Skeletal preparation and measurements of a young transient Killer Whale (*Orcinus orca*) from Southeast Alaska.

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Abstract

In March 2011, a 4m juvenile male killer whale was found dead on Kruzof Island, near Sitka, Alaska. A NOAA authorized necropsy team conducted a necropsy and the bones were brought to Sitka with the plan of cleaning and preparing the skeleton for museum display. In this paper we describe the cleansing process and skeletal measurements. The bones were measured using two different methods prior to hanging and display. The first technique involved photographing and measuring each individual bone by hand, including greatest lengths, curvilinear measurements and masses. The second technique was a specialized digitizing of each bone by a three dimensional scanning process by Idaho State University's Virtual Zooarcheology of the Arctic program. This included data from a CT scan of the skull by Sitka Community Hopsital. A digital version of each bone was created that may be manipulated and measured using computer software. These two protocols for killer whale skeletal measurements will allow comparisons between bones of a single skeleton, between skeletons of different individual killer whales and perhaps between the skeletons of killer whales and other small odontocetes. Following meristic and morphometric data collection, the skeleton was made a permanent display at the Sitka Sound Science Center (SSSC).

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Abstract

In March 2011, a 4m juvenile male killer whale was found dead on Kruzof Island, near Sitka, Alaska. A NOAA authorized necropsy team conducted a necropsy and the bones were brought to Sitka with the plan of cleaning and preparing the skeleton for museum display. In this paper we describe the cleansing process and skeletal measurements. The bones were measured using two different methods prior to hanging and display. The first technique involved photographing and measuring each individual bone by hand, including greatest lengths, curvilinear measurements and masses. The second technique was a specialized digitizing of each bone by a three dimensional scanning process by Idaho State University's Virtual Zooarcheology of the Arctic program. This included data from a CT scan of the skull by Sitka Community Hopsital. A digital version of each bone was created that may be manipulated and measured using computer software. These two protocols for killer whale skeletal measurements will allow comparisons between bones of a single skeleton, between skeletons of different individual killer whales and perhaps between the skeletons of killer whales and other small odontocetes. Following meristic and morphometric data collection, the skeleton was made a permanent display at the Sitka Sound Science Center (SSSC).

Introduction

A dead killer whale Orcinus orca was found on the shore of Kruzof Island, Southeast Alaska, in March 2011. The National Marine Mammal Stranding Network team was dispatched to conduct a necropsy on the animal. The Sitka Sound Sound Center was permitted to retain the carcass for skeletal rearticulation and display. The whale was male, approximately 4 years of age, and possibly died from an injury to the sternum There were harbor seal claws and hair in the stomach and therefore a mammal ecotype or transient, now termed Bigg's killer whale (Level A Necropsy Report, Dr. S. Raverty, BC MAL).

Researchers at the Sitka Sound Science Center secured permits to retain the skeleton in order to compile meristic data from the bones. The goal was to articulate the skeleton for public display at the SSSC. Worldwide, only 6 fully articulated killer whale skeletons were on public display and there have been even fewer skeletons that have had bones measured and cataloged[1]. There are a number of protocols for measurements of whole or nearly whole cetaceans post necropsies (Norris, 1961), but are few, if any, standard postcranial measurements for cetacean skeletons (Olson, pers comm).

[1] Since this project began the Port Townsend Marine Science Center has published a bone atlas for a skeleton from an adult female killer whale ("Orca Bone Atlas").

Besides availability, a major challenge likely limiting numbers of displayed whale skeletons is the huge effort to transport, and difficulty to store and clean bones.

The cleaning preparation of the bones took nearly a year. In this paper we will briefly summarize the necropsy report, the process of cleaning the bones, measurement of the bones, and final display. The bones were also scanned using a 3d scanner as part of the Idaho State University Virtual Zooarcheology of the Arctic project. This skeleton and another from Port Townsend Marine Science Center are the only killer whale skeletons for which this complete type meristic record exists.

The goal of measuring the killer whale skeleton was to allow comparisons and establish a baseline for morphology. The following techniques could be used as a general standard for measuring killer whale bones that will allow replication with new skeletons, and comparisons to be drawn between bones, or between animals.

Necropsy review and initial bone preparation

In March 2011, Jan Straley of the University of Alaska Southeast, along with the National Marine Fisheries Service (NMFS) Marine Mammal Stranding Network, Dr. Shannon Atkinson of the University of Alaska Fairbanks, and a large number of volunteers were coordinated to collect the skeleton and perform the necropsy. The US Forest Service donated a vessel and time to ferry people from Sitka to the location of the whale on Kruzof Island. Dr. Stephen Raverty, a veterinarian from Canada's Department of Fisheries and Oceans lead the necropsy. NPS and NOAA provided bear lookouts and protection. The necropsy and skeletal collection was performed on site and external measurements were taken of the body length, lengths of fins and flippers, blubber thickness, and girth of the animal.

