab᾽ l e g h a e, he he l ge b e ha᾽ he᾽malle ela i e g h a e; a d if b e᾽ ha e he᾽ame ela i e g h a e, he he l ge b e ha᾽ he la ge ab᾽ l e g h a e. The a ea de he ela i e g h a e c e be ee age 0 a d age τ e e᾽e ᾽ he ela i e le g h (diame e) f he b e a age τ, a d ῆ gi e b

$$\int_0^{\tau} \frac{1}{f\ t}$$

e e ed (Fig. 4A). M e e , ela i e g h c e f he l a a d ca me aca a e e- dic ed cl el e emble e a he . A imila ela i e g h a e edic ed f i g b e diame e , al h gh he c - e ime la e (Fig. 4C). Am g he leg b e , he fem e- dic ed be ela i el l ge d i g he eek a d a half, a hich ime he ibi a ake he lead (Fig. 4B). The diame e f he fem e- dic ed be ela i el la ge ha ha f he ibi - a d i g he a d e half eek (Fig. 4D).

The fem edic ed a ach ela i e ma - im m le g h bef e he a me a a , al h gh ela i e g h c e f he b e e emble e a he (Fig. 4B). I c a , he a me- a diame e edic ed g i g a ab 18 da , hile he fem diame e c i e g (Fig. 4D).

The ela i e g h f he h me diame e al a e ceed ha f le g h (Fig. 4E). ela i e g h f he l a a d ca me aca diame e edic ed e ceed ha f he le g h il da 16, he he i a i e e ed (Fig. 4G,I). F he leg b e , ela i e g h i le g h e ceed ela i e g h i diame e h gh e- edg- i g de el me (Fig. 4F,H,J).

D i g a al de el me , he ibi a edic ed g a ima el e e ime i a al le g h (Table 1; c m a e K a d S_0), he ea he fem , a me a a , a d h me g l ab f ime hei i i ial le g h . The l a a d ca me aca g ab i e ime hei a al le g h . Th , he leg e e ie - ce le a al g h ha he i g. A i ec i f he K al e i Table 1 h ha he fem make ela i el le c ib i (25%) al leg le g h ha d e he h me (36%)

al i g le g h. A c m a f j e ile g h
edic i /da a a d ad l da a i Fig e 1 a d 2
h ha he b e f he i g, a ell a he fe-

