

Supplemental material for

**Pleistocene seabirds from Shiriya, northeast Japan: systematics and
oceanographic context**

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Appendix

List of comparative materials examined; specimens are listed by species/subspecies and then geographical regions. Sex composition and number of partial skeletons are given in parentheses (m, male; f, female; u, unsexed; p, partial skeleton). For brevity, 'Japan' is used to designate the central Japanese islands (Hokkaido, Honshu, Shikoku, Kyushu, and surrounding islands); the specimens from Bonin and Ryukyu islands are listed separately.

Anatidae. *Dendrocygna viduata*: KUGM RA 204 (u). *D. bicolor*: California, MVZ 21560, 21561 (1 m, 1 f). *D. javanica*: KUGM RA 206 (u). *Biziura lobata*: Australia, MVZ 143332, 143336 (1 m, 1 f). *Cygnus columbianus*: California, MVZ 22430 (m). *Anser albifrons frontalis*: California, MVZ 46018, 70321 (1 m, 1 f). *A. indicus*: MVZ 136143 (m, captive). *Branta bernicla*: California, MVZ 72532, 73081 (1 m, 1 f). *Oxyura jamaicensis*: California, MVZ 49436, 50542 (1 m, 1 f). *Merganetta armata*: Peru, MVZ 126374 (f). *Tachyeres patachonicus*: Argentina, UWBW 41025 (f). *Sarkidiornis melanotos*: NSMT PV A386 (u, captive). *Chloephaga melanoptera*: Peru, MVZ 125160, 155161 (1 m, 1 f). *Tadorna tadorna*: Netherlands, USNM O 432291 (m). *T. ferruginea*: Japan, YIO 62471 (u). *T. tadornoides*: Australia, MVZ 141913, 141914 (1 m, 1 f). *Malacorhynchus membranaceus*: Australia, MVZ 143321, 143325 (1 m, 1 f). *Cairina moschata*: El Salvador, MVZ 85522 (u). *Aix sponsa*: California, MVZ 66326, 123049 (1 m, 1 f). *A. galericulata*: Korea, MVZ 150922 (m). *Chenonetta jubata*: Australia, MVZ 133420, 155858 (2 f). *Nettapus coromandelianus*: MVZ 155165 (m, captive). *Anas strepera*: California, MVZ 151624, 151625 (1 m, 1 f). *A. falcata*: USNM O 638068 (f, captive). *A. penelope*: Japan, EP 6, MVZ 124058 (2 m). *A. americana*: California, MVZ 120311, 120312 (1 m, 1 f). *A. platyrhynchos*: California, MVZ 53248–53251 (2 m, 2 f); Japan, HUNHM 60469 (u). *A. luzonica*: USNM O 428598 (m, captive). *A. zonorhyncha*: Japan, EP 84, KUGM RA 42, YIO 62887 (2 m, 1 f). *A. discors*: California, MVZ 117198 (m). *A. chryseata*: California, MVZ 22433, 22434 (1 m, 1 f). *A. acuta*:

California, MVZ 22436, 22437 (1 m, 1 f); Japan, EP 4 (m). *A. querquedula*: California, MVZ 27649 (m). *A. crecca*: Japan, EP 7, YIO 62351, 62387 (2 m, 1 f). *A. carolinensis*: California, MVZ 74910, 74911 (1 m, 1 f). *Netta rufina*: Astrakhan Oblast', UWB 56614, 56615 (1 m, 1 f). *N. peposaca*: MVZ 135151, 135152 (1 m, 1 f, both captive). *Aythya valisineria*: California, MVZ 49426, 151650 (1 m, 1 f). *Ay. americana*: Nevada, MVZ 77314, 79402 (1 m and 1 f). *Ay. ferina*: California, USNM O 641828 (u); Japan, EP 8 (m). *Ay. nyroca*: Netherlands, USNM O 432300 (m). *Ay. collaris*: California, MVZ 125280, 151649 (1 m, 1 f). *Ay. fuligula*: Tyumen Oblast', UWB 56541, 56543 (1 m, 1 f); Japan, EP 5 (f). *Ay. marila*: California, MVZ 132953, 151652 (1 m, 1 f). *Ay. affinis*: California, MVZ 51716, 51718 (1 m, 1 f). *Polysticta stelleri*: Alaska, MVZ 60346, 60347, 126647, 126648 (2 m, 2 f). *Somateria fischeri*: Bering Sea, MVZ 28961, 129374–129377 (3 m, 2 f); Alaska, UWB 53816, 69935 (4 m, 1 f). *S. spectabilis*: Bering Sea, MVZ 126653, 126656, 126657, UWB 80827, 80829 (4 m, 1 f). *S. mollissima*: Alaska (ssp. *v-nigrum*), MVZ, 28964, 60356, 126649, 126650 (2 m, 2 f); Massachusetts (ssp. *dresseri*), UWB 38168 (m). *Histrionicus histrionicus*: Alaska, MVZ 49749, 57231, 60342–60344, 97129, 119054 (4 m, 3 f). *Melanitta perspicillata*: Washington, UWB 30167, 30169 (1 m, 1 f); California, MVZ 19095, 41843, 46811, 49391, 49502, 54433, 54436, 70626, 70627, 151662–151664, 176016, 183939 (7 m, 5 f, 2 u). *M. fusca deglandi*: Washington, UWB 14285, 26043, 14285 (2 m, 1 u); California, MVZ 19093, 19094, 46122, 46132, 46133, 46803, 54432, 54592, 70624, 70625, 74901, 151658–151661 (5 m, 4 f, 6 u). *M. fusca stejnegeri*: Japan, YIO 64405 (u). *M. nigra americana*: British Columbia, MVZ 53897 (m); Washington, UWB 38985, 40000 (1 m, 1 f); Japan, YIO 64406 (u). *Clangula hyemalis*: Alaska, MVZ 60325–60327, 60330, 60331, 68390, 68391, 125127, 125128, 126639, 177562 (7 m, 4 f). *Bucephala albeola*: California, MVZ 45050, 151004 (1 m, 1 f). *B. clangula*: California, MVZ 120323, 122571 (1 m, 1 f); Japan, MVZ 128710 (f). *B. islandica*: British Columbia, MVZ 63056 (f). *Mergellus albellus*: Japan,

NSMT PV A213, YIO 21339 (1 m, 1 f). *Lophodytes cucullatus*: Bering Sea, MVZ 63057 (f). *Mergus merganser*: California (ssp. *americanus*), MVZ 31362, 66591 (1 m, 1 f); China (ssp. *orienatlis*), USNM O 292743, 292750 (2 m). *M. serrator*: California, MVZ 151673, 151674 (1 m, 1 f). *M. squamatus*: China, USNM O 292752 (m).

Podicipedidae. *Tachybaptus ruficollis*: Germany (ssp. *ruficollis*), USNM O 289609 (f); Azerbaijan, UWBM 86353 (m); China (ssp. *poggei*), USNM O 291999–292003 (3 m, 2 f); Indonesia (ssp. *tricolor*), USNM O 226002; Papua New Guinea, MVZ 149265 (m). *T. novaehollandiae*: New Caledonia, USNM O 561519, 561520 (1 m, 1 f). ‘*T.*’ *dominicus*: Mexico (ssp. *bangsi*), MVZ 78678, USNM O 344901 (1 m, 1 f); Guatemala, USNM O 343476 (m); El Salvador (ssp. *brachypterus*), MVZ 85506, 85507 (2 m); Cuba, USNM O 347811 (m); Colombia (ssp. *brachypterus*), MVZ 141720 (f); Ecuador, USNM O 500433 (f); Brazil, USNM O 345750 (m). *Podilymbus podiceps*: Washington, UWBM 34524, 34550, 35933 (1 m, 2 f); California, MVZ 28867, 74909, 74925, 87985, 118985, 118986, 151553, USNM O 431389 (6 m, 2 f); Uruguay, USNM O 635999 (f). *Rollandia rolland*: Bolivia, MVZ 141721 (f); Argentina, USNM O 614508, 614512 (2 f). *R. microptera*: Peru, MVZ 126353–126355, 126361–126365, 127171, 14722 (1 m, 8 f). *Poliocephalus poliocephalus*: Australia, MVZ 143233–143243 (5 m, 6 f). *Podiceps grisegena*: Netherlands, USNM O 555663 (m); Japan, KUGM RA 0627, MVZ 125422, NSMT AS 1244, 1402, YIO 70514, 71202 (1 m, 1 f, 4 u); British Columbia, MVZ 65619, UWBM 26456 (1 m, 1 f); Washington, USNM O 561876, 561878–561880, 612739–612778, UWBM 14214, 26226, 36652, 36653, 39934–39938, 39940–39952, 39954–39958, 42038–42053, 43070, 43622–43632, 43634, 43635, 43655, 43660, 43663, 43665, 43781, 43787 (62 m, 44 f, 2 u); Wisconsin, MVZ 125125 (m). *P. cristatus*: France, USNM O 344645 (u); Netherlands, USNM O 502552, 502553, 554119, 554120, 554867, 555153, 557532, 557533, 560591, 560592, 560594–560596, 610489 (7 m, 7 f); Astrakhanskaya Oblast’, UWBM 56440 (f); Khabarovskiy Kray,

UWBM 46892, 47186 (1 m, 1 f); Japan, NSMT AS 1190 (u); Australia, MVZ 154307 (m); New Zealand, 18294, 18295 (2 u). *P. auritus*: Kamchatska, USNM O 17273 (m); China, USNM O 318985 (f); Alaska, MVZ 137042 (m); British Columbia, MVZ 53896, 63049, 63050 (3 f); Manitoba, UWBM 36468, 37060 (2 m); Washington, UWBM 12537, 13925, 14174, 18561, 26754, 30067, 31742, 35916, 35917, 35941, 36654, 38693 (6 m, 4 f, 2 u); California, MVZ 46799, 53269, 53270, 53894, 53970, 70616, 120300, 151548–151550, 170855 (5 m, 9 f, 2 u). *P. nigricollis*: China, USNM O 292771, 292772 (2 m); Korea, MVZ 150921 (f); Manitoba, UWBM 37062 (m); Washington, UWBM 15491, 33947, 35731, 35732, 35734, 35736 (3 m, 3 f); California, MVZ 49495, 49529, 49530, 51387, 53257–53264, 53774, 54387, 54403, 54407, 54474–54476, 56244, 66498, 66499, 125154, 150921, 151551, 151552, 171438 (9 m, 8 f, 10 u); Peru, MVZ 125154 (f). *P. occipitalis*: Argentina, USNM O 227487 (m). '*P.*' *major*: Peru, MVZ 154307 (f); Uruguay, KUGM RA 0628 (u); Argentina, USNM O 227343, 227344, UWBM 37692, 41035, 41037 (1 m, 2 f, 2 u). *Aechmophorus occidentalis*: Washington, UWBM 14181, 14216–14218, 14284, 20348, 20527 (1 m, 2 f, 4 u); California, MVZ 180136, 183769, 189515–189521, 189524, 189525, 189528, 189529, 189531–189533, 189537, 189539, 189540 (9 m, 9 f, 1 u). *A. clarkii*: Washington, UWBM 42991, 42995, 44677, 54950, 54959, 76789 (3 m, 3 f); California, MVZ 179313, 180135, 189572–189544 (3 m, 2 f).

Gaviidae. *Gavia stellata*: Tyumenskaya Oblast', UWBM 56951 (m); Sakha Republic, UWBM 44259–44261 (1 m, 2 f); Chukotskiy Avtonomnyy Okrug, UWBM 43925, 44122 (1 m, 1 f); Alaska, MVZ 68384–68388, UWBM 79183 (3 m, 3 f); Washington, UWBM 37497, 47782, 50640–50644, 50649, 50653, 50655, 50656, 50659, 50662, 50671, 50675, 50679 (5 m, 9 f, 1 u); Oregon, UWBM 38284 (m); California, MVZ 19031, 19033–19035, 46126, 46800, 49330, 49496, 49639, 70611–70615, 79299, 151540, 151541, 164468, UWBM 62987 (4 m, 9 f, 2 u); Delaware, UWBM 69507 (u). *G. arctica*: Netherlands, USNM O 554272, 554273 (1

m, 1 f); Japan, NSMT AS 1162 (u); locality unknown, USNM O 623393 (m). *G. pacifica*: Chukotskiy Avtonomnyy Okrug, UWBM 44118 (f); Japan, NSMT AS 1202, 1220 (2 u); Alaska, MVZ 60236, 126636, 137251, 140830, 160723, UWBM 52080 (2 m, 3 f, 1 u); Washington, UWBM 28567, 36153, 41984, 50632–50639, 50641, 50645–50648, 50650–50652, 50654, 50657, 50658, 50660, 50661, 50664–50670, 50673, 50674, 51478, 51479, 51480, 51484, 65176, 84514 (20 m, 23 f, 1 u); California, MVZ 19028–19030, 19032, 49303–49329, 49392, 49393, 49395, 49396, 151542–151547, USNM O 346557, 491292, 492477, UWBM 62988 (7 m, 3 f, 36 u); locality unknown, MVZ 28982 (u). *G. immer*: Alaska, MVZ 137040, 137041 (2 m); Washington, UWBM 13914, 18574, 30068, 32949, 33422, 35806, 37247 (2 m, 3 f, 3 u); California, MVZ 54408, 125317, 125365, 175970 (1 m, 1 f, 2 u); Nevada, UWBM 19815 (u). *G. adamsii*: Alaska, MVZ 129366, 133560, USNM O 289437, 491479, 559809–559811, UWBM 50549, 50716, 51924–51926 (5 m, 5 f, 3 u); Northwest Territories, USNM O 11050 (u); Washington, UWBM 39069, 42007 (2 f).

Hydrobatidae and Oceanitidae. *Oceanites oceanicus*: Antarctica, MVZ 169107, 160108 (1 m, 1 f); South Shetland Islands, USNM O 488308 (m); North Pacific, USNM O 614721 (f). *O. gracilis*: Galapagos, MVZ 151389 (m); South Pacific, USNM O 491398, 491399 (1 m, 1 f). *Garrodia nereis*: New Zealand, USNM O 559030 (f). *Pelagodroma marina*: Peru, USNM O 496759, 496760 (1 f, 1 u). *Fregetta grallaria*: South Pacific, USNM O 613927, 613928 (1 m, 1 f). *F. tropica*: Antarctic, USNM O 559800 (f); South Atlantic, USNM O 553239 (f). *Nesofregetta fuliginosa*: Phoenix Islands, USNM O 498012 (m); Christmas Island, USNM O 498015 (f). *Hydrobates castro*: Japan, YIO 901, 62054, 65295 (1 f, 2 u; 2 p); Tennessee, USNM O 526349 (u; p); St. Helena Island, USNM O 525795 (m; p). *H. matsudairae*: Indian Ocean, USNM O 487597 (f; p); Japan, YIO 63000 (m; p); Bonin Islands, YIO 1079 (f; p). *H. melania*: California, MVZ 19086, 67951–67954, UWBM 30652 (3 m, 2 f, 1 u); Baja California, USNM O 19030, 498404–498410 (3 m, 4 f, 1 u); Panama, USNM O 428578 (m;

p). *H. homochroa*: California (including Farallon Islands), MVZ 68337–68340, 93676, UWBM 36358, USNM O 491301, 500220, 500221, 561080 (5 m, 2 f, 3 u). *H. microsoma*: Baja California, MVZ 121580, USNM O 498392–498401 (5 m, 6 f); locality unknown, USNM O 502287 (u). *H. tethys*: Ecuador (including Galapagos), UWBM 33900–33902 (1 m, 2 f); North Pacific, USNM O 613241, 613242, 613244–613246, 613248, 613251, 613253, 613254, 613257, 613258, 613260, 613933–613944, 614189–614192, 614194–614916, 614198, 614199, 614201 (17 m, 15 f). *H. leucorhous*: Japan, MVZ 124048; Hawaiian Islands, USNM O 559296 (u); Alaska, USNM O 488651, 639042–639044 (1 m, 3 f); British Columbia, UWBM 14206, 14207, 26372, 26374, 27375 (3 m, 1 f, 1 u); Washington, UWBM 19311, 19312, 19332, 21231, 21232, 30158, 38820 (4 m, 2 f, 1 u); Oregon, MVZ 80623, USNM O 499037, 499628, 553129 (1 f, 3 u); California, MVZ 17038, 161908–161910, 169141, USNM O 19444 (1 m, 1 f, 4 u); Baja California, 19445, 291878, 498389–498391 (3 m, 1 f, 1 u); Colombia, USNM O 346545 (m; p); North Pacific, USNM O 497979, 498223–498225, 498227, 498229–498244, 498360, 498361, 613261–613275, 614207–614217 (24 m, 24 f, 1 u); New Brunswick, USNM O 490750–490752 (3 m); Newfoundland, USNM O 17803, 18077, 18078, 428056 (1 m, 3 u); Maine, USNM O 17784 (m); Maryland, USNM O 321798 (u; p); Virginia, USNM O 17784 (m; p). *H. monorhis*: Primorskyi Kray, USNM O 500261, 557492 (2 u); Japan, YIO 929, 20663, 61916, 64457, 65054, 70510 (1 m, 3 f, 2 u; 4 p). *H. tristrami*: Hawaiian Islands, USNM O 289202, 289203, 498485 (3 u); North Pacific, UWBM 55363, 55738, 55740, 61903, YIO 61701 (2 m, 3 f). *H. markhami*: Hawaiian Islands, USNM O 497962, 554848 (1 m, 1 f). *H. furcatus*: Japan, YIO1227, 61703, 62694, 63084, 63085, 63110, 63251, 63259, 63260, 63263, 63549 (1 m, 2 f, 8 u; 13 p); Alaska, MVZ 60296, UWBM 31294–31297, 32000, USNM O 14354, 14355, 344543, 620278, 620279, 638709, 63710 (6 m, 6 f, 1 u); British Columbia, UWBM 26377 (m); Washington, UWBM 14229, 30529, 30616, 87877 (1 f, 3 u); California, MVZ 72288, 86674, USNM O 557603, 559559,

559560 (3 m, 1 f, 1 u); North Pacific, USNM O 556268–556274 (4 m, 2 f, 1 u); locality unknown, USNM O 16990–16993 (4 u). *H. hornbyi*: Peru, NSNM 491400, 491401, 496729 (2 m, 1 f; 1 p); locality unknown, USNM O 346546 (f; p).

