

1 **Ontogeny and evolution of the elasmosaurid neck highlight a**  
2 **greater diversity of Antarctic plesiosaurians**

3 ARTHUR S. BRUM<sup>1\*</sup>; TIAGO R. SIMÕES<sup>2</sup>; GEOVANE A. SOUZA<sup>1</sup>; ANDRÉ E. P.  
4 PINHEIRO<sup>3</sup>; RODRIGO G. FIGUEIREDO<sup>4</sup>; MICHAEL W. CALDWELL<sup>5,6</sup>;  
5 JULIANA M. SAYÃO<sup>1</sup>; ALEXANDER W. A. KELLNER<sup>7</sup>

6

7 <sup>1</sup>Laboratório de Paleobiologia e Paleogeografia Antártica, Departamento de Geologia e  
8 Paleontologia, Museu Nacional-Universidade Federal do Rio de Janeiro, Quinta da Boa  
9 Vista, São Cristóvão, 20940-040, Rio de Janeiro, RJ, Brazil.

10 <sup>2</sup>Department of Organismic & Evolutionary Biology & Museum of Comparative  
11 Zoology, Harvard University, Cambridge, MA 02138, USA.

12 <sup>3</sup>Departamento de Ciências, Faculdade de Formação de Professores, Universidade do  
13 Estado do Rio de Janeiro, Campus São Gonçalo, Rua Dr. Francisco Portela, Bairro do  
14 Patronato, São Gonçalo, RJ, Brazil.

15 <sup>4</sup>Departamento de Biologia, Universidade Federal do Espírito Santo, Alto Universitário,  
16 Guararema, 29500-000, Alegre, ES, Brazil.

17 <sup>5</sup>Department of Biological Sciences, University of Alberta, Edmonton, Alberta T6G  
18 2E9, Canada.

19 <sup>6</sup>Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton,  
20 Alberta T6G 2E9, Canada.

21 <sup>7</sup>Laboratório de Sistemática e Tafonomia de Vertebrados Fósseis, Departamento de  
22 Geologia e Paleontologia, Museu Nacional/Universidade Federal do Rio de Janeiro,  
23 Quinta da Boa Vista s/n, São Cristóvão, Rio de Janeiro, RJ, Brazil.

24 \* Corresponding author: arthursbc@yahoo.com.br

25

26 **SUPPLEMENTARY MATERIAL**

27 This supplementary material contains:

28 SUPPLEMENTARY MATERIAL AND METHODS

29 Phylogenetic analyses

30 Statistical analyses

31 SUPPLEMENTARY RESULTS

32 Locality and Horizon

33 Phylogenetic analyses

34 Normality tests

35 Statistical analyses of cervical vertebrae

36 Statistical analyses of dorsal vertebra

37 SUPPLEMENTARY FIGURES

38 SUPPLEMENTARY TABLES

39 SUPPLEMENTARY REFERENCES

40

41 **SUPPLEMENTARY MATERIAL AND METHODS**

42 **Phylogenetic analysis.** The codification of the specimen in the matrix of  
43 O’Gorman (2020) with codification of *Jucha* by Fischer *et al.* (2021) is available in the  
44 files “OG(20120) & Fischeretal(2021).nex” and “OG(2020) & Fischeretal(2021).tnt”.

45 **Statistical analyses.** The whole dataset employed in our statistical analyses to cervical  
46 and dorsal vertebrae are compiled in the file “Dataset.xlsx”. All the compiled cervical  
47 vertebrae specimens are listed in **Supplementary Table 1**. The whole dataset of PAST  
48 files to cervical vertebrae are available in the files: “Supp cervical adult  
49 morphotypes.dat”; “Supp cervical adult genus level.dat” and “Supp cervical juvenile  
50 genus level.dat”.

51 All the analyzed dorsal vertebrae specimens are listed in **Supplementary Table 2**. The  
52 whole dataset of PAST files to cervical vertebrae are available in the files: “Supp dorsal  
53 adult genus level.dat”.

54 We plotted the VLI values in histograms and performed the normality test  
55 Shapiro-Wilk (*W*) to determine whether we could perform non-parametric analyses.

56

57 **SUPPLEMENTARY RESULTS**

58 **Locality and horizon.** The photographed sites shown in Figure 1 of the article are  
59 available in **Supplementary Figure 1**.

