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**SUPPLEMENTARY DATA**

for

New fossil penguins (Aves, Sphenisciformes) from the Oligocene of New Zealand reveal

the skeletal plan of stem penguins

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## MORPHOLOGICAL CHARACTER DESCRIPTIONS

Citations for the first use of each character in a phylogenetic context are indicated with abbreviations as follows. A = Ando, 2007; AH = Acosta Hospitaleche et al., 2007; BG = Bertelli and Giannini 2005; C = Clarke et al., 2007; CL = Clarke et al., 2010; GB = Giannini and Bertelli 2004; K = Ksepka et al., 2006; KC = Ksepka and Clarke, 2010; KT = Ksepka and Thomas, in press, OH = O'Hara, 1986. Characters 229-245 are new to the present study.

A nexus file of the combined phylogenetic dataset is available at the Journal of Vertebrate Paleontology website or from Dryad (<http://datadryad.org/>).

### Integument

- (1) Tip of mandibular rhamphotheca, profile in lateral view: pointed (0); slightly truncated (1); strongly truncated, squared off (2); truncated but with a rounded margin (e.g., as seen in Procellariiformes) (3). (GB1)
- (2) Longitudinal grooves on the base of the culmen: absent (0); present (1). (GB2)
- (3) Longitudinal grooves on the base of latericorn and ramicorn: absent (0); present (1). (GB3)
- (4) Feathering of maxilla, extent: totally unfeathered (0); slightly feathered, less than half the length of maxilla (1); feathering that reaches half the length of maxilla (2); feathering surpassing half the length of maxilla (3). Ordered
- (5) Ramicorn, inner groove at tip: absent (0); present and single (1); present and double (2). Ordered. (GB5)
- (6) Orange or pink plate on ramicorn: absent (0); present (1). (GB6)
- (7) Plates of rhamphotheca, inflated aspect: absent (0); present (1). (GB7)
- (8) Gape: not fleshy (0); margin narrowly fleshy (1); margin markedly fleshy (2). Ordered. (GB8)
- (9) Ramicorn color pattern: black (0); red (1); pink (2); yellow (3); orange (4); green (5); blue (6). (GB9)
- (10) Latericorn and ramicorn, light distal mark: absent (0); present (1). (GB10)
- (11) Latericorn color: black (0); red (1); orange (2); yellow (3); green (4); blue (5). (GB11)
- (12) Culminicorn color: black (0); red (1); orange (2). (GB12)
- (13) Maxillary and mandibular unguis, color: black (0); red (1); yellow (2); green (3); blue-gray (4). (GB13)
- (14) Ramicorn, ultraviolet color spot (reflectance peak): absent (0); present (1). (KC14)
- (15) Bill of downy chick, color: dark (0); reddish (1); pale, variably horn to yellow (2); blue (3). (GB14)
- (16) Bill of immature, color: dark (0); bicolored red and black (1); red (2); yellow (3); gray (4). (GB15)
- (17) External nares: present (0); absent (1). (GB17)
- (18) Nostril tubes: absent in adult (0); present in adult (1). (GB16)
- (19) Nostril tubes: absent in hatchling (0); present in hatchling (1). (GB16)
- (20) External nares: well-separated (0); fused at midline (1). (KC19)

- (21) Iris color: dark (0); reddish-brown (1); claret red (2); yellow (3); white (4); silvery gray (5). (GB18)
- (22) Scale-like feathers: absent (0); present (1). (GB19)
- (23) Rachis of contour feathers: cylindrical (0); flat and broad (1). (GB20)
- (24) Rectrices: form a functional fan (0); do not form a fan (1). (GB21)
- (25) Remiges: differentiated from contour feathers (0); indistinct from contour feathers (1). (GB22)
- (26) Apterias: present (0); absent (1). (GB23)
- (27) Molt of contour feathers: gradual (0); simultaneous (1). (GB24)
- (28) Yellow pigmentation in crown feathers (pileum): absent (0); present (1). (GB25)
- (29) Head plumes (cristae pennae): absent (0); present (1). (GB26)
- (30) Head plumes (cristae pennae), aspect: compact (0); sparse (1). (GB27)
- (31) Head plumes (cristae pennae), aspect: directed dorsally (0); directed posteriorly, not drooping (1); directed posteriorly, drooping (2). (GB28)
- (32) Head plumes (cristae pennae), position of origin: at base of bill close to gape (0); on the recess between latericorn and culminicorn (1); on forehead (2). Ordered. (GB29)
- (33) Head plumes (cristae pennae), color: yellow (0); orange (1). (GB30)
- (34) Nape (occiput), crest development: absent (0); slight (1); distinct (2). Ordered. (GB31)
- (35) Periocular area. color: black (0); white (1); yellow (2); bluish gray (3). (GB32)
- (36) Fleshy eyering: absent (0); present (1). (GB33)
- (37) White eyering: absent (0); present (1). (GB34)
- (38) White eyebrow (supercilium): absent (0); narrow, from postocular area (1); narrow, from preocular area (2); wide, from preocular area (3). Ordered. (GB35)
- (39) Loreal area (lorum), aspect: feathered (0); with spot of bare skin in the recess between latericorn and culminicorn (1); with spot of bare skin contacting eye (2); bare skin extending to the base of bill (3). Ordered. (GB36)
- (40) Auricular patch (regio auricularis): absent (0); present (1). (GB37)
- (41) Throat pattern: black (0); white (1); yellow (2); irregularly streaked (3); with chinstrap (4). (GB38)
- (42) Collar: absent (0); at most slight notch present (1); present, diffusely demarcated (2); black, strongly demarcated (3). Ordered. (GB39)
- (43) Breast, golden in color: absent (0); present (1). (GB40)
- (44) Dorsum color: black (0); dark bluish gray (1); light bluish gray (2). (GB41)
- (45) Black marginal edge of dorsum between lateral collar and axillary patch, contrasting with dorsum: absent (0); present (1). (GB42)
- (46) Black dots irregularly distributed over white belly: absent (0); present (1). (GB43)
- (47) Flanks, dark lateral band reaching the breast: absent (0); present (1). (GB44)
- (48) Distinct dark axillary patch of triangular shape: absent (0); present (1). (GB45)
- (49) Flanks, extent of dorsal dark cover into the leg: incomplete, not reaching tarsus (0); complete, reaching tarsus (1). (GB46)
- (50) Rump: indistinct in color from dorsum (0); distinct white patch (1). (GB47)
- (51) Tail length: short, the quills barely emerge from the rump (0); quills distinctly developed (1). (GB48)
- (52) Outer rectrices, color: same as inner rectrices (0); lighter than inner rectrices (1). (GB49)