Diomedidae. *Diomedea epomophora*: New Zealand, USNM O 561848, 554692 (1 m, 1 u). *D. exulans*: Singapore, USNM O 321465 (u); Chile, USNM O 17036, 290071, 559552 (3 u); Amsterdam Island, USNM O 488376 (f); locality unknown, MVZ 29114, USNM O 3490, 18554, 321749, 345309, 345310, 561349 (7 u). *D. antipodensis*: New Zealand, UWBM 81027, 81028, 81036–81038, 81045 (4 m, 2 f). *Phoebetria fusca*: Amsterdam Island, USNM O 488378, 48379 (1 m, 1 f); Indian Ocean, USNM O 488374, 488383 (2 f). *P. palpebrata*: South Pacific, USNM O 502518 (f). *P. irrorata*: Galapagos, MVZ 140903, 151384, 151385 (immature), USNM O 491447, 491448 (2 f, 4 u); Peru, MVZ 157987 (u). *P. nigripes*: Japan, YIO 64776, 70740 (2 u; 1 p); Torishima Island, YIO 393, 60005, 64769, 64775, 64777 (1 m, 4 u); Alaska, USNM O 610581, 622480 (2 m); UWBM 32419, 33356–33358, 33361 (3 m, 2 f); Washington, USNM O 432183, UWBM 30197, 30528 (2 m, 1 u); Oregon, USNM O 431382, 431383, UWBM 38285 (1 f, 1 u); California, MVZ 54002, 64627, 66508, 67950, 72294, 175959, 175960, USNM O 19740 (1 m, 1 f, 6 u; 3 p); Hawaiian Islands, USNM O 289168, 289169, 289170, 289173, 289174, 488172–488174, 488176, 497920, 497964 (4 m, 4 f, 3 u); North Pacific, USNM O 7216, 17331, 630952–630957, 630959, 630960, 630964–630967, 630969, 630975, 630976, UWBM 36346, 65754, 65755, 65757–65764 (14 m, 12 f, 2 u); locality unknown, NSMT AS 1212 (u). *P. immutabilis*: Japan, YIO 405, 61913, 62817, 64205, 64206, 64426–64428, 64746, 65292 (2 m, 3 f, 5 u; 4 p); Ryukyu Islands, YIO 61914 (m; p); Bonin Islands, YIO 404 (f; p); Oregon, USNM O 431309 (u); California, MVZ 177560, USNM O 12299 (1 m, 1 u); Midway Atoll, MVZ 142647, 142648 (1 m, 1 f); Hawaiian Islands, USNM O 289155–289158, 289160–289166, 488177–488181, 497965, 498067, 498136–498139, 498426, 498428, 498429, 500859 (9 m, 9 f, 9 u); North Pacific–

Bering Sea, USNM O 623524, 630948–630951, 630962, 630963, 630968, 630970–630974, 630977–630982, UWBm 18982, 19001, 33201, 33359, 35364, 39576, 39577, 43235 (19 m, 8 f). *P. albatrus*: Kamchatska, USNM O 16960, UWBm 12001 (2 u); Korea, USNM O 18224, 18225 (2 u); Japan, YIO 354, 61909 (2 m; 2 p); Torishima Island, YIO 353, 63610, 63370, 63441, 63552, 64761, 64768, 65296 (2 m, 3 f, 3 u; 3 p); Alaska, MVZ 15540, 28980, USNM O 78978, UWBm 55909, 56978 (2 m, 3 u; 1 p); Washington, USNM O 6586, 6587 (2 u; 2 p); Oregon; UWBm 82972 (u); locality unknown, USNM O 19052–19054 (3 u). *Thalassarche chlororhynchos*: Uruguay, USNM O 635731 (m); Amsterdam Island, USNM O 488384 (m). *T. chrysostoma*: South Georgia Island, USNM O 553247 (m). *T. melanophris*: New Zealand, USNM O 491324 (f); Uruguay, USNM O 227887, 490222, 631073, 631184, 635729 (1 m, 2 f, 2 u); Argentina, 490923, 490924 (2 m); Falkland Islands, USNM O 1833, 1834 (2 u); South Georgia Island, USNM O 553256 (m); locality unknown, USNM O 491324, 561350 (1 f, 1 u). *T. impavida*: New Zealand, UWBm 80944, 80965, 80972, 80984, 81030, 81032 (2 m, 4 f). *T. bulleri*: New Zealand, USNM O 554698, UWBm 10970, 80971, 81021, 81022, 81023, 81024, 81025, 81042, 81537, 82118 (6 m, 4 f, 1 u). *T. cauta*: Tasmania, USNM O 623376 (m); New Zealand, USNM O 502133 (u). *T. steadi*: New Zealand, UWBm 80958, 80963, 81004, 81015, 81016, 81039 (4 m, 2 f). *T. salvini*: Peru, MVZ 127172 (immature), 161426, UWBm 80945, 80956, 80959, 80960, 80969, 80978, 80979, 81000, 81001, 81005, 81013 (5 m, 6 f, 2 u; 1 p).

Procellariidae. *Macronectes halli*: South Georgia Island, USNM O 553248 (u). *M. giganteus*: Antarctica, MVZ 149369, 142961 (2 m). *Fulmarus glacialis* (ssp. *glacialis* or *auduboni*): Newfoundland, USNM O 17801, 17798 (2 u); Greenland, USNM O 16781 (u); Iceland, USNM O 623297–623299 (2 m, 1 f); Netherlands, USNM O 560935 (m); North Atlantic, USNM O 16987 (m). *F. glacialis rodgersii*: Japan, EP 150, KUGM RAJ 10091013, NSMT AS 575, 869, 1425, NSMT PV A322, A323, A327, A 331, A332, A336, A346,

NSMT AS 483, 575, 869, YIO 64756, 64779, 70465 (2 m, 2 f, 15 u); Alaska, USNM O 12613, 226080–226082, 498482, 500862, 561169–561172, 610585, 638824, 638825, 638827, 638828, UWBm 26891, 33175–33177, 33183, 33187–33190, 33193, 40974–40980, 42454, 51226 (20 m, 7 f, 6 u); Northwest Territories, USNM O 15732, 347258 (1 m, 1 u); British Columbia, UWBm 26373 (m); Washington, MVZ 182936–182939, 182952, 182953, 182960, 182961, UWBm 13943, 28709, 30052, 30053, 30055, 31165, 31660, 31910, 31926 (2 m, 9 f, 11 u); Oregon, USNM O 489360, UWBm 26332 (f); California, MVZ 46127, 49367, 49368, 49400, 53829, 54418, 89468, 118980, 151558–151562, 169103, 171439–171441, USNM O 502290, 557599, 557600–557602 (6 m, 4 f, 8 u); Hawaiian Islands (including Midway Atoll), USNM O 489327, 498110–498114 (6 u); North Pacific, USNM O 561910–561912, UWBm 26512, 26516 (2 m, 3 f). *F. glacialoides*: Argentina, UWBm 57106, 57107 (2 u); Antarctica, MVZ 169103, USNM O 559719, UWBm 38024–38027 (3 m, 2 f). *Thalassoica antarctica*: Antarctica, MVZ 169104, USNM O 554832, 554844 (3 m). *Daption capense*: Antarctica, USNM O 488312, 559725, 559733 (2 m, 1 f). *Pagodroma nivea*: Antarctica, MVZ 149382, 149383, 149386, 149389, 169105, 169106, USNM O 502506, 559740 (6 m, 2 f). *Halobaena caerulea*: Antarctica, USNM O 559758, 559764 (1 m, 1 f). *Pachyptila vittata*: New Zealand, USNM O 554703 (u). *P. turtur*: Australia, MVZ 143244 (u). *Aphrodroma brevirostris*: Antarctica, USNM O 561329, 561330 (1 m, 1 f). *Pterodroma leucoptera*: Pacific Ocean, USNM 613884 (f). *P. longirostris*: North Pacific, UWBm 55677, 55678 (2 m). *P. hypoleuca*: Hawaiian Islands, UWBm 15473, 19360, YIO 70507 (1m, 1 f, 1 u). *P. nigripennis*: North Pacific, USNM O 613895, 613897 (1 m, 1 f). *P. solandri*: North Pacific, UWBm 61910, 61911 (1 m, 1 f); Australia, USNM 500641 (u). *P. neglecta*: North Pacific, USNM O 497176, 562779 (2 m). *P. inexpectata*: North Pacific, UWBm 55612, 55694 (2 m). *P. phaeopygia*: Hawaiian Islands, UWBm 38269 38275 (1 m, 1 f). *P. externa*: North Pacific, UWBm 64595, 64596 (1 m, 1 f). *P. lessonii*: Australia, UWBm 62924 (m); New Zealand, UWBm 80986 (f).

Procellaria aequinoctialis: New Zealand, UWBM 81508–81510, 81512, 81513, 81515 (3 m, 3 f); Antarctica, USNM O 559784, 559787 (1 m, 1 f). *P. westlandica*: New Zealand, USNM O 554695 (u). *Calonectris leucomelas*: Japan, EP 92, NSMT AS 998, 1255, NSMT PV A209, 299, 316, YIO 60623, 64363, 64764, 64951, 70482 (1 m, 1 f, 9 u); Indonesia, USNM O 558348–558351, 559033–559035 (4 m, 3 f); North Pacific, UWBM 55320, 55602–55604, 55727 (5m, 1 f). *C. diomedea*: North Carolina, USNM O 620710–620718 (5 m, 4 f); Italy, USNM O 612133 (m); Greece, USNM O 488776, 488777, 555936 (2 m, 1 u). *C. borealis*: Massachusetts, USNM O 17767, 17770, 17773–17776, 17788–17791, 17831, 347825 (12 u); Northwest Atlantic, USNM O 620715, UWBM 38170, YIO 70508 (2 f, 1 u). *Puffinus pacificus pacificus*: Pacific, USNM O 614180, 614182 (1 m, 1 f). *P. pacificus cuneatus*: Hawaiian Islands, USNM O 289184, 289185 (1 m, 1 f); Japan, YIO 64733 (u). *P. bulleri*: California, MVZ 133402, 140362 (1 m, 1 u); Pacific, USNM O 620814, 620815 (1 m, 1 f). *P. tenuirostris*: Japan, EP 52, 264, 267, 268, NSMT AS 38, YIO 60626, 60751–60753, 64680, 65437 (2 m, 9 u); Alaska, MVZ 60253–60255, 60257, 160556, 160726, 164649 (4 m, 1 f, 2 u); California, MVZ 19085, 119007, 165772 (1 f, 2 u); North Pacific, USNM O 223154 (m); Australia, USNM O 612627 (f); Tasmania, MVZ 134924 (f). *P. griseus*: Japan, EP 18, 131–134, NSMT AS 1303, YIO 70490 (3 m, 1 f, 3 u); California, MVZ 15495, 19083, 19084, 41135, 49370–49383, 49369, 49401–49408, 54424–54427, 84697, 161907 (1 m, 1 f, 31 u); Hawaiian Islands, USNM O 498254; New Zealand, YIO 60624 (m); Pacific, USNM O 613236 (m). *P. gravis*: North Pacific, USNM O 561135, 561145 (1 m, 1 f). *P. carneipes*: North Pacific, USNM O 620812, 621658 (1 m, 1 f). *P. creatopus*: Washington, USNM O 558424 (m); California, MVZ 119005, 119005, 155189 (2 m, 1 u); Pacific, USNM O 559553 (f). *P. nativitatis*: Hawaiian Islands, USNM O 289177–289179, 497941, 498068, 615081 (4 m, 2 f, 1 u); Phoenix Islands, USNM O 497998, 498000, 498001 (1 m, 2 f); North Pacific, 615081, 613922 (2 m). *P. subalaris*: California, MVZ 151386, 151387 (1 m, 1 f). *P. gavia*:

New Zealand, USNM O 614345 (u). *P. opisthomelas*: California, MVZ 19080–19082, 49544, 151563, 151564 (3 m, 2 f, 1 u); Mexico, USNM O 559675, 559676 (2 u). *P. newelli*: Hawaiian Islands, USNM O 502216, 502217, 502524, 502532, 639473, 639489, 639506–639508, 639514, 639545, 639546 (6 m, 5 f, 1 u). *P. bailloni*: Phoenix Islands, USNM O 498003, 498006 (1 m, 1 f). *P. puffinus*: Virginia, USNM O 572999 (f); North Carolina, USNM O 560860, 560861, 610341 (2 m, 1 f, 2 p); Brazil, USNM O 491459, 491460, 491470, 491471, 611759 (2 f, 3 u); Uruguay, USNM O 491958 (u); Argentina, USNM O 227465 (m; p). *P. yelkouan*: Greece, USNM O 488785, 488788–488790 (1 m, 2 f, 1 u); Turkey, USNM O 289433 (f). *P. mauretanicus*: Spain, USNM O 613580, 613581, 614146–614148, 620502, 620503 (7 u). *Pseudobulweria rostrata*: California, MVZ 00 (f). *Bulweria bulwerii*: Japan, YIO 65406 (u); Pacific, USNM O 491908, 498248, 498249 (1 m, 2 f).

Phalacrocoracidae. The same material as used by Watanabe *et al.* (2018).