Collecting the skeleton involved cutting the bones free of the muscle and soft tissue. As much tissue as possible was removed on the beach. Tissue and bone segments were carved down to pieces that were a reasonable size and weigh to be carried back to the boats and removed from the island. Once back in Sitka, the pieces were frozen until the cleaning process began.

Cleaning the bones

The longest portion of processing the skeleton was the cleaning of the bones. In May, the bones were placed in saltwater net pens adjacent to the SSSC facility to allow for decomposition of remaining flesh aided by scavenging invertebrates and small fish. In June, the bones were boiled to remove remaining muscle and other soft tissue. As the specimen was a young individual, the boiling was kept minimal to avoid damaging the soft immature bones. This left soft tissue that needed to be scrubbed and scraped free by hand. Students in the Making Waves middle school summer camp held at the SSSC participated in this manual cleaning as part of their camp project. Community volunteers signed up through the University of Alaska Southeast to participate in a week-long whale rearticulation class in late July 2011. This group of volunteers was extremely varied, ranging in age from seven to seventy. Members assisted in fine detail cleaning, casting models of bones and teeth for educational purposes, and the construction of portions of the hanging bar for the spinal column.

Once the soft tissue was cleared from the bones, the bones were degreased. The skeleton was macerated in fresh water. As time progressed, the bones were soaked in ammonia for repeated periods up to ten days, and one week in gasoline to remove remaining oil from thicker bones.

After as much oil as possible had been leeched from the bones, they were placed in concentrated 2-15% peroxide solutions for between a day to three days to bleach and whiten the bones In total this process of cleaning took 10 months.

Measurements, masses and photographs

Once clean, the bones were enumerated, photographed, measured and weighed. Photographs were taken while placed on a metric grid, either centimeters or millimeters based on the size of the specific bone, smaller bones on the smaller grid. Each picture was taken with an identification card in frame to aid in sorting photographs. If the anatomical orientation of the bone was known, the card included the viewing angle of the photograph and bones were placed in a head-on orientation in relation to the living animal as much as possible. If the final anatomical orientation of the bone had not been determined at the time of photography, they were simply spun in place rather than changing the orientation to maintain the head-on point of view. This spinning resulted in some photographs that lacked consistent orientations in each viewpoint.

Perrin's (1975) measurements for small cetacean skulls were used for this killer whale. The post-cranial measurements were initially taken per Perrin's protocols and then significantly expanded upon. Bone measurements were from anatomical landmarks, if possible, to help facilitate consistent repetitions between bones. Lacking acceptable processes or distinguishing marks, some bones had simpler measurements recorded such as greatest length or greatest width. Time constraints necessitated some bones were not entirely bleached when they were photographed. It was difficult to determine if every bone had the same moisture content, which would effect the bone mass measurement One bone was embedded in silicone before it was weighed so this weight is not comparable to the other bones.

Specialized techniques

This project was benefited with two specialized techniques to study the skeleton. The first was Idaho State University's Idaho Virtualization Laboratory VZAP project, which digitally scanned every individual bone or element into a digital virtual format. This process creates high definition renders of each bone that may be rotated, measured and shared through a computer. . The second specialized data collection was the skull and ear bones were CT scanned by the radiology department at Sitka Community Hospital. This gave interior views of the skull not possible with other techniques. The data from the skull CT scan was used by the VZAP project to produce, cut away renders of the skull were created.

Articulation

The articulation occurred lead by Dr. Atkinson, Alaina Avery, and Dr. Jason Waite following guidelines from Lee Post's (2005) "*The Whale Building Book.*" A paper documenting the articulation process is in preparation (S. Atkinson pers comm).

Results

Necopsy Summary

The animal was a male. His dorsal fin was 44cm and still in the falcate juvenile shape, rather than the tall straight dorsal fin characteristic of mature males. He was 4.14m in length from snout to tail notch. His blubber thickness was between 3.2cm and 4.2cm and there was evidence of harbor seal claws in his stomach. This indicates that starvation was an unlikely cause of death, and that this individual's diet included marine mammals, placing him in the transient or Brigg's grouping of killer whales.