- (53) White line connecting leading edge of flipper with white belly: absent (0); present (1). (GB50)
- (54) Flipper, upperside, light notch at base: absent (0); present (1). (GB51)
- (55) Leading edge of flipper, pattern of upperside: black (0); white (1). (GB52)
- (56) Leading edge of flipper, pattern of underside: white (0); incompletely dark (1); completely dark and wide (2). (GB53)
- (57) Flipper, underside, dark elbow patch: absent (0); present (1). (GB54)
- (58) Flipper, underside, tip pattern: immaculate (0); patchy, in variable extent (1); small circular dot present (2). (GB55)
- (59) Immature plumage, white eyebrow (supercilium): absent (0); or present (1). (GB56)
- (60) Immature plumage, throat pattern (jugulum): black (0); or mottled (1); or white (2); or brown (3). (GB57)
- (61) Immature plumage, flanks, dark lateral band: absent (0); or present (1). (GB58)
- (62) Chicks hatch almost naked: no (0); yes (1). (GB59)
- (63) Dominant color pattern of first down: pale gray (0); distinctly brown (1); bicolored, dark above and whitish below (2); uniformly blackish gray (3). (GB 60)
- (64) Dominant color pattern of second down: pale grey (0); distinctly brown (1); bicolored, dark above and whitish below (2); uniformly blackish gray (3). (GB61)
- (65) Chick, second down, collar: absent (0); present (1). (GB62)
- (66) Feet, dorsal color: dark (0); pink (1); orange (2); white-flesh (3); blue (4). (GB63)
- (67) Feet, soles distinctly darker than dorsal surface: absent (0); present (1). (GB64)
- (68) Feet, unguis digiti: flat (0); compressed (1). (BG65)

#### Reproductive Biology

- (69) Clutch size: two eggs (0); one egg (1). (GB65)
- (70) Incubatory sac: absent (0); present (1). (GB66)
- (71) Nest: no nest, incubation over the feet (0); nest placed underground, either burrowed in sand or inside natural hollow or crack (1); open nest, a shallow depression on bare ground or in midst of vegetation (2). (GB67)
- (72) Size of first egg relative to the second egg: similar (0); dissimilar, first smaller (1); dissimilar, second smaller (2). (GB68)
- (73) Crèche: absent (0); small, 3-6 birds (1); formed by dozens to hundreds of immatures (2). (GB69)
- (74) Eggs, shape: oval (0); conical (1); spherical (2). (BG71)
- (75) Ecstatic display: absent (0); present (1). (BG72)

#### Osteology

- (76) Premaxilla, tip (rostrum maxillare): pointed (0); weakly hooked (1); strongly hooked (2). Ordered. (GB0)
- (77) Internarial bar (pila supranasalis) shape in cross section: suboval (0); inverted U-shape (1). (C75)
- (78) Internarial bar (pila supranasalis), profile in lateral view: dorsal edge curves smoothly to tip of beak (0); pronounced step in dorsal edge (1). (KC78)
- (79) Basioccipital, subcondylar fossa (fossa subcondylaris): absent or shallow (0); deep (1). (BG73)
- (80) Supraoccipital, paired grooves for the exit of v. occipitalis externae (sulcus vena occipitalis externae): poorly developed (0); deeply excavated (1). (BG74)