Scolopacidae. *Bartramia longicauda*: Alberta, USNM O 641407 (m); North Dakota, USNM O 610845 (f). *Numenius phaeopus*: Khabarovskiy Kray, UWBM 46885 (m); Japan, MVZ 124070 (f); Alaska, MVZ 134531 (f). *N. minutus*: Australia, USNM O 347648 (f). *N. americanus*: Mexico, MVZ 54887 (m). *N. arquata*: Netherlands, USNM O 553828, 614127 (1 m, 1 f). *N. madagascariensis*: Korea, USNM O 633463, 633468 (1 m, 1 f). *Limosa lapponica*: Netherlands, USNM O 555156 (f); Alaska, MVZ 166874, USNM O 499267 (2 m). *L. fedoa*: California, MVZ 159647 (m). *L. haemastica*: Argentina, USNM O 614608, 614609 (1 m, 1 f). *L. limosa*: Korea, MVZ 135050, 151014 (1 m, 1 u). *Arenaria interpres*: Japan, MVZ 124080, 124081 (1 m, 1 f). *A. melanocephala*: California, MVZ 19108 (m). *Calidris tenuirostris*: Korea, MVZ 151023 (f); Japan, MVZ 123993 (f). *C. canutus*: California, MVZ 79337 (m). *C. [formerly Aphaiz] virgata*: Mexico, MVZ 48413 (m). *C. [formerly Philomachus] pugnax*: aviary, MVZ 134845 (m). *C. [formerly Limicola] falcinellus*: Korea, MVZ 151027 (u); Thailand, USNM O 488483 (m). *C. acuminata*: Korea, MVZ 151025 (f). *C.*

himantopus: Manitoba, USNM O 489640, 489657 (1 m, 1 f). *C. ferruginea*: Amirante Islands, USNM O 488414 (m); Mauritius, USNM O 488486 (f). *C. temminckii*: Korea, MVZ 140790 (m). *C. subminuta*: Korea, MVZ 143653 (f?). *C. [formerly Eurynorhynchus] pygmaea*: Chukotskiy Avtonomnyy Okrug, UWBM 44133 (f); Japan, USNM O 292903 (u). *C. ruficollis*: Japan, MVZ 124088 (f). *C. alba*: California, MVZ 156137 (m). *C. alpina*: California, MVZ 156145 (f). *C. ptilocnemis*: Alaska, USNM O 498221, 638904 (1 m, 1 f). *C. bairdii*: Alaska, MVZ 126696 (f). *C. minuta*: Spain, UWBM 19883 (f). *C. minutilla*: California, MVZ 124088 (f). *C. fuscicollis*: North Dakota, MVZ 125741 (m). *C. [formerly Tryngites] subruficollis*: Alaska, MVZ 156026 (m). *C. melanotos*: Alaska, MVZ 160628 (m). *C. mauri*: California, MVZ 179968 (m). *Limnodromus griseus*: California, MVZ 118695 (m). *L. scolopaceus*: California, MVZ 68683 (f). *Scolopax rusticola*: Japan, MVZ 128730 (f). *S. minor*: Michigan, MVZ 155441 (m). *Gallinago hardwickii*: Japan, MVZ 124087, NSMT AS 14, NSMT PV A416, A417 (1 m, 3 u; 2 p); Australia, USNM O 612667 (f). *G. stenura*: Korea, MVZ 151108 (u); Thailand, USNM O 343218–343220 (3 f); Indonesia, USNM O 557034, 557035 (2 m; 1 p). *G. megala*: Mongolia, USNM O 621521, UWBM 57928, 57944 (2 m, 1 f); Khabarovskiy Kray, USNM O 500256 (m); Korea, USNM O 143540, 148817, 148818, 151149 (1 m, 3 f); Ryukyu Islands, YIO 62826 (m; p); Taiwan, USNM O 611820 (m); New Guinea, MVZ 149283 (u). *G. nigripennis*: Kenya, MVZ 135145 (f); Zimbabwe, USNM O 488842 (m); South Africa, UWBM 52822, 52823 (1 m, 1 f). *G. media*: Denmark, USNM O 621541–621543 (1 m, 2 f); Kenya, USNM O 431836 (m); Tyumenskaya Oblast', UWBM 56761 (f). *G. gallinago*: Iceland, USNM O 623274, 623275 (2 f); France, USNM O 499072 (u); Egypt, USNM O 603468–603473 (3 m, 3 f); Tyumenskaya Oblast', UWBM 56957 (m); Magadanskaya Oblast', UWBM 52616 (f); China, USNM O 289955, 291652, 292366, 292763 (2 m, 2 f); Korea, MVZ 156098, USNM O 633385, 633417, 633450, 633452 (3 m, 2 f); Japan, NSMT PV A507, YIO 63940, 64570, 64592, 64593, 70934 (2 m, 3 f, 1 u; 5

u); Ryukyu Islands, YIO 64571, 64594, 64595 (3 f; 3 p); Bonin Islands, YIO 64569 (m; p); Philippines, USNM O 561995 (m). *G. delicata*: Nevada, MVZ 125712 (u). *Lymnocyrtes minimus*: Egypt, USNM O 603475, 603476 (1 m, 1 f). *Steganopus tricolor*: Washington, UWBM 31866–31870, 31884–31886 (3 m, 5 f); Idaho, MVZ 67553–67555, 67565 (1 m, 3 f); Nevada, MVZ 51380, 51381, 63547, 134201, 151802–151805 (4 m, 2 f, 2 u). *Phalaropus lobatus*: Japan, MVZ 124009, 124010 (2 u); Alaska, MVZ 126768, 126769, 166875, UWBM 20587, 28349–28352, 28356, 31011, 31022 (6 m, 5 f); Manitoba, MVZ 135166, 135167 (1 m, 1 f); Washington, MVZ 84720, UWBM 18998–19000 (1 f, 3 u); California, MVZ 41114–41116, 63301–63303, 74494–74496, 87463, 151808, 156149–156151 (6 m, 1 f, 7 u); Nevada, MVZ 65101, 65102, 151806, 151807 (1 m, 3 f). *Phalaropus fulicarius*: Alaska, MVZ 68395, 68396, 126741, 126745, 134082, 142041, 142730, 166876, UWBM 28168–28173, 28279, 30001, 30002, 31006–31008 (11 m, 9 f); California, MVZ 66971, 68069, 120368, 123899, 151800, 151801, 171448 (3 m, 3 f, 2 u). *Xenus cinereus*: Korea, MVZ 143651 (f). *Actitis hypoleucos*: Japan, MVZ 124075 (m). *A. macularius*: Arizona, MVZ 41448 (f). *Tringa ochropus*: Cameroun, USNM O 322503, 322504 (m). *T.* [formerly *Heteroscelus*] *brevipes*: Japan, MVZ 123984 (m). *T.* [formerly *Heteroscelus*] *incana*: Alaska, USNM O 612204, 612205 (1 m, 1 f). *T.* [formerly *Catoptrophorus*] *semipalmatus*: Mexico, MVZ 54898 (f). *T. flavipes*: Nevada, MVZ 151786 (m). *T. erythropus*: Germany, USNM O 559071 (u); Sakha Republic, USNM O 557502 (m). *T. nebularia*: Korea, MVZ 151016 (m). *T. melanoleuca*: California, MVZ 54613 (u). *T. totanus*: Korea, MVZ 150928 (m). *T. glareola*: Korea, MVZ 151106 (f). *T. stagnatilis*: Mongolia, UWBM 60151 (f).

Laridae. *Anous stolidus*: Mexico, MVZ 56173 (m). *A. minutus*: Johnston Atoll (ssp. *marcusi*), USNM O 631386, 632002 (1 m, 1 f). *Procelsterna cerulea*: Phoenix Islands, USNM O 498058, 498218 (1 m, 1 f). *Gygis alba*: Johnston Atoll (ssp. *candida*), USNM O 622604, 631391 (1 m, 1 f); Marshall Islands, MVZ 95103 (m). *Rynchops niger*: Virginia, USNM O

610931, 610932 (1 m, 1 f); Florida, MVZ 125775 (m). *Hydrocoloeus minutus*: Netherlands, USNM O 502550, 553647 (1 m, 1 f); Peru, USNM O 498301 (f). *Rhodostethia rosea*: Alaska, MVZ 129400, USNM O 491608, 491611 (2 m, 1 f). *Creagrus furcatus*: Galapagos, MVZ 140952 (m); Peru, USNM O 498301 (f). *Xema sabini*: Alaska, MVZ 60535; USNM O 553905, 557605 (2 m, 1 f). *Pagophila eburnea*: Alaska, MVZ 156027, USNM O 491596, 491598 (1 m, 1 f, 1 u). *Rissa brevirostris*: Alaska, USNM O 638706, 638906 (2 f). *R. tridactyla*: Alaska, MVZ 68398; USNM O 500141, 500154 (1 m, 2 f). *Larus philadelphia*: California, MVZ 49542 (m). *L. genei*: Azerbaijan, USNM O 500267 (u). *L. ridibundus*: Netherlands, USNM O 556296, 556298 (1 m, 1 f); Kamchatka, UWBm 44055, 44056 (2 m). *L. crassirostris*: Japan, MVZ 125474, 125475 (2 f). *L. canus*: California, MVZ 49537 (f). *L. occidentalis*: California, MVZ 156745 (f). *L. argentatus*: California, MVZ 40420 (f). *L. schistisagus*: Kamchatka, UWBm 44341 (m). *Onychoprion fuscatus*: Johnston Atoll, USNM O 621359 (m). *Sternula albifrons*: Egypt, USNM O 553054 (m); Korea, MVZ 150975 (m); Japan, USNM O 641888 (m). *Phaetusa simplex*: Guyana, USNM O 637171, 637257 (1 m, 1 f). *Hydroprogne caspia*: Washington, USNM, 630680, 630684 (1 m, 1 f). *Larosterna inca*: Hawaiian Islands, UWBm 19928 (u). *Chlidonias niger*: California, MVZ 56198. *Sterna hirundo*: Indonesia, USNM O 557037, 560799 (1 m, 1 f). *Thalasseus elegans*: California, MVZ 177555 (m). *T. maximus*: California, MVZ 64503 (f). *T. bergii*: South Africa, USNM O 558526 (m); Australia, MVZ 143412 (f).

Alcidae. For living taxa, generic identification was mainly based on the material examined by Watanabe *et al.* (2016). Most specimens of *Uria lomvia* and *U. aalge* stored in USNM O were examined to assess the variation of the processus acrocoracoideus of the coracoid. In addition, the following specimens were included in mensural comparisons. *Cerorhinca monocerata*: Japan, EP 105–108, 110, 112, 114, 115, HUMNH 60455, 60456, KUGM RA 14052601, 14070391, 17070802, 14071302, NSMT AS 1313, YIO 12811, 12817, 62370,

62469, 62588, 62589, 62657, 62658, 62632, 63693, 63938 (8 m, 5 f, 13 u; 12 p); California, MVZ 19037, 19038, 41135, 45034, 49331–49339, 49397, 54409, 54410, 72299, 88694, 151844–151846, 156800, 158762 (4 m, 1 f, 18 u). *Fratercula cirrhata*: Japan, EP 152, 153, NSMT AS 599, 622, YIO 65097, 65098 (3 m, 3 u; 2 p); Alaska, MVZ 68418, 68419, 125348, 126818, 159161, YIO 12905–12908 (5 m, 3 f, 1 u; 4 p); California, MVZ 41147, 54411 (2 u); North Pacific, HUMNH 60427–60434, 60439–60446, 60453, 60454, NSMT VP A362, A363 (11 m, 6 f, 3 u); aviary, YIO 62943 (immature), 63976 (1 m, 1 u; 2 p); locality unknown, NSMT VP A364, A365, A536, A572–A576, YIO 64420, 70606 (1 m, 2 f, 8 u; 3 p). *F. arctica*: Newfoundland, YIO 12856–12861 (4 m, 2 f; 6 p); aviary, YIO60955 (immature), 60957, 60958, 62490, 62491, 64404, 65273, 65391 (4 m, 1 f, 2 u; 2 p). *F. corniculata*: Japan, EP 154 (u); Alaska, MVZ 28957, 28960, 28967, 60637, 68413–68417, 134084, 160699, YIO 12878 (5 m, 5 f, 2 u; 3 p); California, MVZ 30713, 30714 (2 u, 1 p); North Pacific, HUMNH, 60418–60422, 60425, 60426, NSMT VP A366 (3 m, 2 f, 3 u; 1 p); aviary, NSMT AS 1438 (u); locality unknown, NSMT VP A577 (f). *Ptychoramphus aleuticus*: Alaska, HUMNH 60404–60406 (2 m, 1 f); California, MVZ 19040, 54000, 54001, 49390, 68344, 74497, 83269, 156753 (2 m, 1 f, 6 u). *Aethia psittacula*: Japan, EP 24 (u); Alaska–Bering Sea, HUMNH 60409, LACM O 107192, MVZ 89469, 142738 (2 m, 1 f, 1 u); North Pacific, NSMT VP A355, UWBW 43384 (1 m, 1 u); locality unknown, NSMT AS 564, YIO 62863 (2 u). *A. pusilla*: Japan, YIO 12773, 63904, 63941, 63989, 64945 (4 m, 1 f; 5 p); Alaska–Bering Sea, HUMNH 60407, LACM O 110833, MVZ 60612, 60619, 61001, 134083 (2 m, 3 f, 1 u); California, MVZ 168469 (m; p); locality unknown, NSMT VP A356, A357 (2 u; 2 p). *A. pygmaea*: Alaska-Bering Sea, HUMNH 60408, LACM O 110691, 110841, 110842, MVZ 60629 (2 m, 3 f). *A. cristatella*: Japan, YIO 62652, 63998, 64022 (1 m, 1 f, 1 u; 3 p); Alaska–Bering Sea, HUMNH 60402, 60403, LACM O 110616–110618, 110671, UWBW 26200, 26201, 26212, 30102, 32090 (6 m, 4 f, 2 u); California, CAS 70170 (m; p); North Pacific,

CAS 84951, 84952 (1 f, 1 u); locality unknown, NSMT AS 835, 845, YIO 62864, 65101 (4 u; 3 p). *Cepphus grylle*: Greenland, USNM O 16776, 344752–344761, 347071 (7 m, 3 f, 2 u); Iceland, USNM O 292349 (u); Alaska, USNM O 491647, 491648, 612213, 612214, UWBM 78969 (4 f, 1 u); Northwest Territories, USNM O 347265 (m); Nunavut, USNM O 347077 (m; p); Quebec, USNM O 18071 (f; p); New Brunswick, USNM O 18072, 18073, 321491 (3 u); Newfoundland, USNM O 225763 (u); locality unknown, USNM O 16975 (u; p). *C. columba*: Alaska, MVZ 160710, USNM O 18206, 223728 (1 m, 2 u; 1 p); Washington, USNM O 612988, 612989 (1 m, 1 f); California, MVZ 41124, 63287, 68343, 70636, 123900, USNM O 498420, 498422–498424 (3 m, 3 f, 3 u; 1 p). *C. carbo*: Magadanskaya Oblast', UWBM 43349, 43842–43845, 43859, 43860, 44429, 44430 (3 m, 6 f, 2 p); Japan, HUMNH 60457, MVZ 119013, USNM O 347755–347757, YIO 63725 (1 f, 4 u; 1 p).

Synthliboramphus antiquus: Magadanskaya Oblast', UWBM 43338, 43339 (2 f); Japan, MVZ 123166–123168, 126464, 128734, NSMT VP A60, A427, YIO 12622, 62590, 62659–62663, 63903, 64509, 64516, 65084 (6 m, 8 f, 5 u; 13 p); Alaska, HUMNH 60399–60401 (2 m, 1 f); Washington, UWBM 38779, 39594 (1 m, 1 f); California, MVZ 19044, 19045, 62755, 66972, 70638, 70639, 71104, 89695 (2 m, 4 f, 2 u); North Pacific, HUMNH 60397, 60398 (2 f); locality unknown, NSMT AS 67, 1150, NSMT VP A351m A352, A428, YIO 64931, 70601, 70883 (1 f, 7 u; 4 p). *S. wumizusume*: Japan, AMB BR-40–50, BR-68–70, HK-07–10, HK-26–41, HK-43–50, KY-1, KY-2, MM-2–4, NB-01–04, NB-32, SK-01–05, SN-12–14, YIO 12717, 63111, 64734, 64735, 65044, 65266, 71211, 72344, 72260 (3 m, 1 f, 66 u; 66 p); North Pacific, UWBM 55587, 55695–55698 (4 m, 1 f); locality unknown, NSMT AS 1116, 1275, NSMT VP A10, A353, A359 (1 m, 4 u; 3 p). *S. scrippsi*: California, MVZ 46884 (u). *S. hypoleucus*: Guadalupe Island, MVZ 434046, 134054 (1 m, 1 f). *S. craveri*: Baja California, MVZ 54725, 54742 (2 m). *Uria lomvia arra*: Japan, EP 116–118, 120–124, 158, NSMT AS 1055, YIO 60951, 63209, 63266–63269, 63615, 65128 (2 m, 3 f, 13 u; 7 p); Alaska, MVZ

60576–60578, 68408–68412, 129408, 133577, 133578, 142054, 142055, 142737, 156028 (11 m, 3 f, 1 u); North Pacific, HUMNH 60414–60417 (1 m, 1 f, 2 u); locality unknown, NSMT AS 387 (u; p). *U. aalge aalge*: Iceland, YIO 64505 (f; p). *U. aalge inornata*: Japan, HUMNH 60410–60412, MVZ 124097 (4 f); Alaska, MVZ 60554 (m); North Pacific, HUMNH 60413 (f). *U. aalge californica*: MVZ 19046–19048, 46806, 49341–49363, 49394, 53825, 53826, 54413, 54416, 54417, 68070, 70631–70635, 151839–151842, 170863–170869, 176038, 183432 (13 m, 9 f, 30 u). *U. aalge* ssp.: locality unknown, YIO 60952–60954, 62449, 62450, 62489, 64421 (1 m, 4 f, 2 u; 2 p).