m deP (ΔAIC =

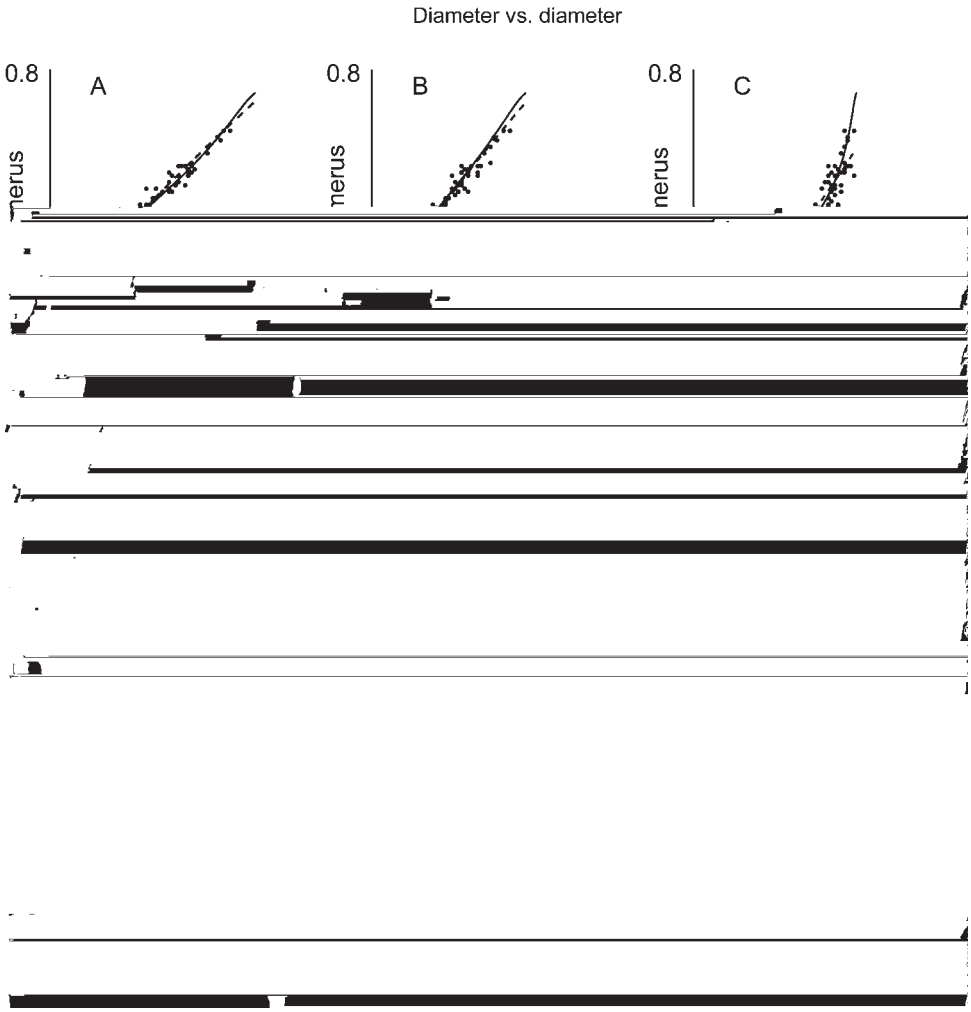

Fig. 6. All me ic ela i ᵓ f ᵓelec ed ai ᵓ f b e diame e ᵓ i Larus glaucescens. See Fig e 4 f de aiP h i e e each g a h.

(m del 9), P am g he be ᵓ m deP f b h he le g h a d diame e f each f he ᵓ i b e ᵓ, he l m del f hich hP P e. B h he Ja - ᵓ chek a d H lli g III m deP de ᵓ c ibe ᵓ igm idal g h, hich i l e ᵓ a i i ial ha ᵓ e f e - e ial i c ea ᵓ e i ch d c e mi ᵓ P a d/ h - e h (b e le g h) a d e i ᵓ ial g h a d calci ca i (b e diame e), f ll ed b a ha ᵓ e f dimi P hi g g h ha leadP g h e mi- a i . The ma imal ab ᵓ l e g h a e cc ᵓ a a ime ha c e ᵓ dP i h he i ec i i f he g h c e (a ᵓ, Fig ᵓ. 1,2).

The i ec i i cc ᵓ ea l i g h f he h me ᵓ, hich ide ᵓ ea l ᵓ a d m ᵓ cle a achme ᵓ f he a idl el ga i g i g, a d i g h f he fem a d a ᵓ me a a ᵓ ᵓ, hich ide ea l e e ᵓ ial l c m ᵓ f he ᵓemi ec cial j e ile. C e ᵓ el, hP i cc ᵓ ela i el la e i g h f he l a a d ca me aca ᵓ, hich a e a ch ed he i- ma a d ᵓ ec da igh fea he ᵓ, e ᵓ ec i el, ha bec me f c i al l a edgi g. I ᵓ h , ea l ma imal ab ᵓ l e g h a e ᵓ cha ac- e i e b e ᵓ ha a ᵓ ᵓ me ad l- e beha i al f c i ali ela i el ea l d i g j e ile de el me .

Rela i e diffe e ce ᵓ i b e dime ᵓ i ᵓ i diffe - e l ᵓ i ed ga P m ᵓ e e dP c ᵓᵓ ed b Galile i he ᵓ e e ee h ce (Galilei, 1638 [1914]). Rel- a i e g h c e ᵓ f b e dime ᵓ i ᵓ ide i ᵓ igh i g h i ela i i ial ᵓ i e. ThP all ᵓ f a "fai " c m a P be ee a i ᵓ b e ᵓ. If all a ᵓ f a 1-da - ld ha chli g - ceeded g a he ᵓ ame ela i e a e, a i di id- al ha a ᵓ 44-da ᵓ ld, he a e age age a edg- i g, ld e ai he i ᵓ i e hibi ed a ᵓ a ha chli g, al h gh i ld be m ch la ge , m e a k ad, a d able . C m a P ᵓ am g ela i e g h c e ᵓ f b d a ᵓ all f a a ᵓ ᵓ e ᵓ me f h le-b d m h ge e ᵓ P.

M ᵓ i e e ᵓ i g i hP ega d P he ela i e g h f i g a d leg b e le g hᵓ, e ᵓ ec i el.

The hatchling humerus immediately functions to support the entire wing, which lies folded against the side of the body and attached to the body at a single point. GeCon this supporteCo function, as well as rapid growth of the nascent but all-important pectoralis (”ight) muscle already attached to this bone, humeral growth dominates forelimb development for the “rst 2 weeks. Beginning in the

b e . Chick begi alk i hi a da f ha ch-
i g, he ea he igh cc ab 6 eek
la e ; he g h a e h e ec he dif-
fe i g l c m ge ie . N abl , b h ibi -
a al a d a me a a al diame e achie e
ea l achie e ad l i e ell bef e edgi g,
al h gh he c i e g i le g h.