- (81) Frontal, shelf of bone bounding salt-gland fossa (fossa glandulae nasalis) laterally: absent (0); present (1). (OH10)
- (82) Squamosal, temporal fossa (fossa temporalis), size: fossae separated by considerable wide surface (at least the width of the cerebellar prominence) (0); more extensive, fossae meeting or nearly meeting at midline of the skull (1). (BG76)
- (83) Squamosal, temporal fossa (fossa temporalis), depth of caudal region: flat (0); shallow (1); greatly deepened (2). Ordered. (BG77)
- (84) Squamosal, development of the opening that transmits the a. ophthalmica externa in the caudoventral area of the temporal fossa (near nuchal crest): small or vestigial (0); well-developed (1). (BG78)
- (85) Orbit, fonticuli orbitocraniales: small or vestigial (0); broad and conspicuous openings (1). (BG79)
- (86) Ectethmoid: absent (0); weakly developed, widely separate from the lacrimal (1); well developed, contacting or fused to the lacrimal (2). (BG80)
- (87) Lacrimal, descending process: unperforated (0); perforated (1). (OH11)
- (88) Lacrimal: reduced, concealed in dorsal view (0); small portion exposed in dorsal view (1); well-exposed in dorsal view (2). Ordered. (BG82)
- (89) Lacrimal, contact with frontal: suture (0); fusion (1). (KT89)
- (90) Lacrimal, dorsal process: closely applied to the nasal (0); rostral arm of dorsal process separated from the nasal by a slit-like rostro-caudally elongate opening (1). This character originally referenced the frontal, however the actual separation occurs along the nasal-lacrimal contact. (BG83)
- (91) Nasal cavity, external naris (cavum nasi, apertura nasi ossea), caudal margin: extended caudal to the rostral margin of the hiatus orbitonasalis (0); not extended caudal to the rostral margin of the hiatus orbitonasalis (1). (OH5)
- (92) Nasal cavity, internarial bar (pila supranasalis): wide throughout its length (0); slender, slightly constricted laterally (1). (OH6)
- (93) Basitemporal plate (lamina parasphenoidalis), dorsoventral position with respect to the occipital condyle: ventral to the level of the condyle (0); at the level of the condyle (1); dorsal to the level of the condyle, surface depressed (2). Ordered. (BG86)
- (94) Basipterygoid process (processus basipterygoideus): absent (0); vestigial or poorly developed (1); well developed (2). Ordered. (BG87)
- (95) Eustachian tubes (tuba auditiva): open or very little bony covering near the caudal end of the tube (0); mostly enclosed by bone (1). (BG88)
- (96) Pterygoid, shape: elongated (0); slight lateral expansion of rostral end (1) rostral end broad, pterygoid sub-triangular (2). Ordered. (BG89)
- (97) Palatine, lamella choanalis: curved and smooth plate, slightly differentiated from main palatine blade (0); ridged, distinct from main blade by a low keel (1); extended vertically ventrally forming the crista ventralis (2). Ordered. (BG90)
- (98) Vomer: laterally compressed, vertical laminae and free from palatines (0); horizontally flattened laminae and ankylosed with palatines (1). (BG91)
- (99) Facial foramen (foramen n. facialis): absent (0); present (1). (BG92)
- (100) Jugal arch, bar shape in lateral view: straight (0); slightly curved (1); ventrally bowed (2); strongly curved, sigmoid shape (3). Ordered. (BG93)

- (101) Jugal arch, dorsal process: absent (0); present (1). This pointed process is located on the caudal end of the jugal, adjacent to the condyle for articulation with the quadrate. (BG94)
- (102) Premaxilla, frontal process, naso-premaxillary suture: visible (0); obliterated (1). (BG95)
- (103) Quadrate, relative lengths of otic and orbital processes (processus oticus and processus orbitalis): otic process longest (0); orbital process longest (1). (KC102)
- (104) Quadrate, otic process (processus oticus), rostral border, tubercle for m. adductor mandibulae externus, pars profunda: absent (0); present, as a ridge (1); presence, as a tubercle (2). (BG96)
- (105) Quadrate, otic process (processus oticus), rostral border, tubercle for m. adductor mandibulae externus, pars profunda: contiguous with squamosal capitulum (0); separated from squamosal capitulum (1). (KC014)
- (106) Tomial edge (crista tomialis): plane of tomial edge approximately at the level of the basitemporal plate (lamina parasphenoidalis) (0); dorsal to the level of the basitemporal plate (1). (BG97)
- (107) Mandible, symphysis: extensive bony connection (0); short terminal bony connection (1). (C101)
- (108) Mandible, posteriorly projected midline spur from dentary underlying symphysis: absent (0); present (1). (KC107)
- (109) Mandible, coronoid process (processus coronoideus), position on the dorsal margin of the mandible with respect to caudal mandibular fenestra (fenestra mandibulae caudalis): markedly rostral (0); on the rostral end of the fenestra (1); caudal to fenestra (2). Ordered. (BG98)
- (110) Mandible, rostral fenestra (fenestra mandibulae rostralis): imperforate or small opening (0); large opening (1). (OH8)
- (111) Mandible, caudal fenestra (fenestra mandibulae caudalis): open, can be seen through from the medial or lateral aspects (0); nearly or completely concealed by the splenial medially (i.e., fenestra not visible in the medial aspect) (1). (OH9)
- (112) Mandible, mandibular ramus: depth subequal over entire ramus (0); pronounced deepening at midpoint (1). (BG101)
- (113) Mandible, mandibular ramus: essentially straight or gently sloping (0); pronounced ventral deflection near midpoint (1). (KC112)
- (114) Mandible, dentary, length of dorsal edge relative to mandibular ramus length in lateral view: markedly more than half the length of ramus (0); approximately half the length of ramus (1). (BG103)
- (115) Mandible, articular, medial process (processus medialis): not hooked (0); hooked (1). (BG104)
- (116) Mandible, angular, aspect in dorsal view: sharply truncated caudally (0); caudally projected, forming retroarticular process (processus retroarticularis) (1). (BG106)
- (117) Mandible, angular, retroarticular process (processus retroarticularis), aspect in dorsal view in relation to the articular area for the quadrate between the lateral and medial condyles (condylus lateralis and condylus medialis): broad, approximately equal to the articular area (0); moderately long, narrower than the articular area (1); very long, longer and narrower than the articular area (2). Ordered. (BG105)