The material of Mancallinae from Shiriya was compared with the following specimens. *Pinguinus impennis*: Funk Island, MVZ 56176, 129315, 135170 (composite skeletons). *Mancalla californiensis*: Corona del Mar (Formation uncertain; Becker 1987a), California (Pliocene), USNM-VP 4976 (holotype humerus). *M. cedrosensis*: Almejas Formation, Cedros Island, Baja California (late Miocene), LACM-VP 15373 (holotype associated skeleton), 15410, 23739 (partial skeletons), 15367 (humerus), 15371, 15372, 15394–15399, 15411, 15414, 15415, 15424 (ulnae), 15370, 15391, 15392 (carpometacarp). *M. lucasi*: Niguel Formation, Orange County, California (Pliocene), SDSNH 25237 (holotype including associated humeri and femur), 59049 (humerus). *M. vegrandis*: San Diego Formation, San Diego County, California (Pliocene), SDSNH 77399 (holotype associated skeleton). ‘*M. milleri*’: San Diego Formation, San Diego County, California (Pliocene), LACM VP 2185 (holotype femur). ‘*M. emlongi*’: San Diego Formation, San Diego County, California (Pliocene), USNM VP 243765 (holotype ulna). *Miomancalla howardae*: Capistrano Formation, Orange County, California (Pliocene), SDSNH 68312 (holotype associated skeleton); San Mateo Formation, San Diego County, California (late Miocene), SDSNH 24584 (humerus). *M. wetmorei*: Monterey Formation, Orange County, California (late Miocene), LACM VP 42653 (holotype humerus) and 32429 (ulna). ‘*Praemancalla*

lagunensis': Monterey Formation, Orange County, California (late Miocene), LACM VP 15288 (holotype humerus), 15289 (coracoid), 15287 (carpometacarpus). '*Alcodes ulnulus*': Monterey Formation, Orange County, California (late Miocene), LACM VP 18277 (holotype ulna), 18279, 18280 (ulnae). Several other specimens stored in LACM VP and SDSNH were also examined as mentioned in the text.

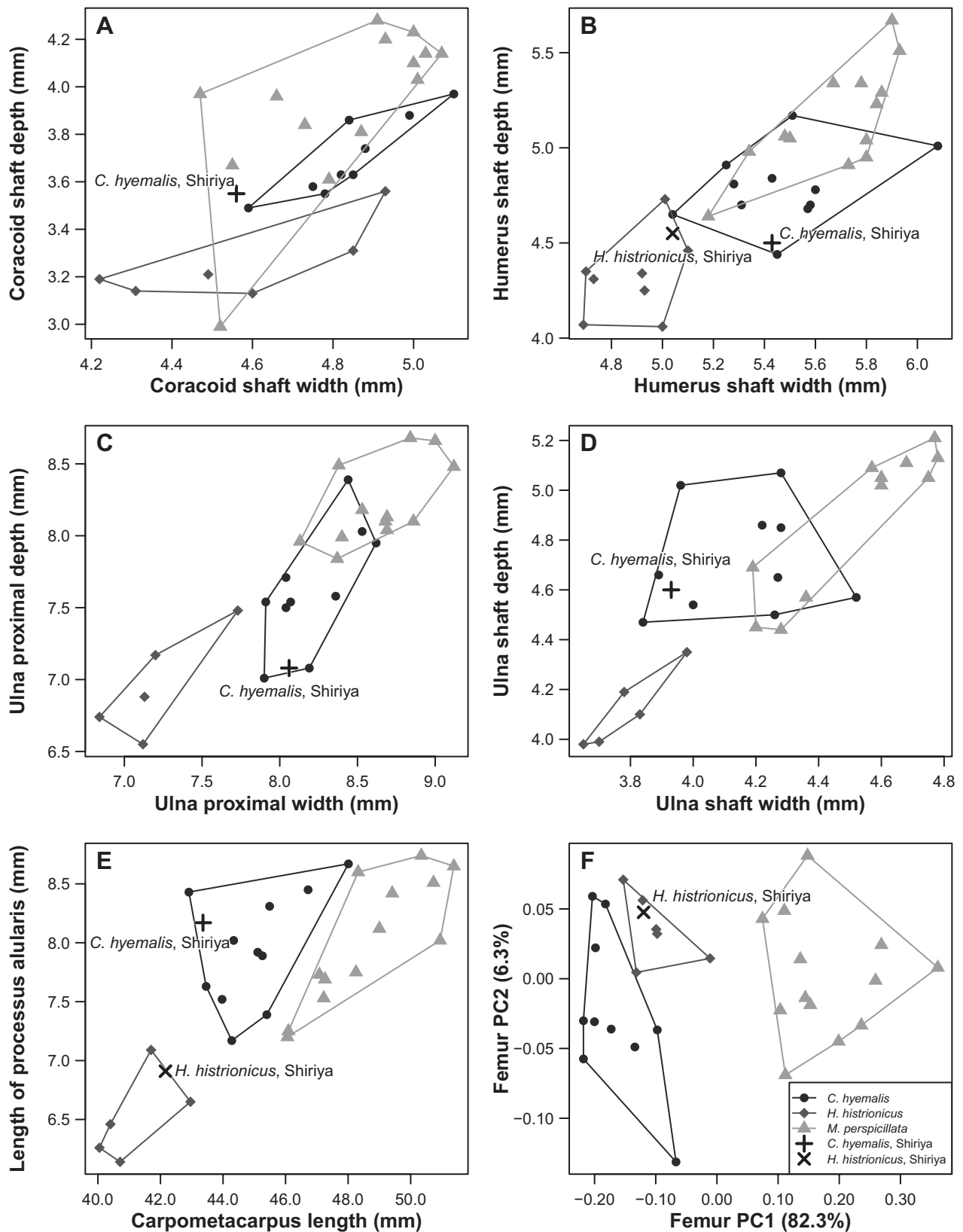


Figure S1. Bivariate scatter plots of individual measurements and principal component (PC) scores for *Histrionicus histrionicus*, *Clangula hyemalis*, and *Melanitta perspicillata*. **A**, coracoidal shaft measurements; **B**, humeral shaft measurements; **C**, proximal ulnar measurements; **D**, ulnar shaft measurements; **E**, carpometacarpal measurements; **F**, PC scores based on seven femoral measurements. See Supplementary Table 1 for details of the analysis. Legend: circle, modern *C. hyemalis*; diamond, modern *H. histrionicus*; triangle, modern *M. perspicillata*; cross, *H. histrionicus* from Shiriya; plus sign, *C. hyemalis* from Shiriya.

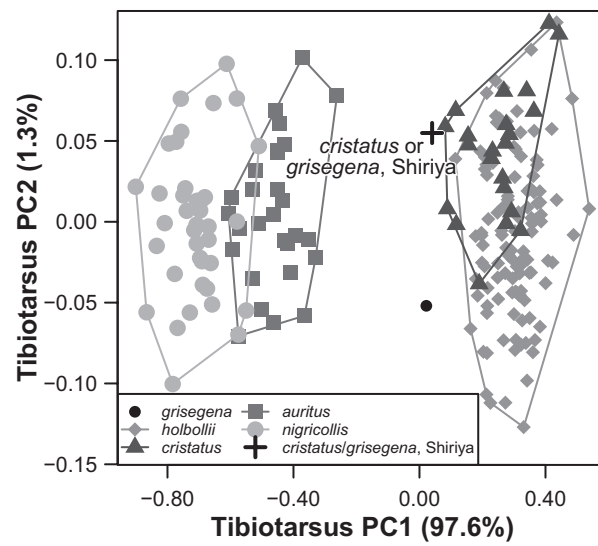


Figure S2. Bivariate scatter plot of individual principal component (PC) scores for *Podiceps*, based on four tibiotarsal measurements. See Supplementary Table 2 for details of the analysis. Legend: black circle, modern *P. grisegena grisegena*; diamond, modern *P. g. holbollii*; triangle, modern *P. cristatus*; square, modern *P. auritus*; large gray circle, modern *P. nigricollis*; plus sign, *P. cristatus* or *grisegena* from Shiriya (NSMT PV 19011).

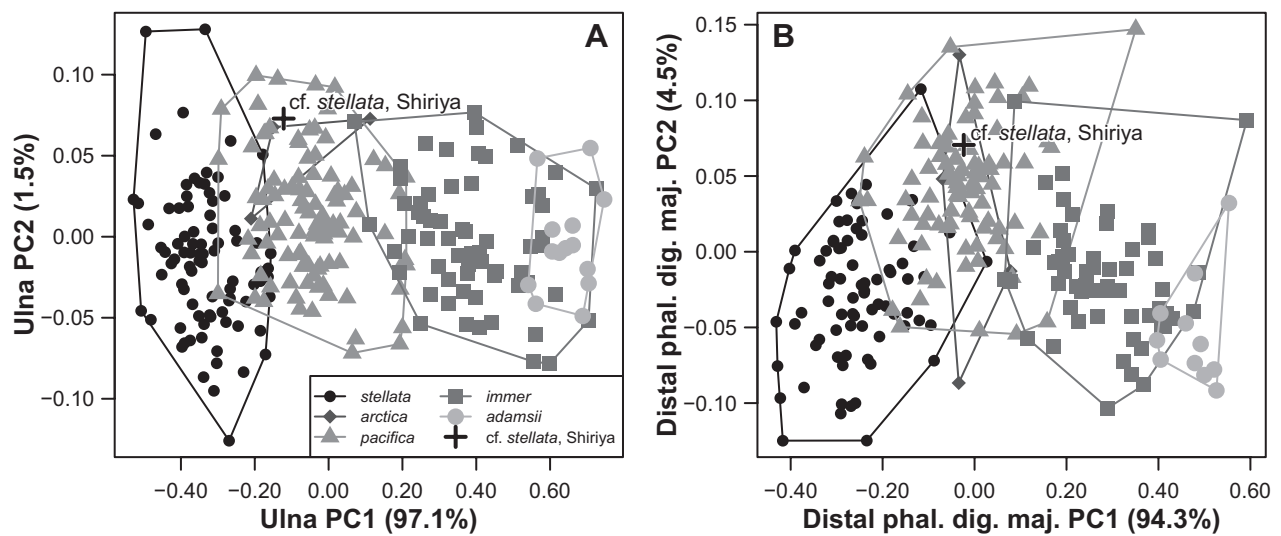


Figure S3. Bivariate scatter plots of individual principal component (PC) scores for *Gavia*. **A**, PC scores based on four ulnar measurements; **B**, PC scores based on three measurements on the distal phalanx of major wing digit. See Supplementary Tables 3 and 4 for details of the analyses. Legend: black circle, modern *G. stellata*; diamond, modern *G. arctica*; triangle, modern *G. pacifica*; square, modern *G. immer*; large gray circle, modern *G. adamsii*; plus sign, *G. cf. stellata* from Shiriya.

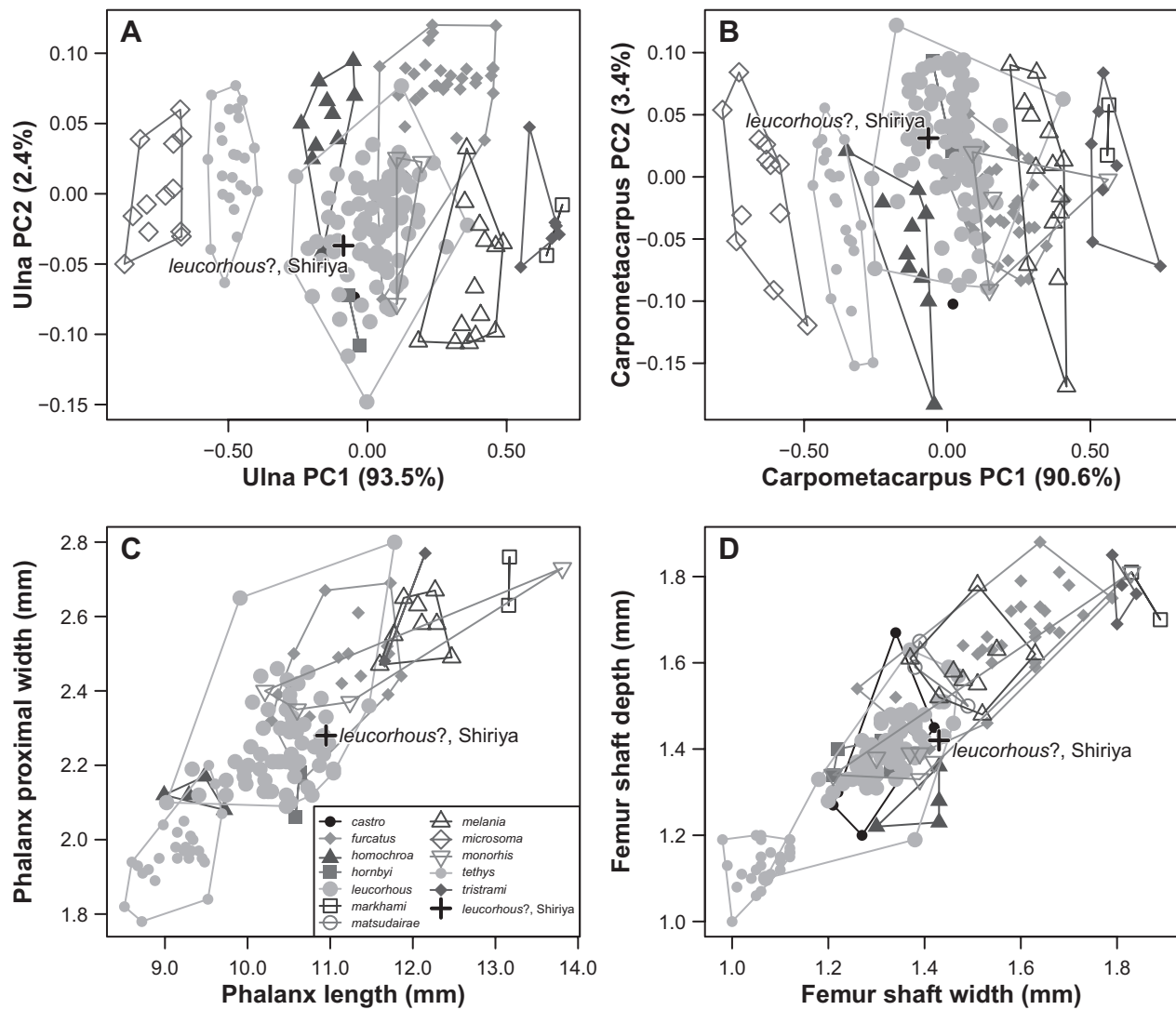


Figure S4. Bivariate scatter plots of individual measurements and principal component (PC) scores for *Hydrobates*. **A**, PC scores based on seven ulnar measurements; **B**, PC scores based on six carpometacarpal measurements; **C**, measurements of the proximal phalanx of major wing digit; **D**, femoral measurements. See Supplementary Tables 5 and 6 for details of the analyses. Legend: black circle, modern *H. castro*; filled light gray diamond, modern *H. furcatus*; filled triangle, modern *H. homochroa*; filled square, modern *H. hornbyi*; large gray circle, modern *H. leucorhous*; open square, modern *H. markhami*; open circle, modern *H. matsudairae*; open triangle, modern *H. melania*; open diamond, modern *H. microsoma*; open reversed triangle, modern *H. monorhis*; small light gray circle, modern *H. tethys*; filled dark gray diamond, modern *H. tristrami*; plus sign, *H. leucorhous?* from Shiriya.

