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Supplementary Material and Methods

Geological and geographical provenance of MACN-PV 19.748

Specimen MACN-PV 19.748 (Figs. 1-2, Extended Data 1, 2, 4-6) of *Vegavis iaai* was collected in January 1993 by the *Instituto Antártico Argentino* (*IAA*) research team *Bioestratigrafía Ross*, headed by Eduardo Olivero (Laboratorio de Geología Andina, CADIC-CONICET). The geological and paleontological field research in 1993 has been conducted by F. Mussel and D. Martinioni, with the skillful help of G. Robles. W. Zinsmeister participated in this field expedition as a guest paleontologist of the *IAA*.

MACN-PV 19.748 was found by W. Zinsmeister, in association with specimen MLP 93-I-3-1, (Noriega and Tambussi, 1995) the holotype specimen of *Vegavis iaai* (Clarke et al. 2005), which was discovered by F. Mussel later during the same field expedition. Both specimens of *Vegavis* were collected on Vega Island in the vicinity of Cape Lamb, between Leal and Sandwich bluffs, roughly at 63°52'S - 57°34'30"W (estimated by means of Google Earth; no GPS navigator was used by the team in 1993). Specimens MACN-PV 19.748 and MLP 93-I-3-1 of *Vegavis iaai* came from the same horizon of the upper-most levels of the Maastrichtian (Upper Cretaceous). The beds containing both fossil bird remains belong to the Marambio Group (Rinaldi, 1982), and, according to the ammonite assemblages, they are ascribed to the *Maorites-Grossouvrites* Sequence (MG, Maastrichtian; Olivero and Medina, 2000). The horizon where these fossil birds were found lies roughly in the lower part of the upper third of Unit K3 of Marenssi *et al*. (2001), just above the levels of Unit B described by Olivero *et al.* (1992; see also Pirrie *et al*., 1991; their figure 11, section DJ.85). The interval of the section including the concretions with the bird remains is constituted by faintly laminated to massive mudstone, silty mudstone, and very fine sandstone beds with net planar contacts and some amalgamation. A more recent stratigraphic approach (see Olivero, 2012; Roberts *et al.*, 2014) places the *Vegavis* holotype MLP 93-I-3-1 in the lowermost subunit of the Sandwich Bluff Member of the López de Bertodano Formation (Rinaldi et al., 1978); MACN-PV 19.748 is from the same unit.

Systematic Paleontology and Additional Description of MACN-PV 19.748

Overview: Histological sampling of the new specimen shows a similar cortical thickness and distribution of fibrolamellar bone seen in extant avian taxa and in the *Vegavis* and *Polarornis* holotype specimens (Chinsamy et al., 1998; Clarke et al., 2005). Like the *Vegavis* holotype, MACN-PV 19.748 shows several characters that are so far known only within Aves relative to outgroup taxa. It is most similar in morphology to Anseriformes with a diving ecology similar to that of *Lophodytes* or *Mergus.* Section III provides detailed apomorphy-based data supporting referral to *Vegavis iaai* (see also Extended Data 5) and differentia from the *Polarornis gregorii* holotype (see also Extended Data 4). For example, Extended Data 5 illustrates the unique combination of a deep circular depression on the proximal femur and muscular scar on the proximal humerus mentioned in the diagnosis of that taxon (Clarke et al., 2005). Both characters have a restricted, but complex distribution in Aves; their combination was proposed to be unique. Table S1 provides measurements of the new specimen.

Cranial material: The pterygoid is preserved in the main block (Figs. 1a-d, Extended Data 2, 5) with a large, projected basipterygoid articulation, a plesiomorphic condition not present in Neoaves. In Neoaves these processes are absent or minute and vestigial. In the size, position and angle of the flat projected articular surface this process is also unlike the condition seen in Paleognathae or even known Mesozoic outgroup taxa. Only in Galloanserae are the basipterygoid processes cranially located, broad and dorsoventrally angled (Cracraft and Clarke, 2001).

In the caudal mandible, the lateral cotyla is developed as a shallow cup distinct from a craniomedially directed shallow medial cotyla (Extended Data 2). No distinct caudal cotyla is present. This conformation is similar to that of Anseriformes (e.g., *Lophodytes* and Pelagornithidae; Mayr and Rubilar-Rogers, 2010), with a flattening of the dorsal margin of the mandible directly rostral to the cotylae that is marked by a small foramen. It is unlike that seen in loons in which these cotylae are broadly contiguous and a caudal cotyla is well developed. A mandibular fenestra, prominent in loons, procellariforms and other Neoaves, just rostral to the cotylar area is absent. In Anseriformes, this mandibular fenestra is also inconspicuous/not well bounded as in the fossil, while in Galliformes it is typically conspicuous.

While the articular/retroarticular region exhibits breakage (i.e., nearly the medial one-half of this region is missing), a retroarticular process appears to have been absent or short (Extended Data 2). The morphology of the articular and retroarticular region are both similar to pelagornithids, the soaring pseudotoothed birds that have also been identified as basal Anseriformes (Bourdon, 2005) or basal Galloanseres (Mayr and Rubilar-Rogers, 2010) but similarly lack the prominent retroarticular process (e.g., Mayr and Rubilar-Rogers, 2010: fig.2A) seen in extant parts of these clades. Markedly deep retroarticular fossae are similarly absent in *Vegavis* as well as Diatrymidae and Mihirungs, both of which have atypical and short retroarticular processes but have been recovered as stem Anseriformes.