- (118) Mandible, medial emargination between medial and retroarticular processes (processus retroarticularis and processus medialis): absent (0); weak concavity (1); strong concavity (2). Ordered. (K108)
- (119) Atlas, processus ventralis: absent or slightly developed (0); well developed, high and prominent ridge on the dorsal surface of the arcus atlantis (1). (BG108)
- (120) Transition to free cervicothoracic ribs begins at: 13th cervical vertebrae: (0); 14th cervical vertebrae (1); 15th cervical vertebrae (2). Ordered. (BG109)
- (121) Cervical vertebrae, transverse process (processus transversus) in last five cervical vertebrae: not elongated laterally (0); greatly elongated laterally (1). (BG111)
- (122) Thoracic vertebrae, posterior-most vertebrae: heterocoelous (0); weakly opisthocoelous; (1); strongly opisthocoelous (2). Ordered. (K114)
- (123) Thoracic vertebrae, deep excavation on lateral face of posterior thoracic vertebrae: absent (0); present (1). (KC124)
- (124) Synsacrum, number of incorporated vertebrae: nine (0); eleven (1); twelve (2); thirteen (3); fourteen (4), fifteen or more (5). (C117)
- (125) Synsacrum, height of crista synsacri between acetabula: flat or weakly projected (0); strongly projected (1). (KC126)
- (126) Caudal vertebrae: seven (0), eight (1), nine (2). Ordered. (BG113)
- (127) Thoracic ribs, uncinat processes (costae, processus uncinati): elongate, narrow (0), wide at base, spatulate (1), extremely wide at base (2). Reference to bifurcation of the processes in state (2) from previous formulations of this character has been removed, as bifurcation shows individual variation in all species of *Pygoscelis*. (BG114)
- (128) Thoracic ribs, uncinat processes (costae, processus uncinati): fused to ribs (0); unfused (1) (KC129)
- (129) Sternum, external spine (spina externa rostri): absent (0); present (1). (OH13)
- (130) Sternum, facies articularis furculae projects as a distinctive process: absent (0); present (1). (BG116)
- (131) Sternum, articular facets for coracoids (sulcus articularis coracoideus): meet or overlap one another at midline (0); separated by wide non-articulatary surface (1). (C122)
- (132) Sternum, labrum internum: continues as sharp ridge onto the base of the spina externa (0); fades away without continuing onto the base (1). (C123)
- (133) Sternum, caudal incisurae: none (0); two (1); four (2). (KC133)
- (134) Furcula, hypocleidium (apophysis furculae): absent or low knob-like process (0); long, blade-like process (1). (BG117)
- (135) Furcula, ramus: sub-ovoid in cross-section at omal end (0); mediolaterally flattened and craniocaudally expanded at omal end (1). (CL218)
- (136) Scapula, acromion: craniodorsally directed, nearly parallel to long axis of scapular shaft at apex (0); forms a blunt triangular projection with apex directed approximately at 45 degree angle from long axis of scapular shaft (1); narrow and tapering, apex omally directed (2); narrow and tapering, apex directed at a right angle to scapular shaft (3). (CL223)
- (137) Scapula, blade, caudal half (corpus scapulae, extremitas caudalis): blade-like (0); slightly expanded (1); broadly expanded, paddle-shaped (2). (BG118)
- (138) Coracoid, length: shorter than humerus (0); greatly elongated, longer than humerus (1). (KC137)