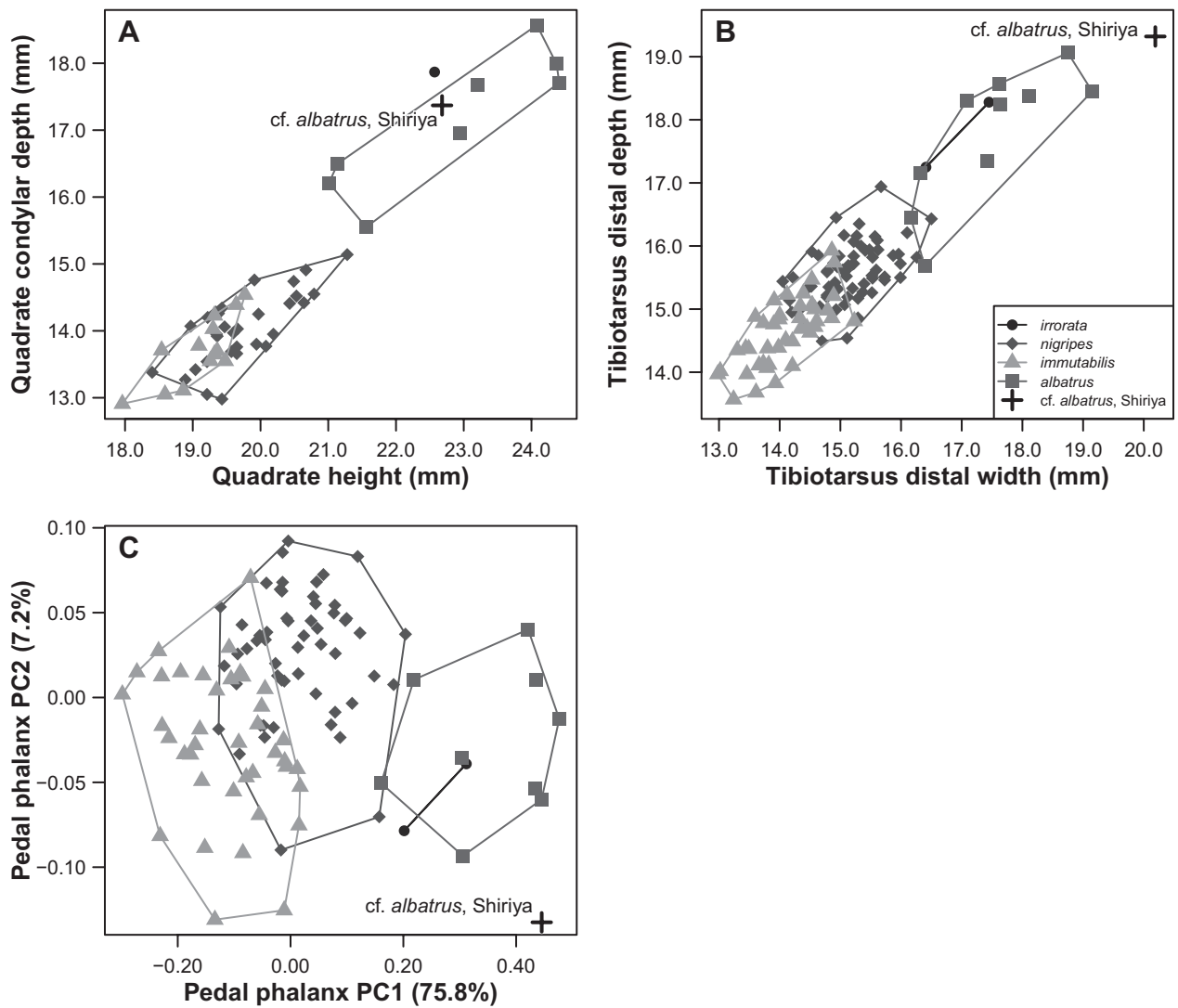


Figure S5. Bivariate scatter plots of individual measurements and principal component (PC) scores for *Phoebastria*. **A**, quadratic measurements; **B**, tibiotarsal measurements; **C**, PC scores based on seven measurements of the proximal phalanx of the third toe. See Supplementary Table 7 for details of the analysis. Legend: black circle, modern *P. irrorata*; diamond, modern *P. nigripes*; triangle, modern *P. immutabilis*; square, modern *P. albatrus*; plus sign, *P. cf. albatrus* from Shiriya.

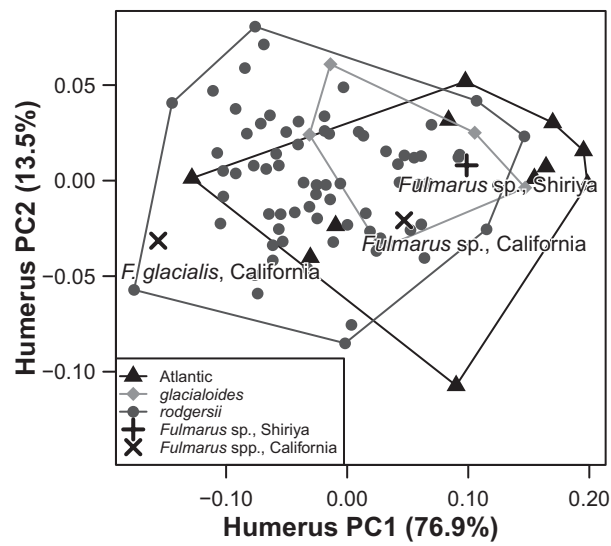


Figure S6. Bivariate scatter plot of individual principal component (PC) scores for *Fulmarus*, based on three distal humeral measurements. See Supplementary Table 8 for details of the analysis. Legend: circle, modern *F. glacialis rodgersii* from the North Pacific; triangle, modern *F. glacialis* from Atlantic (supposedly including both subspecies *glacialis* and *auduboni*); diamond, modern *F. glacialoides* from the Southern Hemisphere; cross, *F. glacialis* and *Fulmarus* sp. from the Pleistocene of California (LACM VP 2019 and LACM VP 4882, respectively); plus sign, *Fulmarus* sp. from Shiriya (NSMT PV 19011).

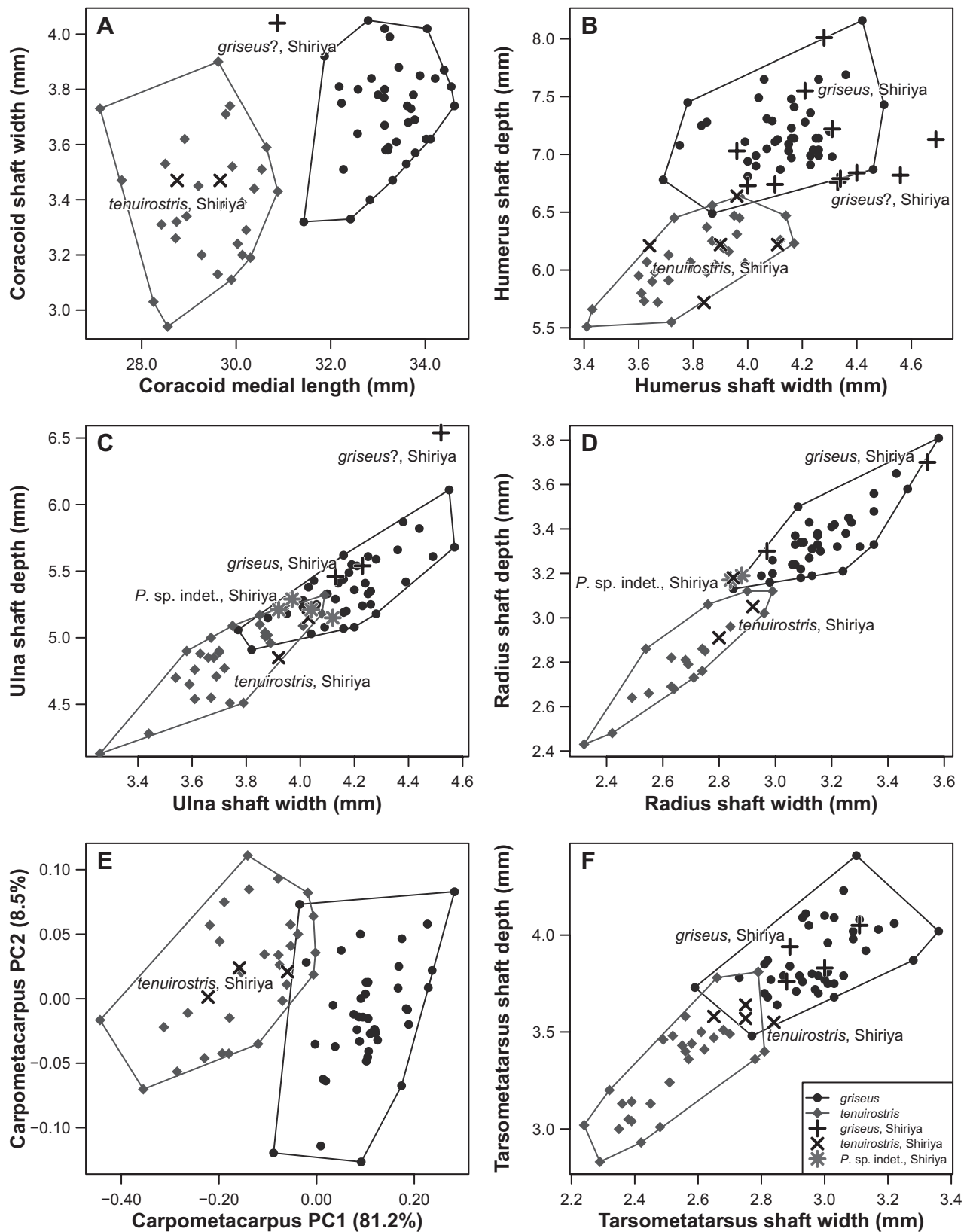


Figure S7. Bivariate scatter plots of individual measurements and principal component (PC) scores for *Puffinus griseus* and *P. tenuirostris*. **A**, coracoidal measurements; **B**, humeral shaft measurements; **C**, ulnar shaft measurements; **D**, radial shaft measurements; **E**, PC scores based on five carpometacarpal measurements; **F**, tarsometatarsal measurements. See Supplementary Table 9 for details of the analysis. Legend: circle, modern *P. griseus*; diamond, modern *P. tenuirostris*; cross, *P. tenuirostris* from Shiriya; plus sign, *P. griseus* from Shiriya; asterisk, *Puffinus* specimens not identified to specific level.

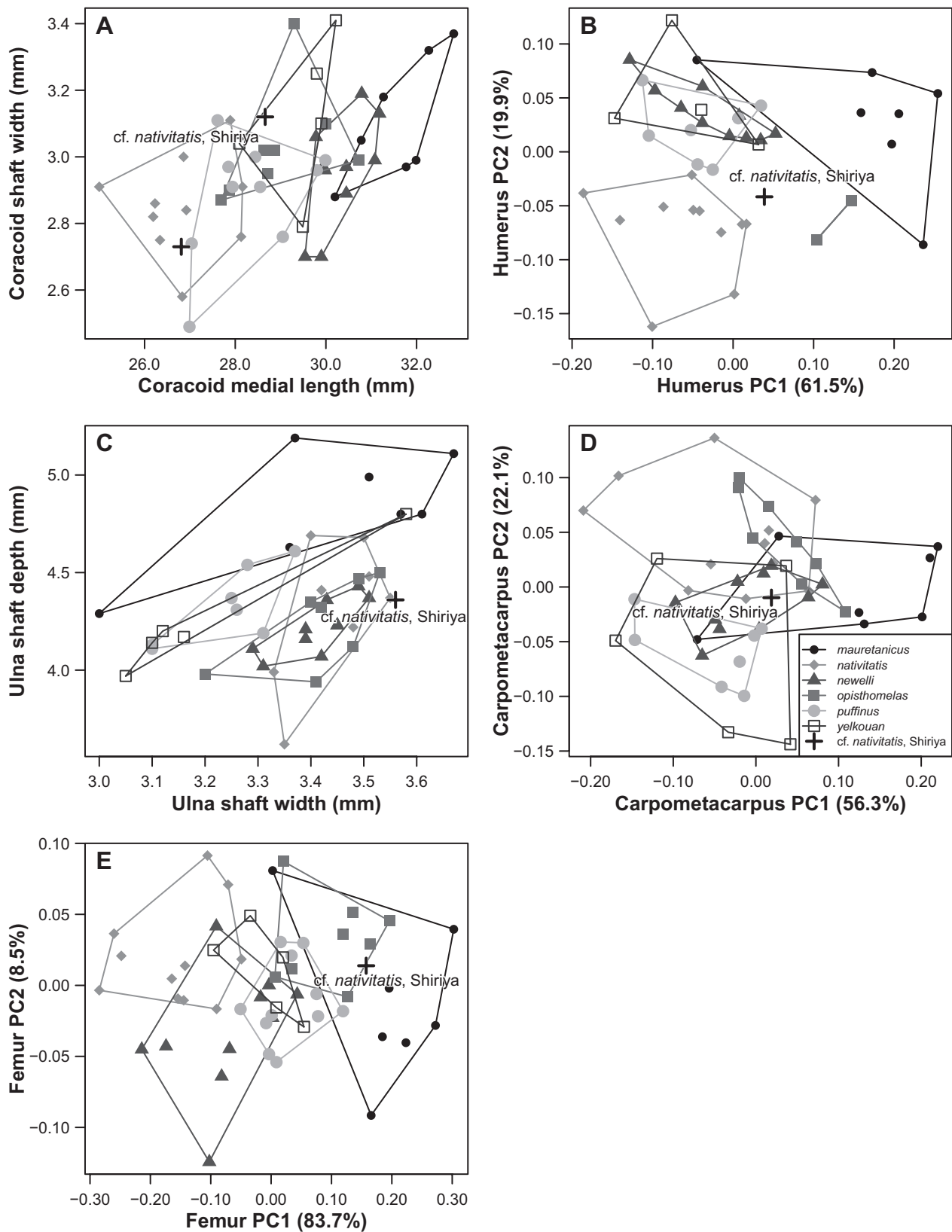


Figure S8. Bivariate scatter plots of individual measurements and principal component (PC) scores for *Puffinus cf. nativitatis*. **A**, coracoidal measurements; **B**, PC scores based on seven humeral measurements; **C**, ulnar shaft measurements; **D**, PC scores based on five carpometacarpal measurements; **E**, PC scores based on four femoral measurements. See Supplementary Tables 10–12 for details of the analyses. Legend: black circle, modern *P. mauretanicus*; diamond, modern *P. nativitatis*; triangle, modern *P. newelli*; filled square, modern *P. opisthomelas*; large gray circle, modern *P. puffinus*; open square, modern *P. yelkouan*; plus sign, *P. cf. nativitatis* from Shiriya.

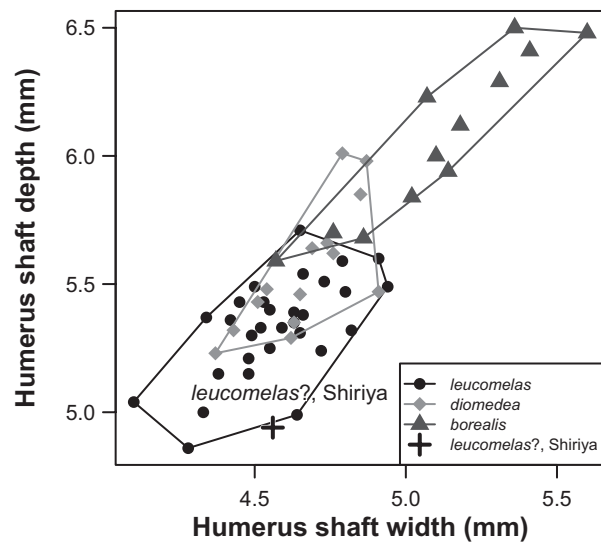


Figure S9. Bivariate scatter plot of individual measurements for *Calonectris*. Legend: black circle, modern *C. leucomelas*; diamond, modern *C. diomedea*; triangle, modern *C. borealis*; plus sign, *C. leucomelas?* from Shiriya.