Unfused growth plates

The veterinary staff performing the necropsy estimated that the killer whale was approximately four years old. Many of the bones had unfused growth plates. The long bones in the flippers had either one or two unfused plates. All of the vertebrae from the thoracic to all but the final caudal vertebrae had two unfused plates. A number of chevrons were in two pieces, which would likely have fused later in life. Many of the sutures in the skull were unfused, which caused some separations as the skull dried. The hyoid was in five pieces, in an adult it would likely have only been two pieces. The sternum was in five pieces, it is unclear how much that would have fused as the animal aged.

Broken bones

The sternum was broken, with evidence of healing. The crack was in the forward right portion. There was a great deal of soft tissue in the crack, but also a thin line of bone that might indicate that it had begun to heal enough for the bone to regrow before the death of the animal.

Rib malformation

A rib, eventually placed as the first right rib, had a malformation on the head end. It possessed a secondary process where it attached to the vertebrae, along with a plug of soft tissue between the two processes. This malformation was likely a birth defect, though there was no noted external malformation from the necropsy.

Bone Catalog

Bone measurements by Perrin (1975) protocols in Figure 1a-c.

Complete bone measurements listed in Figures 2-16

Bone photographs are organized into contact sheets. The skull may be found in Figures 2a-f, lower jaw in Figure 3a, ear bones in Figure 4a,hyoids in Figure 5a, vertebrae in Figures 6a-v, sternum in Figures 7a-b, sternal ribs in Figures 8a-d, ribs in Figure 9a-e, pectoral appendicular bones in Figures 10a-d and Figures 14a-b, pelvic remnants in Figures 15a-b, and chevrons in Figures 16a-d.

The VZAP whale bone catalog may be found online at http://bones.iri.isu.edu/?specid=174

Final Summary

The goal of this rearticulation was to involve community members involved in the scientific process, to document the meristics of this individual, and to allow the public and the scientific community to access what was learned. The process of preparing the bones was a learning experience in itself. The Sitka community was involved in a number of steps, from the initial discovery of the whale on Kruzof Island, to the summer campers helping with cleaning the bones, a community class that helped clean the bones, the VZAP and CT scanning, and the final rearticulation.

Going forward, the skeleton will remain on display for scientists and the public to learn from, through both visits and the data collected about the bones which will be available both on the Sitka Sound Science Center website and by request.

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Figure 1a.

Measurement protocols taken from Perrin (1975)

#	Unit	Measurements in MM, counts of elements in LIGHT GREEN, & numbering of elements in DARK BLUE
1	Condylobasal length - from tip of the rostrum to hindmost margin of occipital condyles	865
2	Length of Rostrum - from tip to line across hindmost limits of antorbital notches	437
3	Width of Rostrum at base - along line across hindmost limits of antorbital notches	247
4	Width of Rostrum at 60mm anterior to line acorss hindmost limits of antorbital notches	255
5	Width of Rostrum at midlength	210
6	Width of premaxillaries at midlength of rostrum	97
7	Width of rostrum at 3/4 length, measured from posterior end	172
8	Distance from tip of rostrum to external nares	557
9	Distance from tip of rostrum to internal nares	602
10	Greatest preorbital width	469
11	Greatest postorbital width	471
12	Least supraorbital width	467
13	Greatest width of external nares	136
14	Greatest width across zygomatic process of squamosal	544
15	Greatest width of premaxillaries	213
16	Greatest parietal width, within postemporal fossae	293
17	Vertical external height of braincase from midline of basisphenoid to summit of supraoccipital, but not including supraoccipital crest	303
18	Internal length of braincase from hindmost limit of occipital condyles to foremost limit of cranial cavity along midline	245
19	Greatest length of left posttemporal fossa, measured to external margin of raised suture	L- 198, R- 202
20	Greatest width of left posttemporal fossa at right angles to greatest length	L- 133, R- 136
21	Major diameter of left temporal fossa proper	L- 123, R- 126
22	Minor diameter of left temporal fossa proper	L- 112, R- 119
23	Projection of premaxillaries beyond maxillaries measured from tip of rostrum line across foremost tips of maxilaries visible in dorsal view	L- 28, R- 30
24	Distance from foremost end of junciton between nasals to hindmost point of margin of surpraorbital crest	56
25	Length of left orbit from apex of preobital process of frontal to apex of postorbital process	L- 104, R- 106
26	Length of antorbital process of left lacrimal	L- 87, R- 79
27	Greatest width of internal nares	149
28	Greatest length of left pterygold	L- 128, R- 132
29	Greatest width of anterior overhand of supraoccipitalcrest	L- 89, R- 102
30	Greatest length of bulla of left tympanoperiotic	82.4
31	Greatest length of periotic of left tympanoperiotic	80.5
32	Length of upper left tooth row - from hindmost margin of hindmost alveolus to top of rostrum	L- 338, R- 347
33	Number of teeth - upper left	11
34	Number of teeth - upper right	12
35	Number of teeth - lower left	12
36	Number of teeth - lower right	12
37	Length of lower left tooth row - from hindmost margin of hindmost alveolus to tip of mandible	357
38	Greatest length of left ramus	697
39	Greatest height of left ramus at right angles to greatest length	205
40	Length of left mandibular fossa, measured to mesial rim of internal surface of condyle	264
41	Deviation of skull from symmetry in dorsal view, in degrees	5
42	Length of basihyal along midline	66
43	Greatest width of basihyal	84
44	Greatest width of left throhyal proximally	52
45	Greatest length of left thyrohyal	134