Also similar to Galloanseres, including Pelagornithidae and Diatrymidae, but unlike loons, the margin of the mandible is strongly dorsally deflected just rostral to the articular region (Extended Data 2). Such a conformation is not present in Gaviidae or Sphenisciformes. Additional details of the mandible include the dorsally directed retroarticular fossa, and a small dorsal hook-like processus are not dissimilar to that seen in, for example, Rallidae or Gaviidae but were not observed in compared Anseriformes. The medial fossa for the attachment of the *m. pterygoideus* is very strongly developed. A pneumatic foramen is not preserved.

Axial skeleton: All preserved presacral vertebrae are heterocoelous (Fig. 1). The first five cervical vertebrae are preserved in articulation with a fragment of the sixth. Enclosed transversaria foramina are not present in the atlas or axis; they are similarly absent in Galliformes but present in *Anseranas* and variable in Anhimidae and in Anatidae. The lateral surface of the third cervical is largely obscured by the carpometacarpus but its cranial-most margin is exposed and there are no traces of an osseous bridge between the body of the neural spine and postzygapophyses (Mayr and Clarke, 2003); absence of this feature was confirmed with CT data. This osseous bridge is also absent in cervical four. A bridge on cervical three is typical of galloanserines and many other birds; it is absent in Gaviidae. A prominent broad neural spine is present on cervicals 2-4, they are present on approximately cervicals 2-3 in *Melanitta* and 2-4 in *Oxyura* and 2-6 in *Gavia*. Epipophyses on cervical vertebrae 2-5 do not overhang the caudal margin of the postzygapophyses.

A second block preserves eight presacral vertebrae in articulation w/ each other and with the ribs (Fig. 1e-h). The most cranial of these vertebrae is a cervical preserved only as a postzygapophysis in articulation with the following two vertebrae. The second of these preserves a prominent lateral fossa in left lateral view. Transverse foramina are enclosed with their ventral margin bounded by a thick laterally projected strut that is swept caudally. This condition is approached by the laterally directed

strut in *Melanitta* or the slightly swept back strut the procellariform *Calonectes*, but was quite distinct from other extant taxa surveyed.

The more caudal thoracic centra are strongly compressed with striking osseous connections between tips of the expanded transverse processes that would have served to significantly stiffen the thoracic region. These include rod-like projections from the broad transverse processes. No notarium is present. Two caudal vertebrae were prepared completely free – none have ossified haemal processes although articular surfaces (i.e., paired cranial and caudal tubercles) indicate free processes would have been present at least on some caudal vertebrae. On one of the fully-prepared free caudal vertebrae, projected prezygapophyses are present and appear dorsoventrally narrow and slightly rod-like. The neural spine on an additional caudal vertebra, preserved in the primary block (Fig. 1 a-d; Extended Data 1) is short and slightly expanded. In all caudal vertebrae preserved the transverse processes are comparatively narrow, short (for those preserved) and swept caudoventrally (Extended Data 1).

Pectoral girdle: The coracoid is relatively short with a broad sternal margin (Fig. 1, Extended Data 1, 2). Its body arcs omally towards an expanded acrocoracoid, creating a slightly concave ventral profile in lateral view. In this morphology it is more similar to that of Procellariiformes than extant galloanserines or Gaviidae, although *Chauna, Presbyornis* and *Anatalavis* all exhibit some of this curvature. As noted in the diagnosis, all Procellariiformes, penguins, and loons exhibit a clavicular articular surface for the clavicle that overhangs the triosseal canal. In the *Vegavis* holotype and Anseriformes there is essentially no projection of this surface (Extended Data 2). The facet is flat to slightly depressed. In Pelagornithidae this lip is also weak but lacks the central depression or concavity seen in the Vega fossils or in Anseriformes. The small, pointed and slightly omally-directed procoracoid (Extended Data 1, 2) process is distinct from that observed in crown Anseriformes, however a similar process is present in Pelagornithidae, and a procoracoid process is present in *Presbyornis*. A supracoracoid nerve foramen is present (Fig.1, Extended Data 2). While this foramen is lacking in crown clade Anseriformes, it is present in the *Vegavis* holotype specimen, *Presbyornis*, Pelagornithidae and stem Galliformes. It is diminutive in both *Vegavis* specimens, markedly smaller than in *Gavia*, and almost obsolete. It is even smaller in the anseriform pseudotooth birds (Mayr and Rubilar-Rogers, 2010). The sternal margin of the glenoid facet terminates omal to the edge of the scapular cotyla and shows a distinct lip (Extended Data 2). A lateral process may have been present; the sternal portion of the lateral margin is not preserved. However, if one was present, it could not be located as high on this margin as it is in loons. The scapula cotyla is deeply concave with a well-developed omal lip (Extended Data 1, 2). The sternal end of the dorsal surface of the coracoid is depressed slightly with a subtle triangular fossa associated with a slightly rugose texture (Extended Data 2). The sternal facet on the medial margin of the dorsal surface of the coracoid is not as omally extensive or as projected as it is in Gaviidae, but is similar to stem Anseriformes.