- (139) Coracoid, scapular cotyle (*scapula cotylaris*): deep and socket-like (0); shallow depression (1). (CL217)
- (140) Coracoid, medial margin, coracoidal fenestra: complete (0); incomplete (1); absent (2). (OH14)
- (141) Coracoid, foramen nervi supracoracoidei: absent (0), present (1). Mayr (2005) cited ontogenetic evidence that this foramen is not homologous to the coracoidal fenestra of penguins. (K122)
- (142) Coracoid, sternal margin (*extremitas sternalis coracoidei*): greatly expanded (0); moderate expansion (1). (BG120)
- (143) Coracoid, profile of the sternal margin (*extremitas sternalis coracoidei*) in ventral view: convex (0) concave (1), flat (2). (K124)
- (144) Coracoid, lateral process (*processus lateralis*): absent or highly reduced (0); well-developed (1).
- (145) Forelimb elements: subcircular in cross section (0); flattened (1). (BG121)
- (146) Humerus, head: very developed and reniform, continuous with tuberculum dorsale: absent (0); present (1). (BG122)
- (147) Humerus, head in posterior view: apex of humeral head located near midline (0); humeral head slopes so that apex of humeral head located ventrally (1). (C132)
- (148) Humerus, incisura capitis: essentially confluent with sulcus transversus (0); clearly separated from sulcus transversus (1). (K127)
- (149) Humerus, capital incisure: extends to secondary tricipital fossa (0); separated from secondary tricipital fossa (1). (CL222)
- (150) Humerus, pit for ligament insertion on proximal surface adjacent to head: absent or very shallow (0); deep (1). (K128)
- (151) Humerus, orientation of *intumescencia humeri* and *tuberculum ventrale*: *intumescencia* projects ventrally from shaft, tuberculum oriented caudally (0); *intumescencia* projects ventrally from shaft, tuberculum oriented ventrally (1); *intumescencia* projected more cranioventrally (so as to be partially obscured in posterior view), tuberculum oriented cranioventrally (2). (K129)
- (152) Humerus, proximal margin of tricipital fossa (*fossa tricipitalis*): weak projection (0); projects so as to be well-exposed in proximal view (1). (K135)
- (153) Humerus, proximal border of tricipital fossa in ventral view: concave proximal margin (0), straight border (1). (KT153).
- (154) Humerus, tricipital fossa (*fossa tricipitalis*), aspect: small with penetrating pneumatic foramina (0); moderate fossa without pneumatic foramen (1); deep fossa without pneumatic foramen (2). (BG123)
- (155) Humerus, tricipital fossa (*fossa tricipitalis*): single (0); bipartite (1). (BG 124)
- (156) Humerus, deltoid crest, *impressio m. pectoralis*: superficial poorly-defined groove (0); shallow, well-defined oblong fossa (1); deep, well-defined oblong fossa (2). Ordered (BG125)
- (157) Humerus, *impressio insertii m. supracoracoideus*: small, semicircular scar (0); greatly elongated with long axis sub-parallel to main axis of humeral shaft (1). (K133)
- (158) Humerus, *impressio insertii m. supracoracoideus* and *m. latissimus dorsi*: separated by a wide gap (0); separated by a moderate gap (1); separated by small gap or confluent (2). Ordered. (K134)



- (159) Humerus, coracobrachialis caudalis scar: clearly separated from head (0); scar contacts distal margin of head (1). (CL219)
- (160) Humerus, coracobrachialis caudal scar: deeply depressed, subcircular (0); flat, ovoid, oriented dorsoventrally (1); flat, elongate and oriented obliquely at approximately 45 degree angle to long axis of shaft (2). (CL220)
- (161) Humerus, groove for coracobrachialis nerve: absent or poorly defined (0); sharp, narrow sulcus (1). (CL221)
- (162) Humerus, shaft, dorsoventral width: shaft thins or maintains width distally (0); shaft widens distally (1). (K136)
- (163) Humerus, nutrient foramen (foramen nutricum): situated on ventral face of shaft (0) situated on anterior face of shaft (1). (C143)
- (164) Humerus, anterior face of shaft elongate depression near ventral margin: absent (0); present (1). (C144)
- (165) Humerus, shaft, sigmoid curvature: absent or weak (0); strong (1). (K137)
- (166) Humerus, development of dorsal supracondylar tubercle (processus supracondylar dorsalis): absent (0); compact tubercle (1); elongate process (2); extremely elongate process. (BG126)
- (167) Humerus, demarcation of sulcus scapulotricipitalis: not demarcated (0); passage a well-marked groove (1); development of trochlear ridge for articulation with os sesamoideum m. scapulotricipitis (2). Ordered. (BG127).
- (168) Humerus, posterior trochlear ridge: extends beyond ventral margin of the humeral shaft (0); does not extend beyond the humeral shaft (1). (BG128)
- (169) Humerus, angle between main axis of shaft and tangent of ulnar and radial condyles (condylus dorsalis and condylus ventralis): less than 45° (0); more than 45° (1); nearly 90° (2). (K141)
- (170) Humerus, ulnar condyle (condylus ventralis): condyle projected and rounded (0); condyle flattened (1). (K142)
- (171) Humerus, shelf adjacent to condylus ventralis: large, ratio of condyle width: shelf width >1.3 (0); moderate, ratio of condyle width: shelf width 1.3-2.0 (1); greatly reduced, less than half condyle width (2). Ordered (K143)
- (172) Radius, shaft: narrow (0); broad and flattened (1). (KC166)
- (173) Ulna, olecranon position and shape of posterior ulnar margin: olecranon arises at level of, or proximally surpassing, humeral cotylae (0) olecranon, a tab-like projection slightly distally displaced from cotylae creating a rounded posterior ulnar margin (1) olecranon a tab-like projection slightly distally displaced from cotylae creating a squared posterior margin; (2) posterior margin is a smooth curve, apex located one fourth of length to distal end; (3) posterior margin with a distinct angle, apex located one fourth of length to distal end (4); posterior margin is rounded and tab-like, apex located at the level of proximal end of the ulna (5). (K144)
- (174) Ulna, distinct process extending toward sulcus humerotricipitalis of humerus: absent (0), present (1). (K145)
- (175) Ulnare: U-shaped (0); triangular, fan-shaped wedge (1). (KC169)
- (176) Carpometacarpus, pisiform process (processus pisiformis): well-projected round tubercle (0); reduced to a low ridge (1). (C155)
- (177) Carpometacarpus, distal facet on metacarpal I: absent (0); present (1). (C156)