Figure 1b.

Measurement protocols taken from Perrin (1975)

#	Unit	Measurements in MM, counts of elements in LIGHT GREEN, & numbering of elements in DARK BLUE
46	Greatest width of left stylohyal	45
47	Greatest length of left stylohyal	167
48	Number of thoracic vertebrae, defines as equal to number of ribs on side with greatest number	10
49	Number of lumbar vertebrae	12
50	Number of caudal vertebrae	22
51	Total number of vertebrae	51
52	Number of fused cervical vertebrae	4
53	Greatest width of articulating surface of atlas	207
54	Height of atlas - from internal anterodorsal margin of neural canal to bottom of anterior face of body	149
55	Length of lateral process of atlas -from margin of anterior articulating surface to farthest point at end of process	23
56	Greatest length of neural spine of atlas	56
57	Height of dorsal ridge of atlas in anterior view	56
58	Length of right dorsolateral spine of atlas	33
59	Length of left lateral process of axis - from margin of posterior articulating surface to distal end of process	84
60	Number of cervical vertebrae with incomplete neural arches	0
61	Cervical vertebra on which left ventrolateral process reaches greatest development	7th
62	Vertebra on which first vertical periferating foramen appears	Ca4
63	First vertebra with greatly reduced metapophyses	Ca14
64	Last vertebra with distinct transverse process	Ca7
65	Last vertebra with distinct neural process	Ca12
66	First vertebra with unfused epiphysis	T1
67	Last vertebra with unfused epiphysis	Ca18
68	First caudal vertebra with vertical neural spine	Ca1
69	Length of neural spine of first thoracic vertebra - from anterodorsal margin of neural canal to tip of spine	43
70	Length of neural spine at second thoracic vertebra	42
71	Length of neural spine at tenth thoracic vertebra	78
72	Length of neural spine at last thoracic vertebra	78 (Last = T10)
73	Height of first thoracic vertebra - from internal anterodorsal margin of neural canal to bottom of anterior face of body	148
74	Greatest width of first thoracic vertebra - across lateral processes	206
75	Height of first lumbar vertebra	232
76	Greatest width of fist lumbar vertebra	229
77	Length of 23rd centrum, exclusive of epiphyses, along ventral midline	107 (L6)
78	Number of vertebral ribs - left	10
79	Number of vertebral ribs - right	10
80	Number of two headed ribs - left	6
81	Number of two headed ribs - right	6
82	Number of floating ribs - left	2
83	Number of floating ribs - right	2
84	Number of sternal ribs - left	8
85	Number of sternal ribs - right	8
86	Greatest length of first left vertebral rib	305
87	Width of first left vertebral rib at apex of proximal curvature	51
88	Greatest length of longest left vertebral rib	796 (5th)
89	Greatest length of first left sternal rib	180
90	Greatest width of manubrium	140

Figure 1c.

Measurement protocols taken from Perrin (1975)