A small section of what appears to be a strongly transversely compressed omal portion of the furcular blade is preserved associated with the right coracoid head (Fig. 1e-g). This condition is unlike that in loons, in which the clavicular articular surface of the furcula is expanded. The scapular shaft is nearly straight with a relatively even width throughout its length and only a slight distal taper (Extended Data 1). The acromion does not project cranial to the large convex coracoid tubercle; it terminates approximately even with it. Two small fragments of the sternum appear to lie near the right coracoid.

Pectoral Limb: The right humerus preserves much of proximal shaft (Extended Data 2). The humeral head is only weakly globose. In addition, there are two small pieces of the left humerus including the humeral head and part of the shaft. The remains of the deltopectoral crest indicate it was cranially deflected as in *Vegavis* and crown avians but unlike *Ichthyornis*. It is elongate and estimated to extend ~1/3 the length of the humeral shaft (Extended Data 2). A flat *m. scapolohumeralis cranialis* scar present on the capital ridge is also present in the *Vegavis* holotype. The capital ridge is more strongly developed, and capital incisure is oriented at a higher angle to the humeral shaft than in Gaviidae. Similarly the pneumotricipital fossa has a more strongly projected dorsal lip than in Gaviidae, while the bicipital crest is less projected cranially. The fossa just distal to the humeral head on the cranial surface is much deeper in the new fossil; a distinctive trait also developed in the *Vegavis* holotype. A second, shallow pneumotricipital fossa is also present. A lineate m. latissimus dorsi scar angles dorsodistally on the distal deltopectoral crest (Extended Data 2) similar to the condition in compared Anseriformes. In loons, this scar is not angled. The dorsal tubercle is essentially un-demarcated.

Portions of the right distal radius and ulna are preserved with the radiale in articulation (Extended Data 1c). On the distal ulna the carpal tuberosity is conformed as a small tubercle, unlike the broad flange in loons and Procellariiformes. The distal trochlear surface of the distal ulna is broader than its proximal extent up the shaft. The tendinal groove does not have well projected edges. The adjacent tendinal pit is large and distally located. The radiale is subtriangular (Extended Data 1, 2). It lacks the distinctive groove or notch on this element in loons. The ulnare has a very prominent tubercle on the caudal end of the dorsal ramus (Extended Data 1, 2). Originally described by Ericson (1997), this feature is present in Anseriformes but absent in Galliformes, Tinamidae, Sheniscidae, Procellariiformes and Gaviidae, other Aves as well as outgroup avialans. The ventral ramus is longer than the dorsal ramus. The tendinal incisure lies close to the midline of the ventral ramus; it lies off center in some Anatidae and Procellariiformes.

The right carpometacarpus preserves manual phalanges in life position with the exception of the distal I:1 and tip of II:1. Digit III:1 is preserved on the left side (Fig. 1). A projected ulnocarpal trochlea is absent. Metacarpal I is short compared to loons and penguins but a typical or plesiomorphic length for birds. The extensor process is low, broad and weakly projected, as in some alcids (*Alca, Uria, Alle*). It is more strongly projected than in loons and penguins. The spatum metacarpale is narrow and extends to the distal end of metacarpal I. The pisiform process is shifted towards the cranial edge of the bone, putting it in line with the cranial margin of the carpal trochlea. Its tip may be slightly deflected cranially; however, this area is incompletely exposed. Metacarpal III is craniocaudally compressed with a small proximal muscular scar. The tendinal groove is straight after passing from the caudodorsal corner of the distal end and, at midshaft, curving slightly onto the dorsal surface. It is indistinct for the proximal 1/3 of the carpometacarpus. Metacarpals II and III are approximately equal in distal extent; III is just slightly shorter than II. The m. interosseus distalis groove is visible and is demarcated by two low ridges. There may be several subtle quill knob impressions.

Manual phalanx II-1 is strikingly narrow and similar to *Presbyornis* (Fig. 1c). It bears a small internal indicus process, but no tendinal groove is visible. Phalanx II-2 is shorter than II-1. A width to length ratio for manual phalanx II:1 about or just under 4.5 was a synapomorphy proposed to unite flamingos with grebes; in the fossil this ratio is estimated to be ~ 4.35-4.5 depending on measurement

location. Manual phalanx III-1 bears a flexor tubercle seen in many avian taxa including Galloanseres (Extended Data 1c); the flexor process in loons is essentially obsolete.

Pelvic limb: The right femur is complete except for a small part of the trochanteric crest (Extended Data 1, 2). The left element is less complete; it is missing the femoral head and much of the medial side of the distal end. However, the left preserves part of the trochanteric crest missing from the right element. The shaft is bowed and narrow. The obturator scar forms a profound, circular depression (Extended Data 2, 5). In this shape it is similar to some Anseriformes and penguins (but not loons). A second, smaller but similarly deep scar is placed proximolateral to the first. The trochanteric crest has virtually no cranial projection and a very small proximal projection, similar to other diving taxa such as loons and grebes. The capital ligament scar is very large (Extended Data 4).