60 **Phylogenetic analysis.** The complete collapsed tree from dataset of O’Gorman (2020)  
61 with *Jucha* codifications—without MN 7820-V and excluding the wildcard OTUs  
62 *Alexandronectes* and *Lagenectes*—is in **Supplementary Figure 2**. This first analysis  
63 considered all characters unordered. Following, the list of the common synapomorphies  
64 recovered from this first analysis:

65 Node 102 (the node number follows the present in **Supplementary Figure 2**):

66 All trees:

67 No synapomorphies

68 Node 103 :

69 All trees:

70 Char. 102: 2 --> 0

71 Char. 164: 0 --> 2

72 Char. 176: 0 --> 1

73 Node 104 :

74 All trees:

75 Char. 159: 0 --> 1

76 Char. 163: 0 --> 1

77 Char. 170: 1 --> 0

78 Char. 180: 0 --> 1

79 Node 105 :

80 All trees:

81 Char. 0: 0 --> 1

82 Char. 18: 2 --> 1

83 Char. 32: 0 --> 1

84 Char. 113: 0 --> 1

85 Char. 119: 1 --> 2

86 Char. 151: 3 --> 2

87 Char. 238: 0 --> 1  
88 Char. 251: 0 --> 1  
89 Node 106 :  
90 All trees:  
91 Char. 2: 1 --> 0  
92 Char. 3: 0 --> 1  
93 Char. 6: 0 --> 1  
94 Char. 8: 1 --> 2  
95 Char. 12: 0 --> 1  
96 Char. 66: 1 --> 0  
97 Char. 69: 0 --> 1  
98 Char. 172: 1 --> 0  
99 Node 107 :  
100 All trees:  
101 Char. 16: 0 --> 1  
102 Char. 76: 0 --> 1  
103 Char. 94: 0 --> 1  
104 Char. 137: 0 --> 1  
105 Node 108 :  
106 All trees:  
107 Char. 30: 0 --> 1  
108 Char. 68: 1 --> 0  
109 Char. 105: 1 --> 0  
110 Char. 157: 1 --> 0  
111 Node 109 :  
112 All trees:  
113 Char. 1: 1 --> 0  
114 Char. 48: 1 --> 0  
115 Char. 49: 2 --> 1  
116 Char. 64: 2 --> 1  
117 Node 110 :  
118 All trees:  
119 Char. 135: 0 --> 1  
120 Char. 136: 2 --> 1

121 Char. 166: 0 --> 1  
122 Char. 171: 0 --> 3  
123 Node 111 :  
124 All trees:  
125 Char. 171: 3 --> 1  
126 Char. 182: 0 --> 1  
127 Char. 183: 0 --> 2  
128 Node 112 :  
129 All trees:  
130 Char. 56: 0 --> 1  
131 Some trees:  
132 Char. 163: 1 --> 0  
133 Char. 174: 0 --> 1  
134 Char. 248: 0 --> 1  
135 Node 113 :  
136 All trees:  
137 Char. 3: 1 --> 0  
138 Char. 17: 1 --> 0  
139 Char. 136: 1 --> 0  
140 Node 114 :  
141 All trees:  
142 Char. 152: 1 --> 0  
143 Some trees:  
144 Char. 1: 0 --> 1  
145 Char. 115: 1 --> 0  
146 Char. 244: 0 --> 1  
147 Node 115 :  
148 All trees:  
149 Char. 45: 1 --> 0  
150 Char. 95: 1 --> 0  
151 Char. 159: 1 --> 2  
152 Char. 171: 1 --> 3  
153 Node 116 :  
154 All trees:

155 Char. 137: 1 --> 2  
156 Some trees:  
157 Char. 18: 1 --> 0  
158 Char. 58: 0 --> 1  
159 Char. 231: 0 --> 1  
160 Node 117 :  
161 All trees:  
162 Char. 120: 1 --> 2  
163 Node 118 :  
164 All trees:  
165 Char. 24: 1 --> 0  
166 Char. 52: 1 --> 0  
167 Char. 81: 0 --> 1  
168 Char. 82: 2 --> 1  
169 Char. 83: 2 --> 0  
170 Char. 112: 1 --> 0  
171 Char. 129: 0 --> 2  
172 Char. 215: 0 --> 1  
173 Char. 256: 0 --> 1  
174 Node 119 :  
175 All trees:  
176 Char. 3: 1 --> 2  
177 Char. 15: 0 --> 1  
178 Char. 33: 0 --> 1  
179 Char. 65: 0 --> 1  
180 Char. 111: 1 --> 0  
181 Node 120 :  
182 All trees:  
183 Char. 157: 0 --> 1  
184 Char. 208: 0 --> 2  
185 Node 121 :  
186 All trees:  
187 Char. 116: 0 --> 1  
188 Char. 119: 1 --> 0