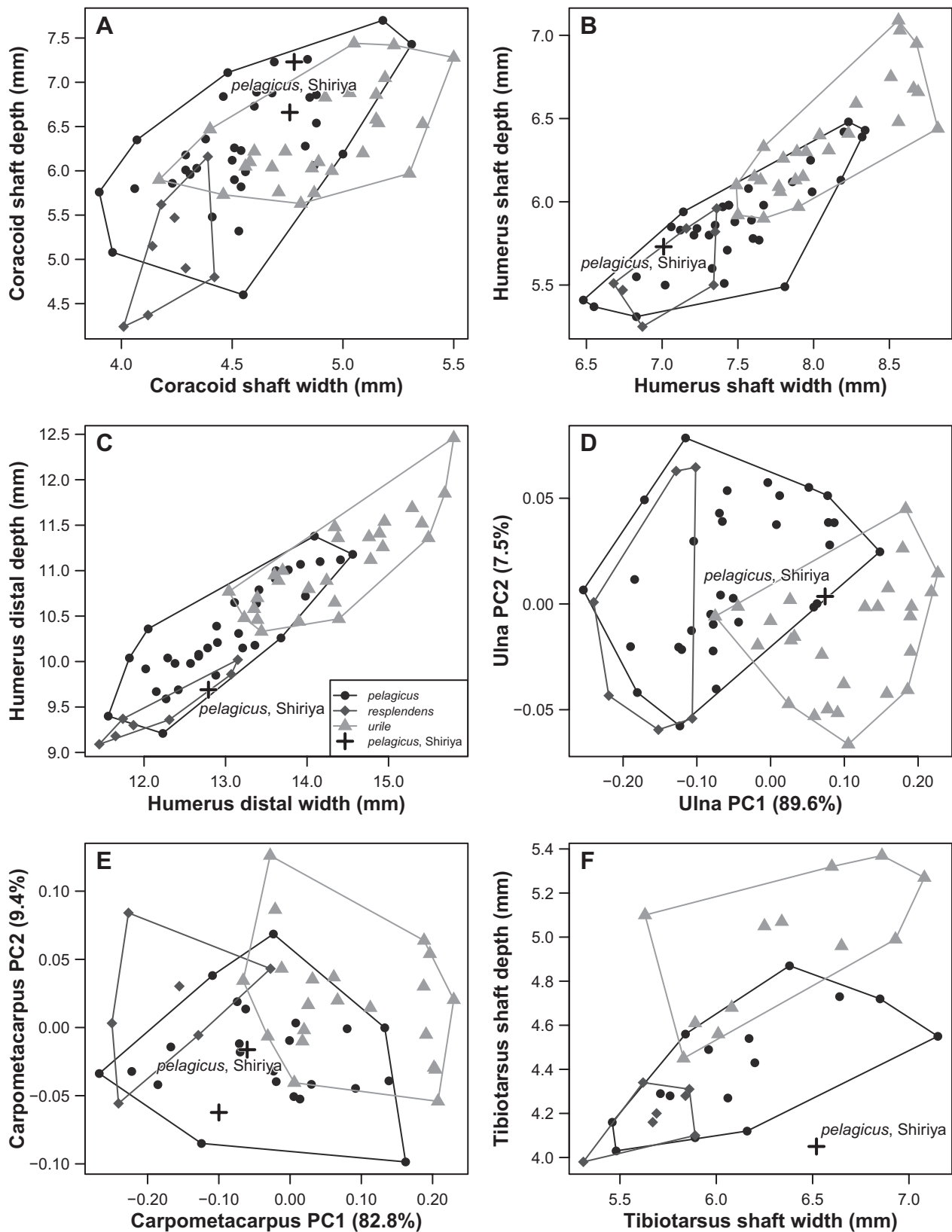


Figure S10. Bivariate scatter plots of individual measurements and principal component (PC) scores for *Phalacrocorcorax pelagicus* and *P. urile*. **A**, coracoidal measurements; **B**, humeral shaft measurements; **C**, distal humeral measurements; **D**, PC scores based on three ulnar measurements; **E**, PC scores based on five carpometacarpal measurements; **F**, tibiotarsal measurements. See Supplementary Tables 13 and 14 for details of the analyses. Legend: black circle, modern *P. pelagicus pelagicus*; diamond, modern *P. p. resplendens*; triangle, modern *P. urile*; plus sign, *P. pelagicus* from Shiriya.

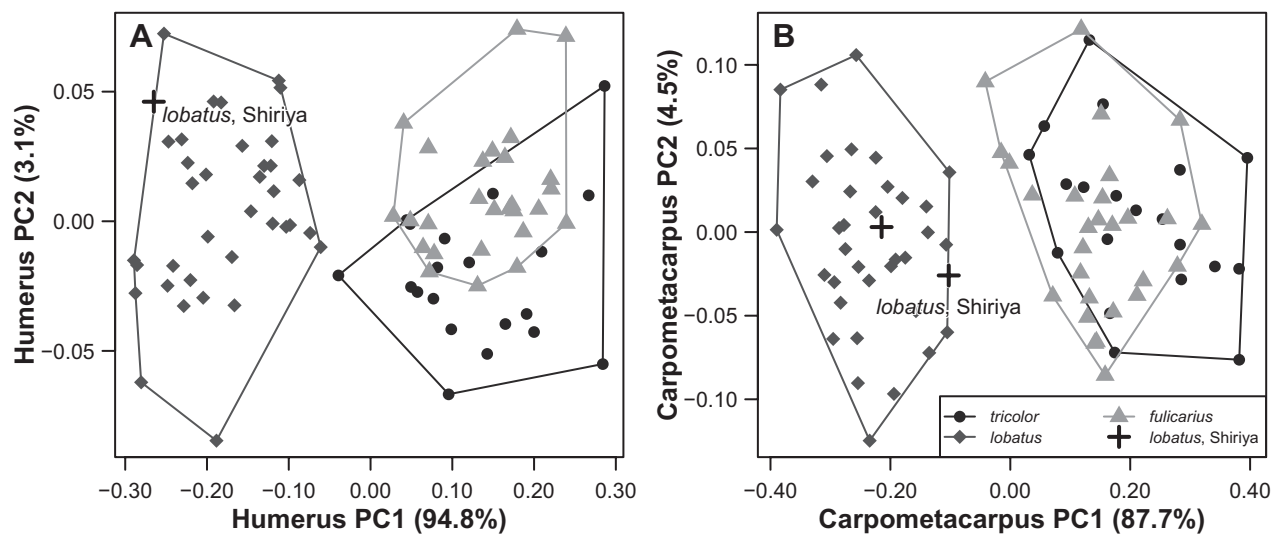


Figure S11. Bivariate scatter plots of individual principal component (PC) scores for *Phalaropus* and *Steganopus*. **A**, PC scores based on three humeral measurements; **B**, PC scores based on six carpometacarpal measurements. See Supplementary Tables 15 and 16 for details of the analyses. Legend: circle, modern *S. tricolor*; diamond, modern *P. lobatus*; triangle, modern *P. fulicarius*; plus sign, *P. lobatus* from Shiriya.

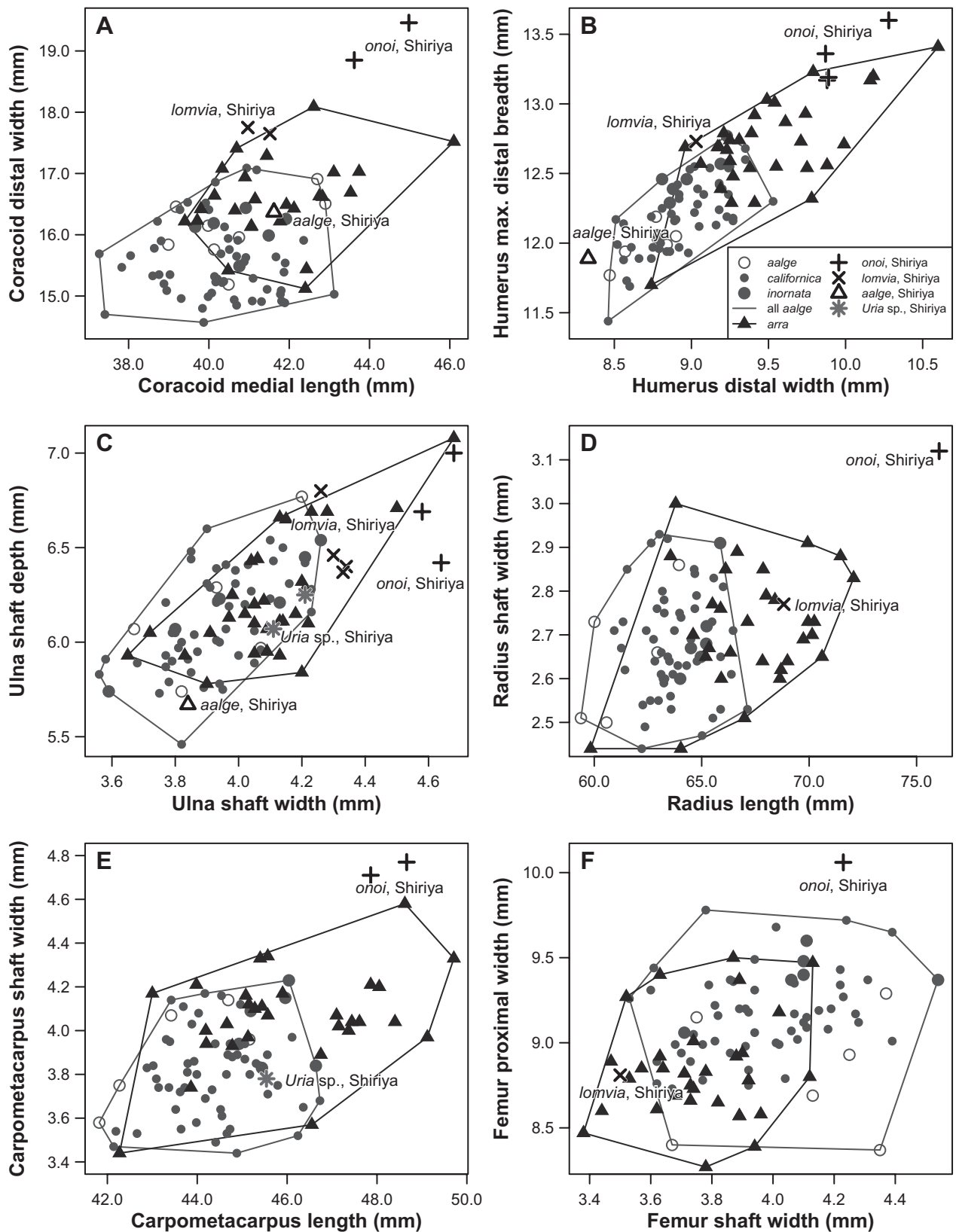


Figure S12. Bivariate scatter plots of individual measurements for *Uria*. **A**, coracoidal measurements; **B**, humeral measurements; **C**, ulnar measurements; **D**, radial measurements; **E**, carpometacarpal measurements; **F**, femoral measurements. Legend: open circle, modern *U. aalge*; small solid circle, modern *U. a. californica*; large solid circle, modern *U. a. inornata*; triangle, modern *U. lomvia arra*; cross, *U. lomvia* from Shiriya; open triangle, *U. aalge* from Shiriya; plus sign, *U. onoi* from Shiriya.

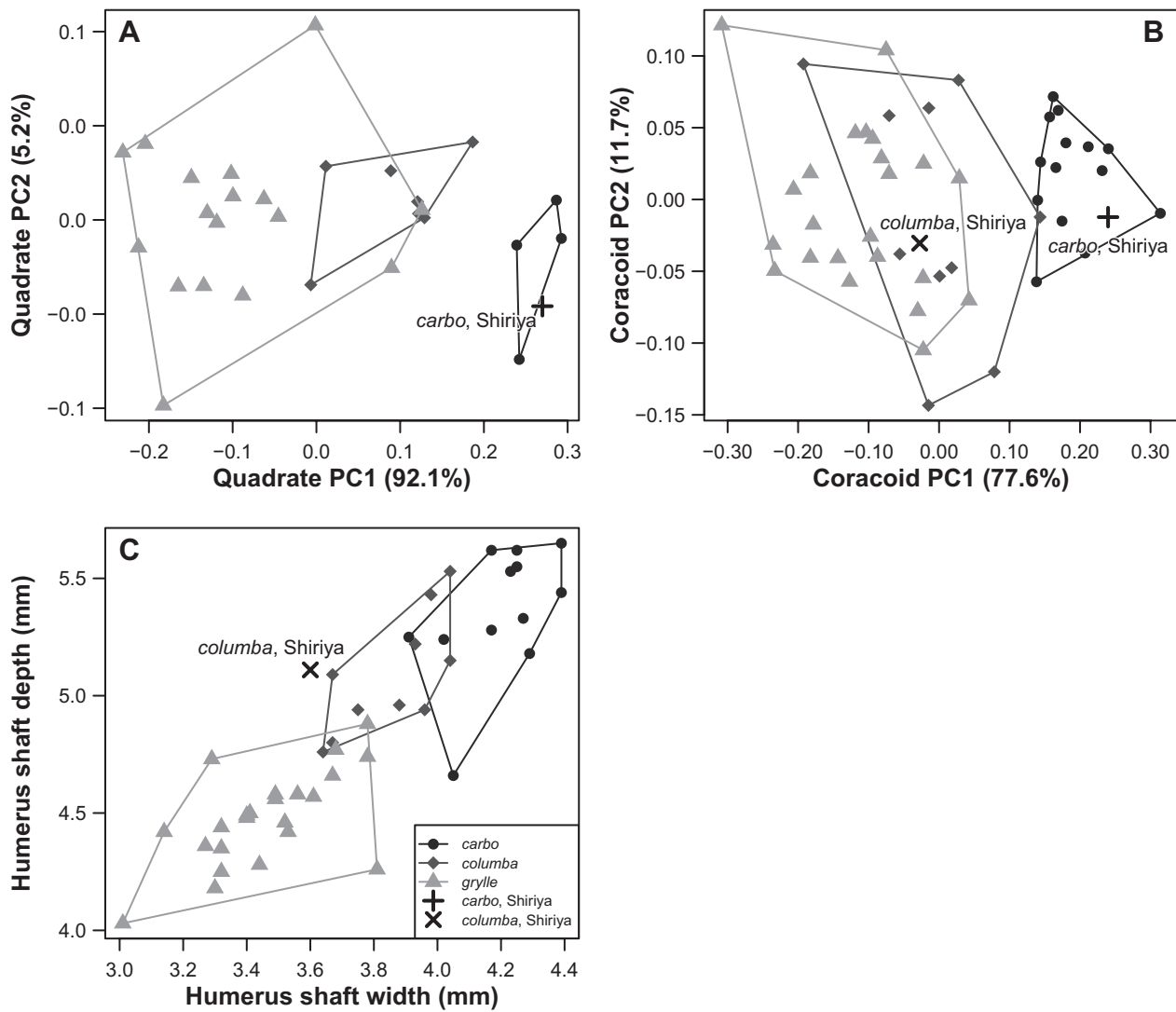


Figure S13. Bivariate scatter plots of individual measurements and principal component (PC) scores for *Cephus*. **A**, PC scores based on three quadrate measurements; **B**, PC scores based on three coracoidal measurements; **C**, humeral shaft measurements. See Supplementary Tables 17 and 18 for details of the analyses. Legend: black circle, modern *C. carbo*; diamond, modern *C. columba*; triangle, modern *C. grylle*; cross, *C. columba* from Shiriya; plus sign, *C. carbo* from Shiriya.