The patellar groove on the femur is deep (Extended Data 1, 2). A series of raised areas of muscle insertion extend down nearly the proximal 1/3 of the lateral surface (Extended Data 1, 2 , 4). These scars are symmetrical and intact on both femora. A medial crest is developed on the caudodistal end of the femur. It becomes obsolete proximally at approximately mid-shaft. The medial shaft diameter in medial view just proximal to the distal condyles is narrower than the corresponding area of the lateral side. In distal view, the medial condyle extends just caudal to the articular face of the fibular trochlea. In loons, the medial condyle is relatively much less projected caudally, and the articular face of the fibular trochlea is broader mediolaterally. Just proximal to the lateral condyle there is a conspicuous, raised scar (Extended Data 1, 2, 4). This large scar is present in Anseriformes but not in surveyed Galliformes or waterbirds (Aequornithia).

A triangular and highly irregularly-shaped element is tentatively identified as the patella (Fig. 1). A bounded fossa/foramen would be positioned approximately caudodorsally with well-developed edges. It is triangular with highly asymmetrically conformed sides in Anseriformes, where it is larger in diving species (e.g., Pycraft, 1906: pl. 39). In stem and crown loons, the proximal extent of the cnemial crest of the tibia is very large, but the patella is thin and strap-like (Wilcox, 1962; Cracraft, 1982). In stem penguins, the patella is relatively small and rectangular (e.g., Ksepka and Clarke, 2010). The surface tentatively identified as cranial contains some matrix and one appressed bone fragment. It is possible that a part of the element is missing. Patellar function in birds appears disparate although ossification of the patella is known as far back as *Confuciusornis* (Clarke, pers. obs.; Regnault et al. 2014).

The cnemial crests of the tibiotarsus are well projected (Extended Data 1, 2, 4). They are, however, significantly less well projected than in the stem loon *Columboides* (Storer, 1956) or in extant Gaviidae. As noted in the diagnosis and differentia, the cranial cnemial crest extends distally down the tibiotarsal shaft as in the *Vegavis* holotype; in *Polarornis* this feature cannot be assessed. This feature is seen in loons, diving ducks and some other Anatidae, but not in most Procellariiformes, penguins or the soaring Pelagornithidae. The sulcus intercnemialis is straight and deep. A projected lip and associated divot are not present in caudal surface of the patellar crest of the tibiotarsus in the new specimen. By contrast, such a lip is present in loons and some Procellariiformes (e.g., *Puffinus*), but is absent in others (e.g., *Daption*), as well as in ducks or suloids, for example. The proximal fibula, removed from the blocks, has a depression on caudomedial face. From the shape of the fibular shaft and proximal tibiotarsus, the fibular crest of the tibia is estimated to have been relatively well projected, proximally-situated and short.

Parts of several isolated phalanges are also preserved (e.g., Fig. 1, Extended Data 1). Two of these are almost complete but remain in the main blocks, and three were prepared out. They are elongate consistent with a foot-propelled diving ecology indicated in the morphology of the patella and tibiotarsus.

The new Antarctic specimen of *Vegavis* further supports an ecologically diverse radiation of basal Galloanseres. Stem Anseriformes from the late Cretaceous and Paleogene are known to comprise soaring pseudotooth birds (Pelagornithidae), wading taxa (e.g. *Presbyornis)*, diving taxa like *Vegavis* and giant flightless forms (e.g., *Diatryma)*. Living Anseriformes, by contrast, are more limited in ecological diversity.

Table S1: Measurements of MACN-PV 19.748: (*in mm;* e=estimated)

Skull

Pterygoid, rostrocaudal length:	9.8
Caudal part of mandible, rostrocaudal length:	19.2
Caudal part of mandible, width across the glenoid fossa:	4.6

Vertebrae

Presacral series	~maximum length of centrum	maximum height
1	4.5	9.2
2	10.4	9.0
3	15.2	15.1
4	16.6	16.8
5	18.8	15.4
13	12.2	
14	14.9	14.3
15	14.0	
16	11.9	
17	11.8	
18	10.0	
19	10	11.6
Caudal series		
1	5.8	5.9
2	5.9	6.8
3	6.2	

Pectoral girdle

Scapula	
craniocaudal length:	74.3
width across acromion process	8.3
least diameter of the blade	5.1

Coracoid	
greatest height	37.4
minimum width at the shaft	5.4
maximum width at the sternal end	22.3
maximum width at the scapular end	10.5

Forelimb

Humerus	
length	127.4 (e)
proximal transverse width	20
transverse diameter of the shaft	5.5
Radius	
length	88.3
proximal transverse width	6.3
transverse diameter of the shaft	3.8
distal transverse width	4.7
Ulna	
length	86.1
proximal transverse width	6.8
transverse diameter of the shaft	4.5
distal transverse width	8.2
Carpometacarpus	
length	50.1
proximal transverse width	5.9
transverse diameter of the shaft	
McI	2.9
McII	2.1
McIII	0.4
total manus length	93.2

Hind limb

Femur	
length	51.8
proximal transverse width	13.3
transverse diameter of the shaft	5.7
distal transverse width	13.4
Tibiotarsus	
length	112 (e)
length of the cnemial crest	12.7
transverse diameter of the shaft	7.4

Fibula	
length	45.7
proximal transverse width	3.4
transverse diameter of the shaft	2.6
distal transverse width	1.1

Comparisons and differentia

The new specimen (MACN-PV 19.748) was reported in an abstract but not described in detail; it was thought to be related to loons and *Polarornis gregori* (Chatterjee et al. 2006; Extended Data 3). However, all comparable skeletal elements are identical in size and in preserved morphologies to the holotype specimen of *Vegavis iaai* (Extended Data 1, 2, 5). As noted above, that specimen and MACN-PV 19.748 were collected from the same locality and horizon on Vega Island during the same field season (Section I, Noriega and Tambussi, 1992; Clarke et al., 2005).