- (178) Carpometacarpus, metacarpal II, distinct anterior bowing: absent (0); present (1). (C157)
- (179) Carpometacarpus, extension of metacarpals II and III: subequal or III slightly shorter (0); metacarpal III projects markedly distal of metacarpal II. (C158)
- (180) Carpometacarpus, metacarpal III, distal articular surface (facies articularis digitalis major): wedge shaped or broadens anteriorly in distal view (0), slightly depressed ovoid surface (1). (C159)
- (181) Carpometacarpus, extensor process (processus extensorius): present (0); absent (1) (KC175)
- (182) Carpometacarpus, metacarpal II, distal expansion: absent (0); present (1). (KC176)
- (183) Phalanges of manus, phalanx digit III proximal process: absent (0); present (1). (BG130)
- (184) Phalanges of manus, relative length of phalanx III-1 and phalanx II-1 (0); subequal (1). (C161)
- (185) Phalanges of manus, length relative to carpometacarpus: long (0); short (1). (BG131)
- (186) Fusion of ilia to synsacrum: unfused (0); partially fused (1); well-fused (2). Ordered. (K149)
- (187) Pelvis, preacetabular ilia: flat, well-separated (0); approach one another, but do not contact at midline (1); contact at midline forming canalis iliosynsacralis (2) (KC181).
- (188) Pelvis, foramina intervertebralia large, forming wide openings on dorsal surface of pelvis: absent (0); present (1). (KC182)
- (189) Ilium, projected postiliac spine: absent (0); present (1).
- (190) Pelvis, size of foramen ilioischadicum and foramen acetabuli: foramen ilioischadicum smaller or similar in size (0); foramen ilioischadicum larger (1). (OH16)
- (191) Pelvis, fenestra ischiopubica: very wide and closed at its caudal end (0); slit-like and open at its caudal end (1). (BG133)
- (192) Ischium, most caudal extent in relation to postacetabular ilium: ischium shorter than ilium (0); ischium projects slightly beyond the ilium (1); ischium projected far caudal to ilium (2). (BG134)
- (193) Patella: absent, unossified, or a small ossicle (0); present as a large, block-like element (1). (KC187)
- (194) Patella, sulcus m. ambiens: shallow groove (0); deep groove (1); perforated (2). (BG135)
- (195) Tibiotarsus, crista patellaris: greatly enlarged (0); slightly developed (1), greatly elongated (2). (BG136)
- (196) Tibiotarsus, shaft, craniocaudal flattening: weak, midshaft craniocaudal depth greater than 75% mediolateral width (0); strong, midshaft craniocaudal depth equal to or less than 75% mediolateral width (1). (C169)
- (197) Tibiotarsus, notch in distal edge of medial condyle (condylus medialis): present (0); absent (1). (AH38)
- (198) Tibiotarsus, lateral condyle (condylus lateralis) in lateral profile: ovoid (0); subcircular (1). (AH37)
- (199) Tibiotarsus, sulcus extensorius: laterally positioned (0); close to midline (1); medially positioned (2). Variation of this feature in penguins was noted by Clarke et al. (2003). (KC193).

- (200) Tarsometatarsus, elongation index (proximodistal length / mediolateral width at proximal end): slender,  $EI > 3$  (0); shortened,  $2.5 < EI < 3$  (1), greatly shortened  $EI < 2.5$  (2). Values for some Antarctic fossils were obtained from the table of measurements in Myrcha et al. (2002). Ordered. (BG139)
- (201) Tarsometatarsus, medial margin, pronounced convexity: absent (0), present (1). (K157)
- (202) Tarsometatarsus, enclosed hypotarsal canals (canales hypotarsi): present (0); absent (1). (BG141)
- (203) Tarsometatarsus, relative plantar projection of medial and lateral hypotarsal crests: medial crest projects farther than lateral (0); projection of medial and lateral hypotarsal crests subequal (1). (KT203).
- (204) Tarsometatarsus, intermediate hypotarsal crests (crista intermediae hypotarsi): distinct, separated by groove (0); non-distinct (1). (K158)
- (205) Tarsometatarsus, dorsal sulcus between metatarsals II and III (sulcus longitudinalis dorsalis medialis): absent or barely perceptible (0); shallow groove (1); moderate groove (2) deep groove (3). (K159) Ordered.
- (206) Tarsometatarsus, proximal vascular foramina on plantar surface: foramen vasculare proximale mediale present, foramen vasculare proximale laterale absent or vestigial (0); both foramina present (1); foramen vasculare proximale laterale present, foramen vasculare proximale mediale absent or vestigial (2). (K162)
- (207) Tarsometatarsus, opening for medial foramen proximalis vascularis distal to crista medialis hypotarsi: absent (0); present (1). Because both this opening and an additional opening perforating the crista medialis hypotarsi are present in Aptenodytes, they are treated as independent characters. (BG140)
- (208) Tarsometatarsus, medial hypotarsal crest (crista medialis hypotarsi) perforated by opening for the medial foramen proximalis vascularis: absent (0); present (1). (BG139)
- (209) Tarsometatarsus, distal vascular foramen (foramen vasculare distale): present, separated from incisura intertrochlearis lateralis by osseous bridge (0); present, open distally (1); absent (2). Ordered. (K163)
- (210) Tarsometatarsus, os metatarsale IV: distal end projects laterally (0); straight (1), distal end deflected medially (2). (K 160)
- (211) Tarsometatarsus, trochleae in distal view: trochlea metatarsi III and IV aligned in same plane (0); trochlea metatarsi IV displaced dorsally (1). (KT211).