#	Unit	Measurements in MM, counts of elements in LIGHT GREEN, & numbering of elements in DARK BLUE
91	Length of manubrium along midline	143.4
92	Depth of anterior notch of manubrium	20.5
93	Length of foramen in manubrium	68.1
94	Number of mesosternal elements	5
95	Number of mesosternal elements fused	0
96	Number of chevron bones	13
97	Number in foremost series of fused chevron bones	4
98	Vertebra bearing first chevron bone	Ca 1 (30th)
99	Vertebra bearing last chevron bone	Ca 13 (43rd)
100	Greatest length of left half of the first chevron bone	22
101	Greatest length of the left half of the largest chevron bone	41 (3rd)
102	Greatest length of the left half of the last chevron bone	23 (13th)
103	Height of scapula - from posterior margin of glenoid fossa to corcovertebral angle	L- 259, R- 253
104	Length of scapula - from posterior margin of glenoid fossa to glenovertebral angle	L- 191, R- 195
105	Greatest length of coracoid process - from anterior margin of glenoid fossa	L- 36, R- 42
106	Greatest width of coracoid process	L- 36, R- 37
107	Greatest width of metacromion process - from apex of ventral curvature to vertebral apex	L- 59, R- 64
108	Greatest length of humorous - measured on ventral side of flipper	116
109	Greatest width of humerus distally	100
110	Greatest length of radius	137
111	Greatest width of radius distally	97
112	Greatest length of ulna	118
113	Transverse breadth of proximal row of carpals	N/A
114	Number of ossified phalanges in first digit	2 (L & R)
115	Number of ossified phalanges in second digit	5 (L & R)
116	Number of ossified phalanges in third digit	4 (L & R)
117	Number of ossified phalanges in fourth digit	3 (L & R)
118	Number of ossified phalanges in fifth digit	1 (L & R)
119	Greatest length of left pelvic rudiment	105 or 97

Figure 3.

Accompanying Photo Page: Figure 3a.

Lower Jaw / Mandible

Mandible	# of teeth	Total Length (mm)	Fossa Length (mm)	Length of Tooth Row (mm)	Height (mm)	Assembled Width (mm)	Total Mass (kg)
Left	12	697	264	347	205		
Right	12	712	245	346	209		
Assembled						510	3.45

Figure 4.

Accompanying Photo Page: Figure 4a.

Ear Bones

Ear bone	Tympanic Length (mm)	Tympanic Width (mm)	Periotic Length (mm)	Periotic Width (mm)	Total Height (mm)	Mass (g)	Misc.
Left	83	49	79	53	79	323.38	Cracked
Right	82	52	79	51	80	322.40	

Figure 2. (Measurements in mm)

Accompanying Photo Pages: Figures 2a. - 2f.

Skull / Cranium

Mass (kg)	20.2
Condylobasal length - from tip of the rostrum to hindmost margin of occipital condyles	865
Length of Rostrum - from tip to line across hindmost limits of antorbital notches	437
Width of Rostrum at base - along line across hindmost limits of antorbital notches	247
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Length of upper left tooth row - from hindmost margin of hindmost alveolus to top of rostrum	L- 338, R- 347
Number of teeth - upper left	11
Number of teeth - upper right	12

Figure 5.

Accompanying Photo Page: Figure 5a.

Hyoids

Bone	Placement	Length at Midline (mm)	Greatest Length (mm)	Greatest Width (mm)	Width Center/ Proximally (mm)	Width Distally (mm)	Depth (mm)	Depth Minimum (mm)	Depth Proximally (mm)	Depth Distally (mm)	Mass (g)
Basihyoid	Center	66	73	84			25				38.08
Thyrohyoid	Left		134	54	52	21		15	34	20	40.01
Thyrohyoid	Right		132	55	53	26		14	34	19	42.65
Stylohyoid	Left		167	45			29				62.14
Stylohyoid	Right		161	46			33				58.29

Figure 7.

Accompanying Photo Pages: Figures 7a. - 7b.

Sternum

Sternum Position	Side	Length (mm)	Length of foramen (mm)	Minimum Width (mm)	Maximum Width (mm)	Depth Minimum (mm)	Depth Maximum (mm)	Mass (g)
Cranial	Left	170	75	45	68	14	25	85.52
Cranial	Right	154	67	44	88	13	23	87.79
Middle	Left	93		42	63	12	19	30.70
Middle	Right	89		43	67	12	18	33.45
Caudal	Center	51			58		16	13.63

Figure 6.

Accompanying Photo Page - Vertebrae: Figures 6a. - 6m.

Accompanying Photo Page - Epiphyses: Figures 6n. - 6w.