Parts of the thoracic vertebrae, scapula, coracoid, humerus, femora, and tibiotarsus can be compared between the holotype and referred specimen (Figs. 1, Extended Data 1, 2, 5). The coracoid, in the holotype and newly referred specimen, has a distinct craniocaudally broad acrocoracoid with a medially flat to slightly concave clavicular articulation surface (Extended Data 1, 2). This morphology is uniquely seen in Anseriformes, while in Gaviiformes, Procellariiformes, Sphenisciformes, a diving taxon from near the K/Pg boundary of New Zealand (Mayr and Scofield 2014) and most other neoavian taxa, the clavicular articulation is distinctly projected to overhang the triosseal canal. Both the *Vegavis* holotype and the new specimen also share a broad cranial depression is present on the proximal humeral surface just distal to the head; the deep circular fossa on the proximal femur is present and the cranial cnemial crest extends down the shaft of the tibiotarsus among other features (Extended Data 5; Clarke et al., 2005). Additional characters with restricted morphologies in Aves present in the holotype and referred specimen (described in Section II) include the shape and location of the sternal articular facet on the coracoid, the extremely elongate and strap-like scapular blade with a well-projected coracoidal tubercle (Extended Data 1, 2).

The new specimen (Table S1) and the *Vegavis* holotype are a little over ~ ½ the size of the *Polarornis gregorii* (Extended Data 3; Chatterjee 2002), which was collected from Seymour Island, Antarctica. The two taxa appear roughly contemporaneous in age with the *Vegavis* concretionary horizon close to the K/Pg on Vega Island (Roberts et al., 2014; Ksepka and Clarke, 2015; ~ 67 Ma) and the *Polarornis gregorii* holotype described from Klb 9, the highest unit in the Lopez de Bertodano formation on Seymour and that includes the K/Pg boundary. *Polarornis*, described as a part of Gaviidae contains few elements comparable to the new remains or the *Vegavis* holotype. Unfortunately, as noted by previous authors (e.g. Mayr, 2009), the *Polarornis* holotype is much less complete than depicted. It was extensively damaged during preparation, and the existence of the proposed braincase, quadrate, morphologies from most of the skull and tibial shaft cannot be confirmed. It does share with the Vega specimen a relatively high cnemial crest, a dorsoventrally narrow trochanteric crest and a moderately-bowed femur (Extended Data 4). A projected cnemial crest is seen in all foot-propelled diving birds, and the femoral characters noted are common in diving taxa as well; none of these characters appear to diagnose a distinct clade.

Polarornis and *Vegavis* are additionally distinguished from each other by the absence of a deep capital ligament scar depressing the femoral head in *Polarornis gregorii* (Extended Data 4). A distinct, round proximoventral fossa on the femur present in *Vegavis* and the new specimen (Extended Data 2:os, 5; Clarke et al., 2005) is also absent in *Polarornis gregorii* (Extended Data 4) as is a conspicuous and well projected distolateral femoral crest (demarcated with a * in Extended Data 4). The shape of the projected cnemial crests is also distinct; the cranial crest shows a caudolateral lip that is absent in *Polarornis* (Extended Data 4) A number of features absent in loons, including the stem taxon *Colymboides* (Storer, 1956), but present in galloanserines are noted above and are additionally illustrated here. These include the flat to slightly concave morphology of the clavicular articular surface on the coracoid (Extended Data 1, 2), the crest on the femur noted above (Extended Data 4) and the presence of a large, irregular and triangular patella (Fig. 1) rather than a prominent and pointed juncture of the cnemial crest and slip-like thin patella. The prominent rostrally-located facet on pterygoid is absent in all Neoaves including Gaviidae (Fig. 1, Extended Data 2, 5).

Extant comparative materials, enhanced contrast staining and CT scanning parameters

All specimens were scanned at The University of Texas High-Resolution CT Facility (UTCT). Over the three years during which scanning was undertaken, the scanning system was upgraded; therefore, a microXCT 400 scanner (built by Zeiss, formerly Xradia, Inc.), a BIR scanner (225 kV Feinfocus X-ray source and an Image Intensifier detector) and a custom NSI scanner built by North Star Imaging were used for different scans (see Table S2). All extant syrinxes and the tracheobronchial juncture of *Alligator* were dissected out and then fixed in a solution typically of 10% neutral buffered formalin and then transferred to 70%-100% ethanol or a combination of ethanol-formalin solution before the staining (Table S2). Staining preparations for iodine contrast enhanced CT were conducted in Texas Natural History Collections, and the solutions used are mainly iodine-ethanol-formalin solutions, which are modified from the I_2E solution used by other researchers (see Li et al. 2016). Precise treatments by specimen are given in Table S2.

Table S2: Enhanced contrast x-ray computed tomography: staining and scanning parameters.