#### Myology

- (212) M. latissimus dorsi, pars cranialis, accessory slip: absent (0); present (1). (BG143)
- (213) M. latissimus dorsi, pars cranialis and pars caudalis: separated (0); fused (1). (BG144)
- (214) M. latissimus dorsi, pars metapatagialis, development: wide (0); intermediate (1); narrow (2). Ordered. (BG145)
- (215) M. serratus profundus, cranial fascicle: absent (0); present (1). (BG146)
- (216) M. deltoideus, pars propatagialis, subdivision in superficial and deep layers: undivided (0); divided (1). (BG147)
- (217) M. deltoideus, pars major: triangular or fan-shaped (0); strap-shaped (1). (BG148)
- (218) M. deltoideus, pars major, caput caudale: short (0); intermediate (1); long (2). Ordered. (BG149)

- (219) *M. deltoideus*, pars minor, origin on the clavicular articulation of the coracoid: absent (0); present (1). (BG150)
- (220) *M. ulnometacarpalis ventralis*: absent (0); present (1). (BG151)
- (221) *M. iliotrochantericus caudalis*: narrow (0); wide (1). (BG152)
- (222) *M. iliofemoralis*, origin: tendinous (0); partially tendinous and partially fleshy (1); totally fleshy (2). Ordered. (BG153)
- (223) *M. flexor perforatus digitis IV*, rami II-III: free (0); fused (1). (BG154)
- (224) *M. flexor perforatus digitis IV*, rami I-IV: free (0); fused (1). (BG155)
- (225) *M. flexor perforatus digitis IV*, insertion of middle rami: on phalanx 3 (0); on phalanx 4 (1). (BG156)
- (226) *M. latissimus dorsi*, pars caudalis, additional origin from dorsal process of vertebrae: absent (0); present (1). (BG157)

#### Other soft tissue

- (227) Oral mucosa (bucca, tunica mucosa oris), buccal papillae group on the medial surface of the lower jaw (ramus mandibularis) at the level of the rictus: small number of rudimentary papillae with no clear arrangement (0); two clear rows of short conical papillae (1); large, elongated papillae with no clear arrangement (2). (BG158)
- (228) Tracheal rings: single (0); bifurcated (1). (KC219)
- (229) Quadrate, processus oticus, caudal margin in lateral view: straight (0); flexed so as to be concave caudally (1). (A9).
- (230) Synsacrum, first incorporated vertebra, position of fovea costalis: caudal to level of processus transversus (0); cranial to level of transverse process (1). This study.
- (231) Synsacrum, ventral surface of first few incorporated vertebrae: rounded or flattened (0); sharp, blade-like ventral margin (1). (A63).
- (232) Pygostyle, shape: tapers to a narrow edge both dorsally and ventrally as in most volant birds (0); triangular in cross-section with a wide, flat ventral margin (1). This study.
- (233) Sternum, orientation of sulcus articularis coracoideus in ventral view: sulci oriented in essentially straight horizontal line (0); sulci directed caudolaterally so as to together form an inverted U shape (1). (A15).
- (234) Sternum, trabecula lateralis projects caudal to main body of sternum: no (0); yes (1). This study.
- (235) Scapula, facies articularis humeralis: rounded, projecting from shaft of scapula (0); compressed and ovoid, projecting from shaft of scapula (1); flattened and nearly merged with shaft of scapula (2). This study.
- (236) Coracoid, facies articularis sternalis, dorsal surface: single facet (0); two facets (1). This study.
- (237) Coracoid, processus acrocoracoideus, region of tuberculum brachiale: craniocaudally compressed (0); craniocaudally expanded, with a large flat surface cranial to tuberculum brachiale (1). (A22)
- (238) Humerus, scar for origin of *m. brachialis*: ovoid fossa on cranial face of humerus at distal end (0); proximodistally elongate scar on dorsal margin of humeral shaft, with diagonally oriented proximal border (1); proximodistally elongate scar on dorsal margin of humeral shaft, with chevron-shaped proximal border (2). (A34).