Vertebrae

Vertebrae	#	Base to canal base (mm)	Base to canal peak (mm)	Total Height (mm)	Centrum width (mm)	Inner Canal Width (mm)	Total Width (mm)	Centrum Depth (mm)	Assembled Depth (mm)	Anterior plate H (mm)	Anterior plate W (mm)	Posterior plate H (mm)	Posterior plate W (mm)	Mass (g)	Epiphyses Fused / Misc. Info.
Cervical	1 thru 4	102	149	205	207	76	247	N/A	87	102	207	102	55	362.12	Fused
Cervical	5	73	146	168	88	73	116	N/A	10	59	77	57	75	61.76	Fused
Cervical	6	72	143	166	87	74	119	N/A	12	59	71	58	71	67.42	Fused
Cervical	7	77	148	167	98	84	168	N/A	16	59	71	61	66	114.12	Fused
Thoracic	1	75	147	190	117	95	204	15	24	63	70	65	68	196.96	Unfused
Thoracic	2	76	147	189	106	87	203	27	32	65	71	63	68	239.99	Unfused
Thoracic	3	73	149	196	96	91	212	34	39	66	71	64	71	256.88	Unfused
Thoracic	4	73	153	199	87	101	209	39	46	66	70	67	69	270.93	Unfused
Thoracic	5	75	160	209	83	95	210	45	53	67	69	67	72	312.6	Unfused
Thoracic	6	76	163	216	75	89	206	49	58	69	69	70	72	323.74	Unfused
Thoracic	7	77	160	218	89	80	201	53	64	72	75	73	75	344.59	Unfused
Thoracic	8	79	159	225	84	73	200	56	67	75	73	75	77	385.12	Unfused
Thoracic	9	80	161	233	91	67	204	58	70	75	75	74	78	402.56	Unfused
Thoracic	10	80	153	231	92	62	225	60	71	75	77	74	80	404.14	Unfused
Lumbar	1	79	153	232	93	57	229	59	69	75	80	75	82	354.66	Unfused
Lumbar	2	81	147	231	100	56	228	61	71	76	83	77	85	365.13	Unfused
Lumbar	3	82	144	231	105	53	229	62	72	77	85	79	86	372.4	Unfused
Lumbar	4	88	141	230	106	49	228	63	72	79	87	80	86	375.31	Unfused
Lumbar	5	91	139	235	108	45	223	62	73	81	87	81	86	430	Silicone, unfused
Lumbar	6	94	140	237	107	42	227	63	74	83	88	81	87	370.28	Unfused
Lumbar	7	94	141	232	110	37	226	64	74	83	89	83	89	380.27	Unfused
Lumbar	8	96	144	222	111	32	226	63	74	84	89	83	87	391.51	Unfused
Lumbar	9	97	146	213	109	29	216	63	75	83	89	85	89	385.03	Unfused
Lumbar	10	102	145	210	109	24	203	63	75	84	89	87	88	386.59	Unfused
Lumbar	11	107	149	209	110	21	192	63	75	87	90	89	91	367.37	Unfused
Lumbar	12	106	140	203	112	19	192	63	75	87	90	90	93	385.34	Unfused
Caudal	1	104	139	198	112	18	187	65	76	91	93	92	95	390.13	Unfused
Caudal	2	104	142	194	114	17	176	65	76	90	95	91	96	379.53	Unfused
Caudal	3	106	138	186	112	15	162	63	75	91	95	89	95	367.78	Unfused
Caudal	4	107	134	181	111	9	156	63	74	89	92	90	94	368.68	Unfused
Caudal	5	109	137	175	109	13	145	62	74	88	91	92	95	342.3	Unfused
Caudal	6	107	126	165	101	4	122	56	74	89	92	89	90	316.3	Unfused
Caudal	7	101	122	157	102	6	116	57	72	88	88	85	85	292.32	Unfused
Caudal	8	113	121	142	91	5	107	51	71	83	85	83	83	255.14	Unfused
Caudal	9	107	111	125	87	6	102	51	71	82	83	81	79	241.81	Unfused
Caudal	10	97	102	104	81	3	87	57	69	72	72	81	78	237.33	Unfused
Caudal	11	96	N/A	100	73	1	84	54	67	77	72	72	67	215.1	Unfused
Caudal	12	N/A	N/A	86	68	N/A	72	49	61	67	65	71	66	164.84	Unfused
Caudal	13	N/A	N/A	74	62	N/A	73	40	51	64	63	57	62	100.58	Unfused
Caudal	14	N/A	N/A	51	58	N/A	67	33	39	51	57	42	54	54.88	Unfused
Caudal	15	N/A	N/A	45	54	N/A	62	29	35	37	46	38	50	34.12	Unfused
Caudal	16	N/A	N/A	40	N/A	N/A	61	34	35	34	45	29	37	27.32	Unfused
Caudal	17	N/A	N/A	35	N/A	N/A	52	N/A	32	28	32	22	29	18.3	Unfused
Caudal	18	N/A	N/A	28	N/A	N/A	46	N/A	28	20	30	16	25	11.33	Unfused
Caudal	19	N/A	N/A	23	N/A	N/A	32	N/A	22	N/A	30	N/A	26	5.17	Fused
Caudal	20	N/A	N/A	12	N/A	N/A	28	N/A	17	N/A	22	N/A	19	2.02	Fused
Caudal	21	N/A	N/A	12	N/A	N/A	20	N/A	15	N/A	13	N/A	7	0.88	Fused
Caudal	22	N/A	N/A	7	N/A	N/A	10	N/A	9	N/A	9	N/A	6	0.13	Fused

Figure 8.