Institution abbreviations, TMM: Vertebrate Paleontology Laboratory, University of Texas at Austin, Austin, TX; UMNH: Natural History Museum of Utah, Salt Lake City, UT; USNM, Smithsonian National Museum of Natural History, Washington DC.MACN, Museo Argentino de Ciencias Naturales, Argentina.

taxon, specimen and sex (where known)	primary fixation protocol	subsequent transfer to ethanol	staining solution (w/v)	duration	scanner	voltage	current	voxel size	image used
Alligator mississippiensis TMM M-16001 (female)	10% neutral buffered formalin , 10days	100%, 4 days	0.25% (I2/ethanol)	6days	Xradia	70kV	0.14mA	54.27µm	16bit tif
Cairina moschata UMNH 23826 (female)	10% neutral buffered formalin , 10days	100%, 4 days	0.25% (I2/ethanol)	6days	NSIscanner	70kV	0.14mA	54.27µm	16bit tif
Colinus virginianus UMNH 23829 (male)	10% neutral buffered formalin , 10days	70% ethanol for 2 years;	1% (I2/8vol ethanol&1vol NBF)	9days	NSIscanner	160kV	0.21mA	27.2µm	16bit tif
Nothoprocta perdicaria UMNH 23840 (male)	10% neutral buffered formalin , 10days	70% ethanol for 2 years;	1% (I2/8vol ethanol&1vol NBF)	9days	NSIscanner	160kV	0.21mA	27.2µm	16bit tif
Chen caerulescens TMM M-12680	10% neutral buffered formalin , 10days	70% ethanol for 2 years; then to ethanol-formalin solution for 2 days	2% (I2/7vol ethanol&1vol NBF)	10days	NSIscanner	170kV	0.18mA	38.5µm	16bit tif
Anseranas semipalmata TMM M-12880	10% neutral buffered formalin , 5days	to ethanol-formalin solution for 2 days	2% (I2/7vol ethanol&1vol NBF)	10days	NSIscanner	170kV	0.18mA	38.5µm	16bit tif
Casuarius casuarius TMM M-12033	10% neutral buffered formalin , 30days	70% ethanol for 3 years; and then to ehanol-formalin solution for 6 days, then to 70% ethanol for 2 days, then to pure ethanol for 3 days	0.8% -1% (I2/ethanol)	16days	NSIscanner	150 kV	0.2 mA	89.7µm	16bit tif
Ortalis vetula TMM M-11681	10% neutral buffered formalin , 30days	70% ethanol for 3 years;	1% (I2/8vol ethanol&1vol NBF)	9days	NSIscanner	160 kV	0.21 mA	27.2µm	16bit tif
Gallus gallus UMNH 23828 (female)	10% neutral buffered formalin , 30days	70% ethanol for 2 years;	1% (I2/8vol ethanol&1vol NBF)	9days	NSIscanner	160 kV	0.21 mA	27.2µm	16bit tif
Chauna torquata TMM M-12955	10% neutral buffered formalin , 5 days	70% ethanol, 18 days	1% (I2/7vol ethanol&1vol NBF)	9days	NSIscanner	169 kV	0.18mA	35.2µm	16bit tif
Gavia immer TMM M-11934	35% ethanol 2 days	70% ethanol, 35 days	1% (I2/7vol ethanol&1vol NBF)	9days	NSIscanner	170 kV	0.18 mA	35.3µm	16bit tif
Phoebastria nigripes TMM M-15008	10% neutral buffered formalin , 2 days	to ethanol-formalin solution for 2 days	1% (I2/9vol ethanol&1 vol NBF)	10days	NSIscanner	170 kV	0.18 mA	38.5µm	16bit tif
Fulmarus glacialis TMM M-11940	10% neutral buffered formalin , 2 days	to ethanol-formalin solution for 2 days	1% (I2/9vol ethanol&1 vol NBF)	10days	NSIscanner	170 kV	0.18 mA	38.5µm	16bit tif
Presbyornis sp. USNM PAL 617185	N/A	N/A	N/A	N/A	Xradia	90kV	0.11mA	22.75µm	16bit tif
Vegavis iaai MACN-PV 19.748	N/A	N/A	N/A	N/A	BIR: 225 kV Feinfocus X-ray source and Image Intensifier detector	220kV	0.2mA	0.05mm*0 .05mm *0.115mm	16bit tif

Identity and comparisons of preserved syrinx elements

A syrinx consists of supporting mineralized cartilage elements, membranes/labia, muscles and nerves. There has been no agreement on the identification of syringeal supporting elements in the literature that can be applied to comparisons between taxa (see for example Prum 1992 for a short

discussion of some problems). Supporting elements are "A elements", "B elements", and "pessulus". "A elements" refer to "tracheosyringeal cartilages", according to King 1989, p. 109; *cartilagines trachealis syringis* of the 1979 Nomina Anatomica Avium) "B elements" refer to "bronchosyringeal cartilages", p. 109; *cartilagines bronchiales syringis* of the 1979 N.A.A.).

Here we use the pessulus as reference for our position labeling system of tracheal and bronchial elements (See Fig. 2, Table S3, Extended Data 7, 8 and main body text). Cranial from the pessulus elements are referred to as tracheal, whereas caudal from it are the left and right bronchial regions. The elements at the tracheobronchial junction have been labeled in reference to the pessulus. Position "0" (Fig. 3, Extended Data 7) refers to the most caudal ring element that is fused with the pessulus. Denotation +1, +2, +3, etc. is used for element positions craniad from position 0, and -1, -2, -3, etc. is used for element positions caudad from position 0.