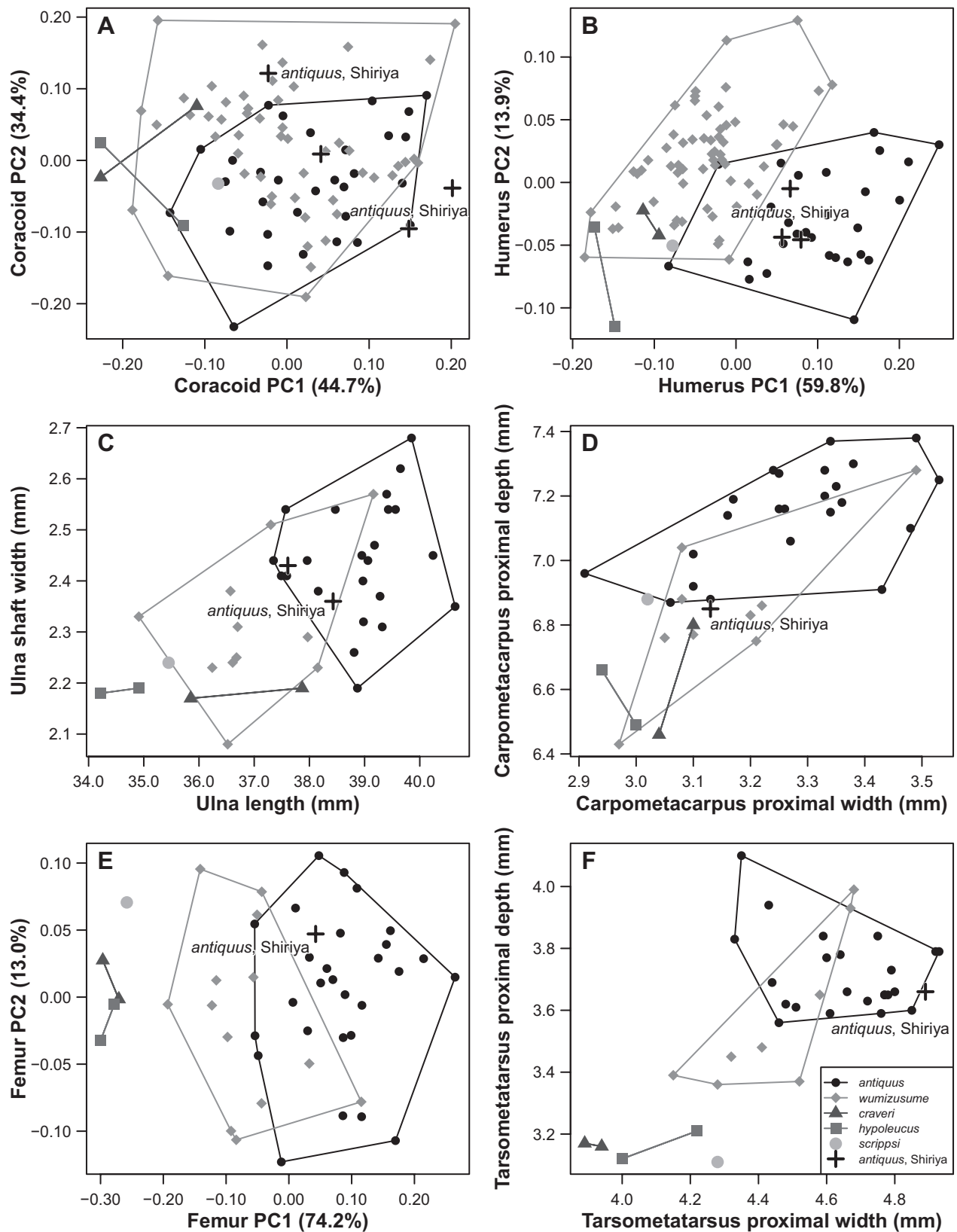


Figure S14. Bivariate scatter plots of individual measurements and principal component (PC) scores for *Synthliboramphus*. **A**, PC scores based on three coracoidal measurements; **B**, PC scores based on seven humeral measurements; **C**, ulnar measurements; **D**, carpometacarpal measurements; **E**, PC scores based on four femoral measurements; **F**, tarsometatarsal measurements. See Supplementary Tables 19–21 for details of the analyses. Legend: black circle, modern *S. antiquus*; diamond, modern *S. wumizusume*; triangle, modern *S. craveri*; square, modern *S. hypoleucus*; large gray circle, modern *S. scrippsi*; plus sign, *S. antiquus* from Shiriya.

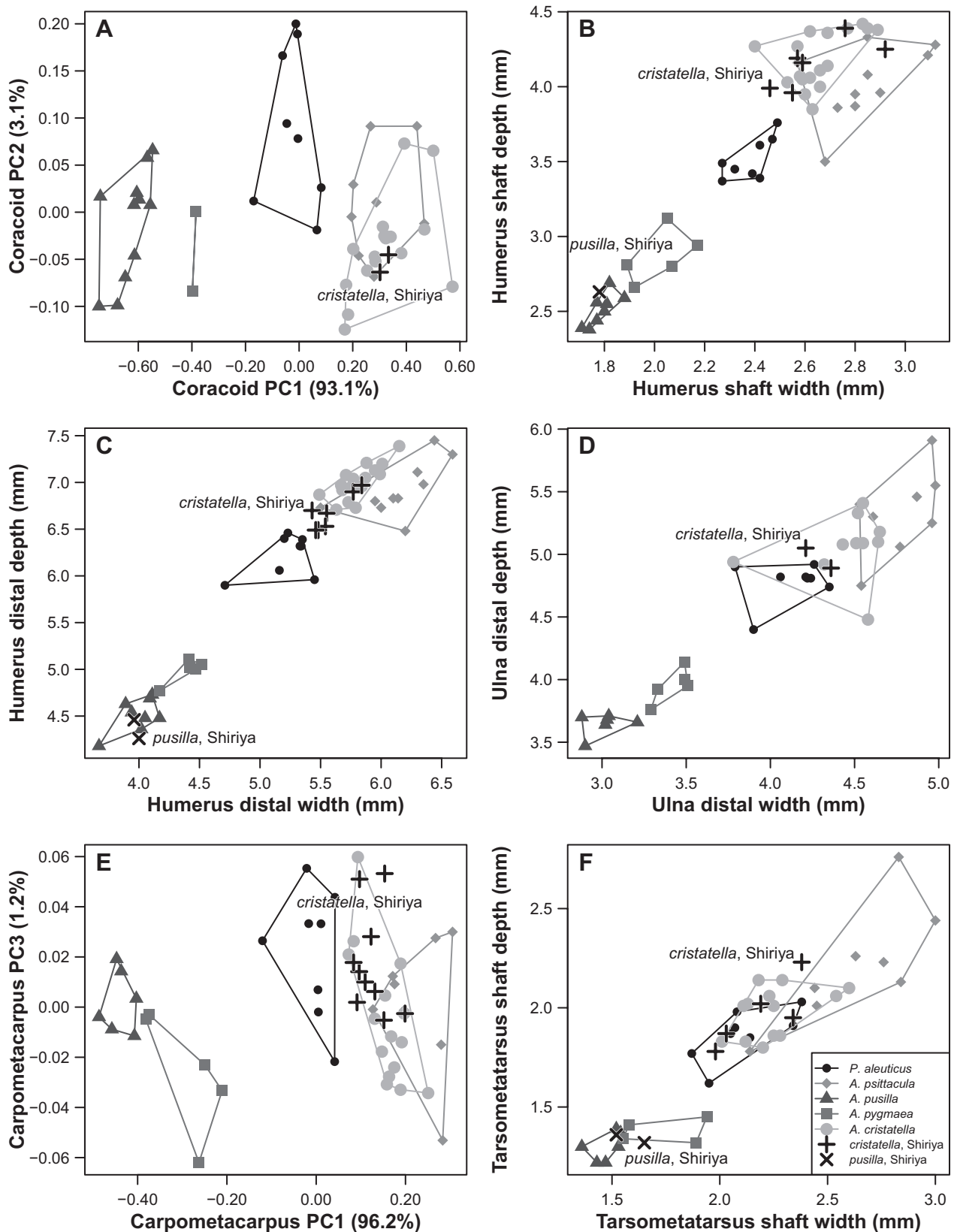


Figure S15. Bivariate scatter plots of individual measurements and principal component (PC) scores for Aethiini. **A**, PC scores based on five coracoidal measurements; **B**, humeral shaft measurements; **C**, distal humeral measurements; **D**, distal ulnar measurements; **E**, PC scores based on three carpometacarpal measurements; **F**, tarsometatarsal measurements. See Supplementary Tables 22 and 23 for details of the analyses. Legend: black circle, modern *Ptychoramphus aleuticus*; diamond, modern *Aethia psittacula*; triangle, modern *A. pusilla*; square, modern *A. pygmaea*; large gray circle, modern *A. cristatella*; cross, *A. pusilla* from Shiriya; plus sign, *A. cristatella* from Shiriya.

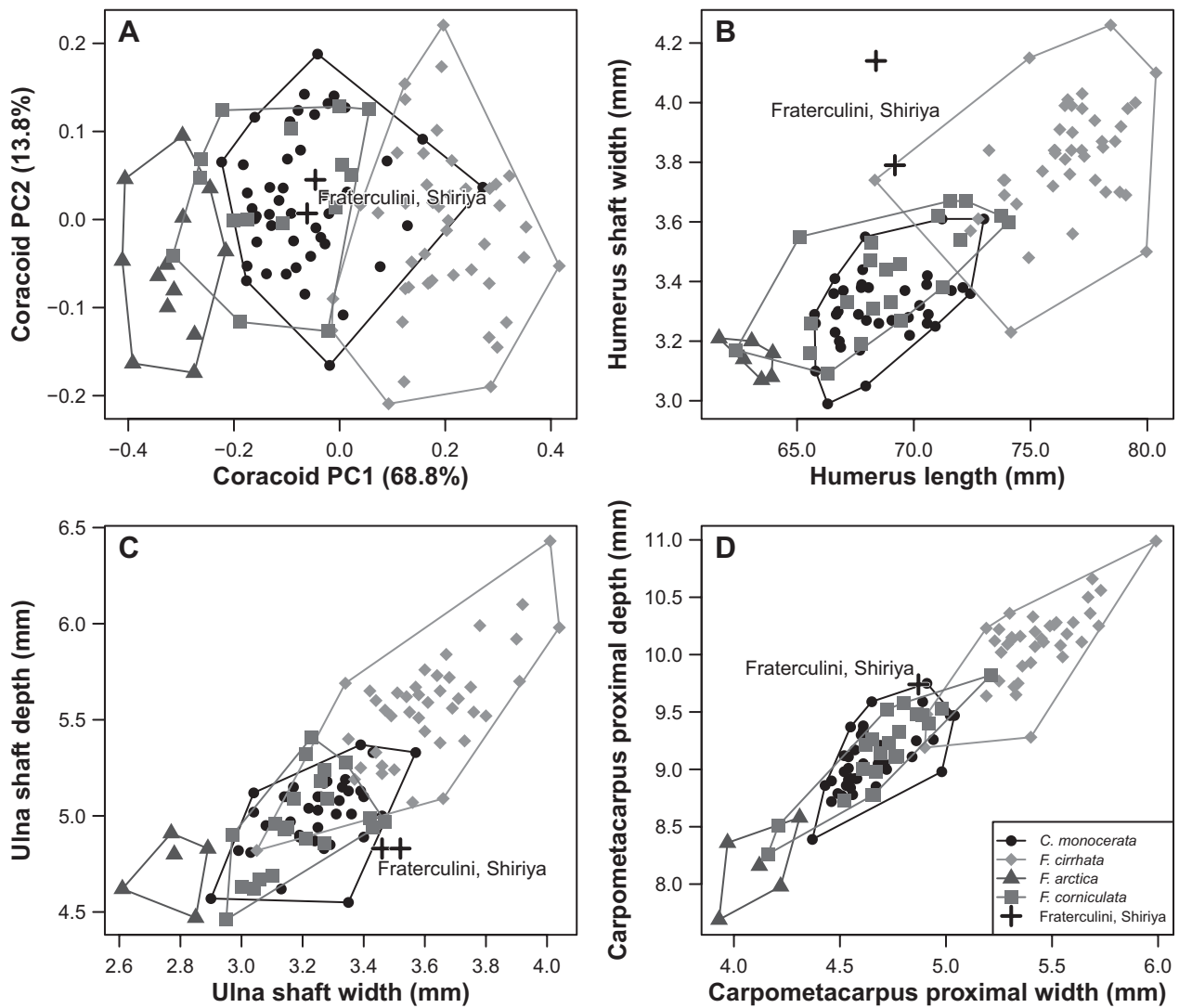


Figure S16. Bivariate scatter plots of individual measurements and principal component (PC) scores for Fraterculini. **A**, PC scores based on six coracoidal measurements; **B**, humeral measurements; **C**, ulnar measurements; **D**, carpometacarpal measurements. See Supplementary Table 24 for details of the analysis. Legend: black circle, modern *Cerorhinca monocerata*; diamond, modern *Fratercula cirrhata*; triangle, modern *F. arctica*; square, modern *F. corniculata*; plus sign, Fraterculini gen. et sp. indet. from Shiriya.

Supplementary Tables

For visual inspection of osteometric dimensions, principal component (PC) analysis was conducted to obtain ordinations. The analyses were based on covariance matrices of natural log-transformed variables. In the figures, points for fossils were plotted a posteriori. In the following tables, summary of the analyses are provided to ensure reproducibility (i.e. new points can be plotted with the means and eigenvectors provided). Eigenvectors, corresponding eigenvalues and proportion of variance explained (PVE), and PC loadings are shown for the PCs shown in the figures.

Supplementary Table 1. Summary of principal component (PC) analysis for *Histrionicus histrionicus*, *Clangula hyemalis*, and *Melanitta perspicillata*, based on seven femoral measurements (Fig. S1F). The sample includes 6 individuals of *H. histrionicus*, 10 *C. hyemalis*, and 13 *M. perspicillata* (total $n = 29$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Length	0.4415	-0.0391	3.8025	0.9569	-0.0234
Proximal W	0.3283	-0.5740	2.2419	0.8470	-0.4088
Head D	0.2789	-0.3747	1.7222	0.8770	-0.3252
W at midshaft	0.3396	0.7172	1.3551	0.8174	0.4766
D at midshaft	0.3725	-0.0066	1.5690	0.9025	-0.0044
Distal W	0.4647	0.1087	2.2949	0.9608	0.0621
Distal D	0.3866	0.0482	2.1033	0.9282	0.0320
Eigenvalue	0.1769	0.0488			
PVE	82.3%	6.3%			

Supplementary Table 2. Summary of principal component (PC) analysis for *Podiceps*, based on four tibiotarsal measurements (Fig. S2). The sample includes 115 individuals of *P. grisegena*, 22 *P. cristatus*, 28 *P. auritus*, and 38 *P. nigricollis* (total $n = 203$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Narrowest W	0.5528	0.1897	1.4828	0.9914	0.0386
Narrowest D	0.5020	0.6961	1.1168	0.9841	0.1549
Distal W	0.4820	-0.5730	2.1550	0.9865	-0.1331
D of CM	0.4582	-0.3888	2.1369	0.9885	-0.0952
Eigenvalue	0.4346	0.0493			
PVE	97.6%	1.3%			

Supplementary Table 3. Summary of principal component (PC) analysis for *Gavia*, based on four ulnar measurements (Fig. S3A). The sample includes 85 individuals of *G. stellata*, 3 *G. arctica*, 99 *G. pacifica*, 62 *G. immer*, and 14 *G. adamsii* (total $n = 262$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Proximal W	0.4796	0.3916	2.4948	0.9862	0.1015
Proximal D	0.5118	0.5567	2.4269	0.9863	0.1353
W midshaft	0.4789	-0.6761	1.7045	0.9795	-0.1744
D midshaft	0.5280	-0.2822	1.9459	0.9886	-0.0666
Eigenvalue	0.3283	0.0414			
PVE	97.1%	1.5%			

Supplementary Table 4. Summary of principal component (PC) analysis for *Gavia*, based on three measurements of distal phalanx of major wing digit (Fig. S3B). The sample includes 76 individuals of *G. stellata*, 4 *G. arctica*, 87 *G. pacifica*, 57 *G. immer*, and 11 *G. adamsii* (total $n = 232$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Length	0.5253	-0.8437	3.1452	0.9434	-0.3310
Proximal W	0.6470	0.4806	1.3858	0.9822	0.1594
Proximal D	0.5527	0.2392	1.4651	0.9831	0.0929
Eigenvalue	0.2440	0.0533			
PVE	94.3%	4.5%			