Accompanying Photo Pages: Figures 8a. - 8d.

Sternal Ribs

Bone	#	Side	Straight Length (mm)	Curvilinear Length (mm)	Greatest Width (mm)	Mass (g)	Misc. Info.
Sternal rib	1	R	168	158	39	45.69	
Sternal rib	1	L	180	165	30	48.01	
Sternal rib	2	R	174	157	35	47.94	
Sternal rib	2	L	168	155	33	45.26	
Sternal rib	3	R	175	173	27	39.71	
Sternal rib	3	L	173	172	26	37.33	
Sternal rib	4	R	189	187	24	33.09	
Sternal rib	4	L	195	194	23	29.98	
Sternal rib	5	R	209	205	17	21.46	Slight cracking
Sternal rib	5	L	211	212	18	24.91	
Sternal rib	6	R	190	187	16	11.14	
Sternal rib	6	L	202	202	16	14.08	Mended
Sternal rib	7	R	94	92	16	3.47	Shorter
Sternal rib	7	L	153	149	14	8.39	
Sternal rib	8	R	213	217	15	11.28	
Sternal rib	8	L	126	130	11	3.68	Cut, replicated

Figure 9.

Accompanying Photo Pages: Figures 9a. - 9e.

Ribs

Bone	#	Side	Straight Length (mm)	Curvilinear Length (mm)	Greatest Width (mm)	Mass (g)	Misc. Info.
Rib	1	R	305	440	51	201.10	Growth
Rib	1	L	315	450	50	230.69	
Rib	2	R	467	604	49	299.36	
Rib	2	L	467	620	52	286.89	
Rib	3	R	550	712	47	301.10	
Rib	3	L	550	722	45	284.12	
Rib	4	R	612	782	41	367.47	
Rib	4	L	595	796	40	300.12	
Rib	5	R	585	760	43	340.12	
Rib	5	L	582	772	43	275.68	
Rib	6	R	615	788	42	348.46	
Rib	6	L	607	794	37	323.56	
Rib	7	R	608	668	32	273.22	
Rib	7	L	602	687	33	263.46	
Rib	8	R	573	632	29	238.51	
Rib	8	L	563	633	32	240.77	
Rib	9	R	524	575	22	203.62	
Rib	9	L	522	584	22	203.93	
Rib	10	R	482	516	21	171.25	
Rib	10	L	485	517	24	172.97	

Figure 10.

Accompanying Photo Page: Figure 10a.

Scapula

Scapula	Left	Right
Curvilinear length of medial border (mm)	425	430
Acromion Width (mm)	59	64
Coracoid Process Width (mm)	36	37
Coracoid Process Length (mm)	36	42
Glenoid Fossa Long Dimension (mm)	98	97
Glenoid Fossa Short Dimension (mm)	64	67
Straight length glenoid to medial border along lateral border (mm)	191	195
Straight length glenoid to medial border over processes (mm)	259	253
Depth of medial border (mm)	14	9
Mass (g)	420	410

Figure 11.

Accompanying Photo Pages: Figures 11a. - 11b.

Humerus

Humerus	Left	Right
Greatest Length (mm)	127	122
Head/anatomical neck to medial epicondyle (mm)	87	85
Head to lateral epicondyle (mm)	111	110
Greatest Width (mm)	107	100
Greatest depth (head) (mm)	103	91
Minimum depth (neck) (mm)	67	64
Trochlea growth plate length (mm)	97	95
Trochlea growth plate width (mm)	50	50
Trochlea growth plate depth (mm)	21	21
Head growth plate standing height (mm)	57	56
Head growth plate total length (mm)	123	123
Head growth plate diameter at larger process (mm)	83	86
Head growth plate width minimum (mm)	56	54
Head growth plate diameter at smaller process (mm)	81	82
Mass (g)	442.13	414.20

Figure 12.

Accompanying Photo Page: Figure 12a.

Radius

Radius	Left	Right
Width of head (mm)	94	97
Width of distal end (mm)	76	78
Straight length head/neck to styloid process (mm)	96	95
Straight length head/neck to opposite styloid process (mm)	114	112
Greatest length (mm)	137	137
Greatest depth (mm)	54	53
Minimum depth (mm)	34	37
Head plate length (mm)	47	44
Head plate width (mm)	62	61
Head plate depth (mm)	22	22
Mass (g)	249.78	219.31

Figure 13.