Al h gh i g b e diame e a e i i iall
malle ha leg b e diame e , hi ela i hi

De B, M h lla d PL, Sc JM. 1991. E ima i f g h a d e i c i a ame e f e da ge ed ecie . Ec l M g 61:115 143.
Di e dahl L, K ame G. 1957. Ube g βe abha gige A de - ge K e i e bei M e (Larus ridibundus. L. canus, L. argentatus, L. marinus). J O i h l 98:282 312.
D EH, B bi IL. 1980. Age eci c cha ge i he maj b d c m e a d cal ic al e f he i g g ll chick . C d 82:398 401.
El e KD, Pa e S. 1979. Agi g g he i g g l f m mea eme f b d a . Bi d Ba d 50:49 55.
Galilei G. 1638 [1914]. Dial g e C ce i g T Ne Scie - ce . Ne Y k: Macmilla .328 . T a la ed f m he I alia a d La i i E gli h b H. C e a d A. de Sal i .
Gille U, Sal m FV. 1995. B e g h i d ck h gh ma hema ical m del i h ecial efe e ce he Ja chek g h c e. G h De el Agi g 59:207 214.
Gille U, Sal m FV. 1999. G h f d ck bil . C d 101:710 713.
Gille U, Zache F, Sal m FV. 2000. B ai , e e, a d k ll g h i emb ic gee e. C d 102:676 79.
Gillila d SG, A k e CD. 1992. E ima i g age f g bi d i h a m l i a ia e mea e f b d i e. A k 109:444 450.
G m e B. 1825. O he a e f he f c i e e i e f he la f h ma m ali , a d a e m de f de e mi i g he al e f li e c e ge cie . Phil T a R S c 182:513 585.
Hall R. 2000. A Ma hema ical M del f L gi di al B e G h. U bli hed Ma e The , C Ch i C l- lege, U i e i f O f d. 33 .
Ha a d JL, Ve beek NA. 2008. Gla c - i ged G ll (La gla ce ce). I : P le A, edi . Bi d f N h Ame ica O li e. I haca, NY: C ell Lab a f O i h l g. R e ie ed f m h ://b a.bi d .c ell.ed / ecie /059.
He SM, De B, Ha a d JL, C hi g JM, Gal ha JG. 2007. P edic i g he d amic f a imal beha i i eld la i . A im Beha 74:103 110.
H lli g CS. 1959. S me cha ac e ic f im le e f eda- i a d a a i m. Ca E m l 91:385 398.
Jame -Vei ch E, B h ES. 1954. Beha i a d Life Hi f he Gla c -Wi ged G ll. Walla Walla C llege P blica i f he De a me f Bi l gical Scie ce a d Bi l gical S a- i , N . 12.
Ja chek A. 1957. Da eak i ki e che G dge e d ei e Be ieh ge m Wach m - d E ag ge e . S a V ch 10:25 37.
Kl ma M. 1965. E al a i f he -called kele m me h d, em l ed i i e iga i f g h all me i bi d . Z M h l Ok l g Tie e 55:250 258.
Li e e BC, S e W. 1992. M h me ic c m a f kel- e f he e e g ebe c m le Aechmophorus f he U i ed S a e a d Ca ada. C d 94:668 679.
Me ie K. 1959. Die All me ie de V gel gel . Z W Z l 161:444 482.
M e L, de Ma ge ie E, Ca a e J, de ic le A, C b J. 2005. R ela i hi be ee b e g h a e a d he hick- e f calci ed ca ilage i he l g b e f he Gall a - e ae (A e). J A a 206:445 452.
OP DM, Nel LS. 1975. The Nelde -Mead im le ce- d e f f c i mi imi a i . Tech me ic 17:45 51.
Pa J. 1975. A ch ha chi g a d chick m ali i he he i g g ll, Larus argentatus. C d 78:481 492.
Peek JM, De B, He he T. 2002. P edic i g la i e d f m le dee . J Wildlife Ma age 66:729 736.
P e WH, Fla e BP, Te k k SA, Ve e li g WT. 1986. N me ical eci e : The A f Scie i c C m i g. Cam- b idge: Camb idge U i e i . P e . 848 .
P ice JS, O aj bi BO, ell GG. 1994. The cell bi l g f b e g h. E J Cli N 48:S131 S149.
Sal e DW, La ki GJ. 1990. Im ac f c hi feedi g cl ch a d hi d-egg i e i gla c - i ged g l . A im Beha 39:1149 1162.
Shimi K, I a e K. 1981. U if ml mi im m a ia ce bia ed e ima i i l g mal a d ela ed di ib i . C mm S a A The a d Me h d 10:1127 1147.
Sch l ZM. 1951. G h i he gla c - i ged g ll. Pa 1. M ele 32:35 42.
Sch l ZM. 1986. O he Wi g f he Wild Wi d, Occa Pa #21. Belli gham, WA: Ce e f Paci c N h e S die .
Smi h JE, Diem KL. 1972. G h a d de el me f g