Supplementary Table 5. Summary of principal component (PC) analysis for *Hydrobates*, based on seven ulnar measurements (Fig. S4A). The sample includes 1 individual of *H. castro*, 33 *H. furcatus*, 10 *H. homochroa*, 2 *H. hornbyi*, 88 *H. leucorhous*, 2 *H. markhami*, 14 *H. melania*, 12 *H. microsoma*, 3 *H. monorhis*, 24 *H. tethys*, and 6 *H. tristrami* (total $n = 195$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Length	0.3580	-0.7250	3.5267	0.9360	-0.3053
Proximal W	0.3714	-0.1790	1.2794	0.9711	-0.0754
Proximal D	0.3859	0.1274	1.2580	0.9748	0.0518
W at midshaft	0.3714	0.3979	0.6366	0.9726	0.1678
D at midshaft	0.3868	0.5019	0.7099	0.9632	0.2013
Distal W	0.3916	-0.1142	1.1955	0.9704	-0.0456
Distal D	0.3796	-0.0536	0.9717	0.9795	-0.0223
Eigenvalue	0.3381	0.0545			
PVE	93.5%	2.4%			

Supplementary Table 6. Summary of principal component (PC) analysis for *Hydrobates*, based on six carpometacarpal measurements (Fig. S4B). The sample includes 1 individual of *H. castro*, 33 *H. furcatus*, 10 *H. homochroa*, 2 *H. hornbyi*, 89 *H. leucorhous*, 2 *H. markhami*, 14 *H. melania*, 12 *H. microsoma*, 4 *H. monorhis*, 22 *H. tethys*, and 7 *H. tristrami* (total $n = 196$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Length	0.4090	0.4204	2.9853	0.9659	0.1927
Proximal W	0.4243	0.3905	0.8031	0.9613	0.1718
Proximal D	0.4175	0.2551	1.5928	0.9777	0.1160
W midshaft	0.4199	-0.7356	0.5217	0.9345	-0.3178
D midshaft	0.4012	-0.2224	0.4159	0.9473	-0.1019
Distal W	0.3757	-0.1226	0.7378	0.9233	-0.0585
Eigenvalue	0.2869	0.0557			
PVE	90.6%	3.4%			

Supplementary Table 7. Summary of principal component (PC) analysis for *Phoebastria*, based on seven measurements of pedal phalanx III–1 (Fig. S5C). The sample includes 2 individual of *P. irrorata*, 55 *P. nigripes*, 39 *P. immutabilis*, and 9 *P. albatrus* (total $n = 105$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Length	0.3835	0.5064	3.8940	0.8736	0.3549
Proximal W	0.3576	−0.5248	1.9280	0.7981	−0.3604
Proximal D	0.3791	0.1789	2.1559	0.8818	0.1281
W at midshaft	0.3262	−0.6197	1.4500	0.7693	−0.4497
D at midshaft	0.3956	0.2078	1.4970	0.8972	0.1450
Distal W	0.3750	0.0911	1.5658	0.9036	0.0676
Distal D	0.4217	0.0270	1.7825	0.9559	0.0188
Eigenvalue	0.1552	0.0478			
PVE	75.8%	7.2%			

Supplementary Table 8. Summary of principal component (PC) analysis for *Fulmarus*, based on three humeral measurements (Fig. S6). The sample includes 72 individuals of *F. glacialis rodgersii*, 11 *F. glacialis* from Atlantic, and 6 *F. glacialoides* (total $n = 89$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
D above PSD	0.7168	0.4545	1.5176	0.9370	0.2489
Distal W	0.5590	0.0790	2.3657	0.8847	0.0524
Distal D	0.4169	-0.8873	2.1081	0.7406	-0.6603
Eigenvalue	0.0808	0.0339			
PVE	76.9%	13.5%			

Supplementary Table 9. Summary of principal component (PC) analysis for *Puffinus griseus* and *P. tenuirostris*, based on five carpometacarpal measurements (Fig. S7E). The sample includes 41 individuals of *P. griseus* and 29 *P. tenuirostris* (total $n = 70$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Length	0.3525	-0.5105	3.9841	0.8485	-0.3983
Proximal W	0.3282	-0.4164	1.5201	0.8454	-0.3476
W midshaft	0.5241	0.3622	1.2728	0.9345	0.2093
D midshaft	0.5723	0.5147	1.2299	0.9373	0.2732
Distal W	0.4072	-0.4122	1.5409	0.8680	-0.2848
Eigenvalue	0.1548	0.0502			
PVE	81.2%	8.5%			

Supplementary Table 10. Summary of principal component (PC) analysis for *Puffinus* cf. *nativitatis*, based on seven humeral measurements (Fig. S8B). The sample includes 11 individual of *P. nativitatis*, 7 *P. mauretanicus*, 10 *P. newelli*, 2 *P. opisthomelas*, 7 *P. puffinus*, and 4 *P. yelkouan* (total $n = 41$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Length	0.2403	-0.1663	4.3891	0.7607	-0.2992
Proximal W	0.3806	0.1204	2.6577	0.9039	0.1625
W at midshaft	0.3079	-0.8320	1.1848	0.5264	-0.8085
D at midshaft	0.5828	0.3921	1.6815	0.8572	0.3278
Distal W	0.2245	-0.2554	1.9920	0.6547	-0.4234
Distal D	0.4683	0.2077	2.1028	0.8453	0.2131
GDB	0.3054	-0.0590	2.3973	0.8840	-0.0971
Eigenvalue	0.1082	0.0615			
PVE	61.5%	19.9%			

Supplementary Table 11. Summary of principal component (PC) analysis for *Puffinus* cf. *nativitatis*, based on five carpometacarpal measurements (Fig. S8D). The sample includes 11 individual of *P. nativitatis*, 7 *P. mauretanicus*, 10 *P. newelli*, 8 *P. opisthomelas*, 7 *P. puffinus*, and 5 *P. yelkouan* (total $n = 48$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Length	0.1993	0.3933	3.7913	0.5378	0.6656
Proximal W	0.3950	0.4255	1.3675	0.7021	0.4745
W midshaft	0.6442	-0.5414	1.1608	0.8438	-0.4448
D midshaft	0.5188	-0.1897	1.0350	0.8027	-0.1841
Distal W	0.3466	0.5790	1.3278	0.6103	0.6394
Eigenvalue	0.0936	0.0587			
PVE	56.3%	22.1%			

Supplementary Table 12. Summary of principal component (PC) analysis for *Puffinus* cf. *nativitatis*, based on four femoral measurements (Fig. S8E). The sample includes 11 individual of *P. nativitatis*, 7 *P. mauretanicus*, 10 *P. newelli*, 8 *P. opisthomelas*, 11 *P. puffinus*, and 5 *P. yelkouan* (total $n = 52$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Proximal W	0.4712	0.0794	1.9327	0.9493	0.0510
Proximal D	0.6051	0.6292	1.2211	0.9383	0.3114
W midshaft	0.3503	-0.7044	1.1383	0.7915	-0.5079
D midshaft	0.5377	-0.3188	1.3041	0.9269	-0.1754
Eigenvalue	0.1339	0.0427			
PVE	83.7%	8.5%			

Supplementary Table 13. Summary of principal component (PC) analysis for *Phalacrocorax pelagicus*, based on three ulnar measurements (Fig. S10D). The sample includes 32 individuals of *P. pelagicus pelagicus*, 6 *P. pelagicus resplendens*, and 26 *P. urile* (total $n = 64$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Proximal D	0.5191	0.6707	2.3084	0.9235	0.3444
W midshaft	0.5208	0.2433	1.7093	0.9546	0.1287
D midshaft	0.6777	-0.7007	1.7563	0.9567	-0.2856
Eigenvalue	0.1259	0.0363			
PVE	89.6%	7.5%			

Supplementary Table 14. Summary of principal component (PC) analysis for *Phalacrocorax pelagicus*, based on five carpometacarpal measurements (Fig. S10E). The sample includes 23 individuals of *P. pelagicus pelagicus*, 6 *P. pelagicus resplendens*, and 21 *P. urile* (total $n = 50$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Proximal W	0.3874	−0.0437	1.8120	0.9353	−0.0355
Proximal D	0.4263	−0.0878	2.5384	0.9268	−0.0641
W at midshaft	0.4475	0.1673	1.4483	0.9470	0.1190
D at midshaft	0.5633	0.5316	1.2055	0.9325	0.2959
L of PA	0.3880	−0.8245	2.2125	0.7987	−0.5707
Eigenvalue	0.1339	0.0450			
PVE	82.8%	9.4%			

Supplementary Table 15. Summary of principal component (PC) analysis for *Phalaropus* and *Steganopus*, based on three humeral measurements (Fig. S11A). The sample includes 20 individuals of *S. tricolor*, 36 *P. lobatus*, and 27 *P. fulicarius* (total $n = 83$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Distal W	0.6019	0.7239	1.3909	0.9740	0.2112
Distal D	0.5433	-0.6807	1.1295	0.9669	-0.2185
GDB	0.5853	-0.1126	1.5766	0.9787	-0.0340
Eigenvalue	0.1726	0.0311			
PVE	94.8%	3.1%			

Supplementary Table 16. Summary of principal component (PC) analysis for *Phalaropus* and *Steganopus*, based on six carpometacarpal measurements (Fig. S11B). The sample includes 20 individuals of *S. tricolor*, 36 *P. lobatus*, and 27 *P. fulicarius* (total $n = 83$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Length	0.4296	0.2201	2.9861	0.9664	0.1123
Proximal W	0.4076	0.1795	0.6880	0.9642	0.0964
Proximal D	0.4141	0.1913	1.5245	0.9626	0.1009
W midshaft	0.3634	-0.3680	0.4114	0.8921	-0.2050
D midshaft	0.3975	-0.7512	0.1876	0.8967	-0.3845
Distal W	0.4333	0.4279	0.6419	0.9301	0.2084
Eigenvalue	0.2217	0.0503			
PVE	87.7%	4.5%			

Supplementary Table 17. Summary of principal component (PC) analysis for *Cepphus*, based on three quadratic measurements (Fig. S13A). The sample includes 4 individuals of *C. carbo*, 7 *C. columba*, and 17 *C. grylle* (total $n = 28$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Height	0.4561	0.0831	2.2317	0.9485	0.0412
Head W	0.4694	0.8234	1.3786	0.9172	0.3840
Ventral W	0.7561	-0.5613	1.5774	0.9819	-0.1739
Eigenvalue	0.1614	0.0385			
PVE	92.1%	5.2%			

Supplementary Table 18. Summary of principal component (PC) analysis for *Cepphus*, based on three coracoidal measurements (Fig. S13B). The sample includes 14 individuals of *C. carbo*, 10 *C. columba*, and 23 *C. grylle* (total $n = 47$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
BFAH	0.7048	-0.6447	1.8425	0.9322	-0.3315
W below PP	0.3705	-0.0212	1.2494	0.7322	-0.0163
D below PP	0.6050	0.7641	1.1967	0.8909	0.4374
Eigenvalue	0.1515	0.0589			
PVE	77.6%	11.7%			

Supplementary Table 19. Summary of principal component (PC) analysis for *Synthliboramphus*, based on three coracoidal measurements (Fig. S14A). The sample includes 31 individuals of *S. antiquus*, 52 *S. wumizusume*, 2 *S. craveri*, 2 *S. hypoleucus*, and 1 *S. scrippsi* (total $n = 88$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
BFAH	0.7826	0.5373	1.5916	0.8339	0.5022
W below PP	0.2653	-0.7448	0.9795	0.3236	-0.7969
D below PP	0.5632	-0.3958	0.9763	0.6813	-0.4200
Eigenvalue	0.0973	0.0853			
PVE	44.7%	34.4%			

Supplementary Table 20. Summary of principal component (PC) analysis for *Synthliboramphus*, based on seven humeral measurements (Fig. S14B). The sample includes 29 individuals of *S. antiquus*, 62 *S. wumizusume*, 2 *S. craveri*, 2 *S. hypoleucus*, and 1 *S. scrippsi* (total $n = 96$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Length	0.3811	-0.0820	3.8701	0.8441	-0.0877
Proximal W	0.4321	0.1380	2.3272	0.8315	0.1282
W at midshaft	0.2649	0.6827	0.8594	0.5134	0.6386
D at midshaft	0.6088	-0.6191	1.3938	0.8578	-0.4211
Distal W	0.3257	0.2213	1.6086	0.7783	0.2553
Distal D	0.2704	0.2290	1.7506	0.6533	0.2671
GDB	0.2190	0.1535	1.9852	0.7706	0.2607
Eigenvalue	0.0955	0.0461			
PVE	59.8%	13.9%			

Supplementary Table 21. Summary of principal component (PC) analysis for *Synthliboramphus*, based on four femoral measurements (Fig. S14E). The sample includes 28 individuals of *S. antiquus*, 13 *S. wumizusume*, 2 *S. craveri*, 2 *S. hypoleucus*, and 1 *S. scrippsi* (total $n = 46$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Length	0.4219	0.1175	3.2243	0.8660	0.1008
W midshaft	0.6128	0.6206	0.7576	0.9032	0.3824
D midshaft	0.5217	-0.7726	0.9518	0.8374	-0.5185
Distal D	0.4176	-0.0642	1.4690	0.8172	-0.0525
Eigenvalue	0.1403	0.0587			
PVE	74.2%	13.0%			

Supplementary Table 22. Summary of principal component (PC) analysis for Aethiini, based on five coracoidal measurements (Fig. S15A). The sample includes 8 individuals of *Aethia psittacula*, 11 *A. pusilla*, 2 *A. pygmaea*, 17 *A. cristatella*, and 8 *Ptychoramphus aleuticus* (total $n = 46$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Medial L	0.4398	-0.3405	3.1614	0.9728	-0.1378
BFAH	0.5310	0.1625	1.5276	0.9773	0.0547
W below PP	0.3504	0.7626	0.9909	0.9146	0.3641
D below PP	0.4720	-0.5168	0.8052	0.9670	-0.1937
W of SA	0.4231	0.0952	1.8954	0.9714	0.0400
Eigenvalue	0.4083	0.0747			
PVE	93.1%	3.1%			

Supplementary Table 23. Summary of principal component (PC) analysis for Aethiini, based on three carpometacarpal measurements (Fig. S15E). The sample includes 8 individuals of *Aethia psittacula*, 6 *A. pusilla*, 5 *A. pygmaea*, 15 *A. cristatella*, and 8 *Ptychoramphus aleuticus* (total $n = 42$).

Variable	Eigenvectors			Mean	PC Loadings		
	PC1	PC2	PC3		PC1	PC2	PC3
Proximal W	0.6108	0.5034	-0.6111	1.1758	0.9851	0.1339	-0.1081
Proximal D	0.5671	0.2605	0.7814	1.8462	0.9860	0.0747	0.1490
L of PA	0.5526	-0.8238	-0.1264	1.3546	0.9708	-0.2386	-0.0244
Eigenvalue	0.2464	0.0406	0.0270				
PVE	96.2%	2.6%	1.2%				

Supplementary Table 24. Summary of principal component (PC) analysis for Fraterculini, based on six coracoidal measurements (Fig. S16A). The sample includes 45 individuals of *Cerorhinca monocerata*, 45 *Fratercula cirrhata*, 13 *F. arctica*, and 15 *F. corniculata* (total $n = 118$).

Variable	Eigenvectors		Mean	PC Loadings	
	PC1	PC2		PC1	PC2
Medial L	0.3928	0.0095	3.6584	0.9288	0.0101
Neck W	0.2765	0.0873	1.2996	0.6687	0.0944
BFAH	0.4819	-0.7604	2.0193	0.7986	-0.5638
W below PP	0.4783	0.6207	1.4248	0.8174	0.4745
D below PP	0.2950	0.1685	1.2329	0.8043	0.2055
W of SA	0.4704	-0.0172	2.4072	0.9164	-0.0150
Eigenvalue	0.1962	0.0878			
PVE	68.8%	13.8%			