Accompanying Photo Page: Figure 13a.

Ulna

Ulna	Left	Right
Trochlea width (mm)	57	58
Length trochlea to head (mm)	119	118
Head width (mm)	66	67
Width Maximum (mm)	63	67
Width Minimum (mm)	38	40
Depth (mm)	31	30
Plate Length (mm)	47	47
Plate Width (mm)	43	42
Plate Depth (mm)	15	13
Mass (g)	113.11	113.40

Figure 14.

Accompanying Photo Pages: Figures 14a. - 14b.

Flippers

Flipper	Digit	Bone	Width (mm)	Length (mm)	Depth (mm)	Mass (g)
Left	1	Meta Carpal	29	25	17	
Left	1	Distal	8	8	6	
Left	2	Meta Carpal	49	35	26	
Left	2	Proximal	43	26	18	
Left	2	Medial 1	26	18	13	
Left	2	Medial 2	18	18	9	
Left	2	Distal	9	8	4	
Left	3	Meta Carpal	35	34	20	
Left	3	Proximal	35	22	13	
Left	3	Medial	23	14	4	
Left	3	Distal	6	3	2	
Left	4	Meta Carpal	34	23	16	
Left	4	Proximal	22	10	7	
Left	4	Distal	5	2	1	
Left	5	Meta Carpal	17	11	12	
Left	5	Distal	3	2	1	
Right	1	Meta Carpal	30	20	14	2.7
Right	1	Distal	9	6	7	0.14
Right	2	Meta Carpal	47	33	21	12.2
Right	2	Proximal	43	26	17	5.27
Right	2	Medial 1	26	17	12	1.52
Right	2	Medial 2	16	15	8	0.58
Right	2	Distal	5	4	3	0.12
Right	3	Meta Carpal	36	34	17	7.73
Right	3	Proximal	35	20	10	2.53
Right	3	Medial	17	10	7	0.46
Right	3	Distal	7	9	4	0.04
Right	4	Meta Carpal	35	23	17	4.11
Right	4	Proximal	27	10	7	0.72
Right	4	Distal	5	4	3	0.05
Right	5	Meta Carpal	20	14	3	0.98
Right	5	Distal	6	4	2	0.02

Figure 15.

Accompanying Photo Pages: Figures 15a. - 15b.

Pelvic bones / Inominates

Inominate	Greatest Length (mm)	Greatest Width (mm)	Depth Range (mm)	Mass (g)	Misc. Info.
Left	105	25	5 to 14	10.32	Whole
Right	97	23	5 to 14	9.54	Cracked

Figure 16.

Accompanying Photo Pages: Figures 16a. - 16d.

Chevrons

Chevron #	Pieces	Standing height	Height L	Height R	Base Leg Length	Width L	Width R	Width Base Leg	Spread	Total Width	Length L	Length R	Mass L (g)	Mass R (g)	Total Mass (g)	Misc. Info.
1	2	10	10	10	N/A	9	8	N/A	12	N/A	22	21	0.66	0.54	1.20	Two pieces
2	2	21	20	22	N/A	8	9	N/A	15	N/A	41	42	1.61	1.82	3.43	Two pieces
3	2	42	41	47	N/A	8	7	N/A	22	N/A	41	39	3.94	4.55	8.49	Two pieces
4	2	42	50	49	N/A	8	9	N/A	22	N/A	34	34	4.93	4.32	9.25	Two pieces
5	1	43	43	42	19	12	12	14	24	52	34	33	8.33	3.3	11.63	Single bone, but Broken
6	1	51	57	55	28	11	10	12	32	52	33	34	N/A	N/A	13.78	Single Bone
7	1	68	71	69	35	11	10	11	34	55	34	35	N/A	N/A	15.90	Single Bone
8	1	65	68	68	27	10	13	6	37	60	34	42	N/A	N/A	19.49	Single Bone
9	2	41	45	43	10	12	11	15	33	55	33	32	N/A	N/A	10.69	Glued before massed
10	2	32	40	41	15	9	10	13	35	53	30	30	N/A	N/A	7.43	Glued before massed
11	2	30	33	35	13	7	7	9	32	49	30	31	N/A	N/A	5.24	Glued before massed
12	2	29	28	26	10	4	6	8	24	32	24	29	N/A	N/A	3.50	Glued before massed
13	2	17	21	22	7	6	6	7	25	35	23	24	N/A	N/A	2.28	Glued before massed