Reconstruction of the disarticulated portions of the *Vegavis iaai* syrinx (Fig. 2, Extended Data 7; Supplementary Figure 1) was a multi-step process. First, elements *I* through *IX* were identified in CT scan images and segmented in VGStudio Max 2.1 (Volume Graphics). All elements were described (Table S3). The reconstruction process was assisted by enlarged, and life size, 3D printouts of all elements. The portion of the syrinx preserved in life position (elements *II* to *IV*) served as a starting point. Loose elements were fitted with elements still articulated to the main structure using the 3D extant syrinx data (Extended Data 8) as additional referents. For example, element *I* was nearly identical to element *II* and articulation of element I with element II, preserved in life position relative to the other elements, was seamless. One displaced half ring (element *V*) was identified as a bronchial half ring (element *IV*) because it was identical to a bronchial half ring on the opposite side that was preserved in articulation. Additional partial rings are identified as most likely to be bronchial half rings (elements VI and VII; see Table S3) but their spacing and orientation with respect to elements IV and V, respectively, could only be hypothesized. Two comma-shaped elements (VIII and IX) are hypothesized as mineralized parts of tracheal rings through inference from typical patterns in extant Galloanseres (see Table S3). As mentioned in the main text, elements at the tracheobronchial juncture in neognath birds are typically more mineralized than those distal (craniad or sternal) to this juncture, which may explain differential preservation of elements close to this juncture in the fossil.

Table S3: Description of the preserved syrinx elements in *Vegavis iaai* (MACN-PV 19.748).

Element (See Fig. 2 and Extended Data 7)	Position schema used here (Extended Data 7,8) and identity following King (1989) and Ames (1971) in parentheses	Description
I	**+2** (Tracheal ring)	1. Disarticulated from other syrinx elements 2. Complete ring with a slight dorsal indentation seen in the lower tracheal rings of extant birds.
II	**+1** (Tracheal ring)	1. Preserved in articulation with syrinx element III 2. The last free tracheal ring before the tracheobronchial junction (TBJ)

		3. It has an even more prominent lumenward bending (compared to element I) which is typical for the dorsal side of lower tracheal rings.
III	**0** (A1 or "lower A element")	1. On the right, two elements form a little more than a half ring and merge in the front (ventral; forming a ventral plate) and in the back (dorsal; forming a dorsal plate). 2. On the left there is only one broader half ring which merges with the ventral plate and with the dorsal plate 3. It has a thick middle bar which spans the lumen: a pessulus. 4. The pessulus fans out laterally (with cranio-caudal flattening) forming wings reaching into the left and right lumen. 5. The pessulus becomes thicker (saddle-like) towards the ventral plate or forms the entire base of the ventral plate.
IV	**-1** (B1)	1. Located on one side (left) and preserved in articulation with element III 2. Half ring 3. Has a ventral expanded and bulbous tip
V	**-1** (B1)	1. Located on opposite side (right) as element IV 2. No attachment to elements I-IV 3. Half ring; one end is expanded (like element IV) and the other end is thin and more significantly bowed. This conformation is also found in B1/B2 elements of extant birds.
VI	**-2** (B2)	1. Located on same site as element V (right) 2. No attachment to previous/other elements 3. Half ring; one end is enlarged and bulbous; the other end is thin, which is again typical for B elements.
VII	**-2** (B2)	1. No attachment to previous/other elements 2. Half ring; one end is slightly thicker; the other end is thin. 3. Slightly bent; similar to element VI (but

		much less curved than element V); therefore it could be a B2 or B3 half ring
VIII	**+3** Partial tracheal ring	1. Short and slightly bent, incomplete 2. No attachment to any other element preserved 3. Although we cannot definitively rule out B (bronchial) element identity, partial mineralization/ossification does not occurs in bronchial half rings in living birds but is known in tracheal rings (e.g. Figure 1 in Miller et al. 2008)
IX	**+3** Partial tracheal ring	1. Short and slightly bent, incomplete 2. No attachment to any other element 3. Although we cannot definitively rule out B (bronchial) element identity, partial mineralization/ossification does not occurs in bronchial half rings in living birds but is known in tracheal rings (e.g. Figure 1 in Miller et al. 2008)

Table S4: Description of seven morphological features of the tracheobronchial juncture evaluated in the 13 extant specimens and the Cretaceous and Eocene fossil syrinxes: (1) pessulus; (2) bronchial ring shape; (3) lateral space/gaps between neighboring tracheal or bronchial rings; (4) shape of bronchial rings; (5) fusion of rings; (6) symmetry/asymmetry at the tracheobronchial juncture; (7) ossification/mineralization of tracheobronchial rings. See Extended Data 7 and Supplementary Figures 1 and 2. Sex of specimens is indicated where known (see also Table S2).