- (239) Radius, proximally projecting spike-like process at cranial margin: absent (0); present (1). This study.
- (240) Ulna incisura radialis: concave in proximal view, so that the ulna contacts the proximal radius at both its caudal and ventral surfaces (0); obsolete, so radius and ulna abut one another at a nearly flat contact (1). This study.
- (241) Ulnare, distal angle: rounded (0); pointed (1). This character refers to the distal angle in the specialized fan-shaped ulnare of penguins and is considered non-comparable for outgroup taxa. This study.
- (242) Tibiotarsus, medial margin in distal view: margin is nearly straight (0); margin strongly convex (1). This study.
- (243) Tarsometatarsus, crista medialis hypotarsi: present (0); absent (1). This study.
- (244) Tarsometatarsus, trochlea metatarsi II strongly plantarly deflected: no (0); yes (1). (A73).
- (245) Pedal digit I: small, with metatarsal I and single phalanx both present (0); metatarsal I reduced to an ossicle, claw represented by a minute ossicle or lost (1); metatarsal I absent (2). Ordered. Codings for Procellariiformes follow Forbes (1882); see also discussion in Mayr (2009).

TABLE S1. GenBank accession numbers for sequences used in the phylogenetic analysis.

| Taxon                    | 12S rDNA          | 16S rDNA  | COI      | Cytochrome <i>b</i> | RAG-1     |
|--------------------------|-------------------|-----------|----------|---------------------|-----------|
| <i>A. forsteri</i>       | DQ137187          | DQ137147  | DQ137185 | DQ137225            | DQ137246  |
| <i>A. patagonicus</i>    | AY139221          | DQ137148  | DQ137186 | AY 138623           | DQ 137247 |
| <i>D. capense</i>        | X82517            | —         | —        | AF076046            | —         |
| <i>D. exulans</i>        | DQ137205          | DQ137165  | DQ137168 | DQ137208            | DQ137229  |
| <i>E. chrysocome</i>     | AY139630          | —         | DQ525796 | —                   | DQ525776  |
| <i>E. chrysolophus</i>   | DQ137197          | DQ137157  | DQ137171 | AF076052            | DQ137223  |
| <i>E. filholi</i>        | DQ525741          | —         | DQ525781 | —                   | DQ525761  |
| <i>E. moseleyi</i>       | DQ525746          | —         | DQ525786 | —                   | DQ525766  |
| <i>E. pachyrhynchus</i>  | U88007,<br>X82522 | DQ 137152 | DQ137170 | DQ137210            | DQ137231  |
| <i>E. robustus</i>       | DQ137193          | DQ137153  | DQ137176 | DQ137126            | DQ137237  |
| <i>E. schlegeli</i>      | DQ137196          | DQ137156  | DQ137175 | DQ137215            | DQ137236  |
| <i>E. sclateri</i>       | DQ137194          | DQ137154  | DQ137169 | DQ137309            | DQ137230  |
| <i>E. minor</i>          | NC004538          | DQ137164  | DQ137174 | NC_004538           | DQ137235  |
| <i>G. immer</i>          | AF173577          | DQ137166  | DQ137167 | DQ137207            | DQ137288  |
| <i>G. stellata</i>       | AF173587          | AY293618  | AY666477 | AF158250            | —         |
| <i>M. giganteus</i>      | X82523            | —         | —        | AF076060            | —         |
| <i>M. antipodes</i>      | DQ137198          | DQ137158  | DQ137184 | DQ137224            | DQ1372245 |
| <i>O. oceanicus</i>      | —                 | —         | DQ433048 | AF076062            | —         |
| <i>O. leucorhoa</i>      | —                 | —         | AY666284 | AF0706064           | —         |
| <i>P. desolata</i>       | —                 | —         | —        | AF076068            | —         |
| <i>P. urinatrix</i>      | X82518            | —         | —        | AF076076            | DQ881818  |
| <i>P. immutabilis</i>    | —                 | —         | DQ433933 | PIU48949            | —         |
| <i>P. palpebrata</i>     | —                 | —         | —        | U48943              | DQ881822  |
| <i>P. aequinoctialis</i> | —                 | —         | —        | U74350              | —         |
| <i>P. brevirostris</i>   | NC007174          | NC007174  | NC007174 | NC007174            | —         |
| <i>P. gravis</i>         | AF175572          | AF173752  | DQ434014 | U74354              | —         |

TABLE 1. (Continued)

|                        |          |           |           |          |           |
|------------------------|----------|-----------|-----------|----------|-----------|
| <i>P. adeliae</i>      | AF173573 | DQ137149  | DQ137183  | DQ137223 | DQ137224  |
| <i>P. antarctica</i>   | DQ137190 | DQ137150  | DQ137181  | AF076089 | DQ137242  |
| <i>P. papua</i>        | DQ137191 | DQ137151  | DQ 137182 | AF076090 | DQ137243  |
| <i>S. demersus</i>     | DQ137199 | DQ137159  | DQ137177  | DQ137217 | DQ137238  |
| <i>S. humboldti</i>    | DQ137201 | DQ137161  | DQ137180  | DQ137220 | DQ137241  |
| <i>S. magellanicus</i> | DQ137200 | DQ 137160 | DQ137178  | DQ137218 | DQ 137239 |
| <i>S. mendiculus</i>   | DQ137202 | DQ137162  | DQ137179  | DQ137219 | DQ137240  |
| <i>T. melanophrys</i>  | AY158677 | AY158677  | NC_007172 | U48955   | AY158677  |

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