Alligator mississippiensis TMM 16001 (female)	1. No pessulus; but three caudal tracheal rings fuse in midline to form a midline cartilaginous septum 2. Complete bronchial rings 3. No space between neighboring tracheal and/or bronchial rings 4. Tracheal and bronchial rings are generally uniformly shaped 5. No rings are fused 6. No asymmetry 7. Cartilaginous
Casuarius casuarius TMM M-12033	1. No pessulus 2. Bronchial half rings with medial wall consisting of soft connective tissue and epithelium 3. Bronchial half rings are equally spaced 4. Bronchial half rings are wider (craniocaudally) than the tracheal rings 5. Neither tracheal rings nor bronchial half rings are fused; distinct dorsal indention make the tracheal rings incomplete 6. No asymmetry 7. Cartilaginous/ partial mineralization
Nothoprocta perdicaria UMNH 23840 (male)	1. No pessulus 2. Bronchial half rings with medial wall consisting of soft connective tissue and epithelium 3. Bronchial half ring (between -1, -2, -3) show small gap laterally 4. Bronchial rings are uniformly shaped, and taper out towards their endpoints (no bulbous expansion) 5. Neither tracheal rings nor bronchial half rings are fused 6. No asymmetry 7. Partially mineralized
Ortalis vetula TMM M-11681	1. Pessulus present 2. Bronchial half rings with medial wall consisting of soft connective tissue and epithelium 3. Large space between bronchial half ring (between -1 and -2) show small gap laterally 4. Bulbous ventral expansion of bronchial half rings 5. Neither tracheal rings nor bronchial half rings are fused 6. No asymmetry 7. Mineralized/ossified
Colinus virginianus UMNH 23829 (male)	1. Pessulus present 2. Bronchial half rings with medial wall consisting of soft connective tissue and epithelium 3. Large lateral space between 0 and -1 4. Angular projection on the ventral aspect of the first bronchial half ring

	5. Neither tracheal rings nor bronchial half rings are fused 6. No asymmetry 7. Cartilaginous
Gallus gallus UMNH 23828 (female)	1. Pessulus present 2. Bronchial half rings with medial wall consisting of soft connective tissue and epithelium 3. Large lateral space between +1 and -1 4. Partially reduction of the bronchial half ring 5. Neither tracheal rings nor bronchial half rings are fused 6. No asymmetry 7. Mineralized/ossified
Vegavis iaai MACN-PV 19.748 See also Table S3	1. Pessulus present 2. Bronchial half rings with medial wall consisting of soft connective tissue and epithelium 3. Small lateral space between -1 and -2. 4. Bronchial half rings with a bulbous expansion 5. Neither tracheal rings nor bronchial half rings are fused 6. Asymmetry 7. Mineralized/ossified
Chauna torquata TMM M-12955	1. Pessulus present 2. Bronchial half rings with medial wall consisting of soft connective tissue and epithelium 3. Large lateral space between -1 and -2 4. Very slim bronchial half rings 5. Neither tracheal rings nor bronchial half rings are fused 6. No asymmetry 7. Mineralized/ossified
Presbyornis sp. USNM PAL 617185 (see also Supplementary Figure 2)	1. Pessulus present (estimated from preserved strut) 2. Bronchial half rings with medial wall consisting of soft connective tissue and epithelium 3. Large lateral space between 0 and -1 4. A partial bronchial half ring on the left appears to be fused ventrally with the last tracheal ring 5. Neither tracheal rings nor bronchial half rings are fused but the organ is mediolaterally compressed 6. No asymmetry 7. Mineralized/ossified
Anseranas semipalmata TMM M-12880	1. Pessulus present 2. Bronchial half rings with medial wall consisting of soft connective tissue and epithelium 3.Small lateral space between 0 and -1 4. Very slim bronchial half rings 5. Fusion of multiple tracheal rings (0 and +1, +2, +3), but the organ is mediolaterally compressed 6. No asymmetry 7. Mineralized/ossified

Cairina moschata UMNH 23826 (female)	1. Pessulus present 2. Bronchial half rings with medial wall consisting of soft connective tissue and epithelium 3. Small lateral space between 0 and -1 4. Robust, uniformly-shaped bronchial half rings (no bulbous expansion) 5. Fusion of multiple tracheal rings (0 and +1, +2, +3) 6. Asymmetry (slight in females, pronounced in males) 7. Mineralized/ossified
Chen caerulescens TMM M-12680	1. Pessulus present 2. Bronchial half rings with medial wall consisting of soft connective tissue and epithelium 3. Large lateral space between 0 and -1 4. Very slim, uniformly-shaped bronchial half rings 5. Fusion of multiple tracheal rings (0 and +1, +2, +3), and the organ is mediolaterally compressed 6. No asymmetry observed, sex of specimen not known. 7. Mineralized/ossified
Gavia immer TMM M-11934	1. Pessulus present 2. Bronchial half rings with medial wall consisting of soft connective tissue and epithelium 3. Medium lateral space between -3 and -4 4. Expansion of the first bronchial ring in ventral aspect 5. Neither tracheal nor bronchial rings are fused 6. No asymmetry 7. Weakly mineralized/ossified
Fulmarus glacialis TMM M-11940	1. Pessulus present 2. Bronchial half rings with medial wall consisting of soft connective tissue and epithelium 3. Small lateral space between -3 and -4 4. Very slim bronchial half rings, which taper out towards their end points (no bulbous expansion) 5. Neither tracheal rings nor bronchial half rings are fused; long septum present conformed of tracheal rings 6. No asymmetry 7. Cartilaginous
Phoebastria nigripes	1. Pessulus present 2. Bronchial half rings with medial wall consisting of soft connective tissue and epithelium 3. Large lateral space between -3 and -4 4. large ventrolateral expansion occurs on the first few bronchial half rings 5. Neither tracheal rings nor bronchial half rings are fused 6. No asymmetry 7. Partially mineralized/ossified

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