189 Char. 120: 1 --> 0  
190 Char. 136: 1 --> 0  
191 Char. 152: 1 --> 0  
192 Char. 160: 1 --> 2  
193 Char. 175: 0 --> 1  
194 Char. 176: 1 --> 0  
195 Char. 185: 0 --> 1  
196 Char. 188: 1 --> 0  
197 Char. 221: 1 --> 0  
198 Char. 222: 0 --> 2  
199 Char. 230: 1 --> 2  
200 Char. 239: 0 --> 1  
201 Char. 240: 1 --> 0  
202 Char. 241: 1 --> 0  
203 Char. 265: 0 --> 1  
204 Node 122 :  
205 All trees:  
206 Char. 53: 0 --> 1  
207 Char. 113: 0 --> 1  
208 Char. 131: 0 --> 1  
209 Char. 141: 0 --> 1  
210 Char. 223: 2 --> 3  
211 Char. 231: 0 --> 2  
212 Char. 237: 0 --> 1  
213 Char. 243: 1 --> 2  
214 Char. 244: 0 --> 1  
215 Char. 250: 1 --> 2  
216 Node 123 :  
217 All trees:  
218 Char. 3: 2 --> 1  
219 Char. 9: 1 --> 2  
220 Char. 103: 0 --> 1  
221 Node 124 :  
222 All trees:



223 Char. 1: 0 --> 1  
224 Char. 111: 0 --> 1  
225 Char. 137: 2 --> 1  
226 Char. 166: 1 --> 0  
227 Char. 246: 0 --> 1  
228 Node 125 :  
229 All trees:  
230 Char. 23: 0 --> 1  
231 Char. 138: 0 --> 1  
232 Some trees:  
233 Char. 64: 1 --> 2  
234 Char. 119: 0 --> 2  
235 Char. 126: 1 --> 3  
236 Node 126 :  
237 All trees:  
238 Char. 29: 0 --> 1  
239 Char. 65: 1 --> 0  
240 Char. 82: 2 --> 1  
241 Char. 131: 1 --> 0  
242 Char. 175: 1 --> 2  
243 Node 127 :  
244 All trees:  
245 Char. 32: 0 --> 1  
246 Char. 187: 0 --> 2  
247 Char. 201: 1 --> 0  
248 Char. 230: 2 --> 3  
249 Node 128 :  
250 All trees:  
251 Char. 83: 2 --> 1  
252 Char. 85: 1 --> 0  
253 Char. 122: 0 --> 1  
254 Char. 159: 1 --> 3  
255 Char. 161: 0 --> 1  
256 Char. 162: 0 --> 1

257      Some trees:  
258      Char. 0: 1 --> 0  
259      Char. 3: 1 --> 2  
260      Char. 12: 1 --> 0  
261      Char. 30: 1 --> 0  
262      Char. 34: 0 --> 1  
263      Char. 53: 1 --> 0  
264      Char. 155: 1 --> 2  
265      Char. 180: 1 --> 0  
266  
267      Node 129 :  
268      All trees:  
269      Char. 158: 1 --> 2  
270      Char. 204: 2 --> 1  
271      Char. 226: 1 --> 2  
272      Char. 243: 1 --> 2  
273      Char. 250: 1 --> 2  
274      Node 130 :  
275      All trees:  
276      Char. 140: 01 --> 2  
277      Char. 188: 1 --> 0  
278      Node 131 :  
279      All trees:  
280      Char. 156: 0 --> 1  
281      Char. 227: 1 --> 0  
282      Char. 234: 2 --> 0  
283      Node 132 :  
284      All trees:  
285      Char. 248: 0 --> 1  
286      Char. 249: 0 --> 1  
287      Char. 263: 0 --> 1  
288      Node 133 :  
289      All trees:  
290      Char. 2: 1 --> 0

291 Char. 13: 0 --> 2  
292 Char. 38: 0 --> 1  
293 Char. 60: 0 --> 1  
294 Char. 153: 0 --> 1  
295 Char. 177: 1 --> 2  
296 Char. 178: 1 --> 0  
297 Char. 187: 0 --> 1  
298 Char. 192: 0 --> 1  
299 Char. 209: 0 --> 3  
300 Char. 222: 0 --> 2  
301 Char. 264: 1 --> 2  
302 Node 134 :  
303 All trees:  
304 Char. 171: 3 --> 0  
305 Char. 206: 0 --> 2  
306 Char. 218: 0 --> 3  
307 Char. 262: 0 --> 1  
308 Node 135 :  
309 All trees:  
310 Char. 36: 0 --> 1  
311 Char. 37: 0 --> 1  
312 Char. 49: 1 --> 2  
313 Char. 152: 1 --> 2  
314 Char. 248: 1 --> 0  
315 Node 136 :  
316 All trees:  
317 Char. 32: 0 --> 1  
318 Char. 47: 0 --> 1  
319 Char. 230: 1 --> 0  
320 Char. 244: 0 --> 1  
321 Node 137 :  
322 All trees:  
323 Char. 45: 1 --> 0  
324 Char. 74: 0 --> 1

325 Char. 150: 1 --> 2  
326 Char. 162: 0 --> 1  
327 Char. 256: 1 --> 0  
328 Char. 268: 0 --> 1  
329 Node 138 :  
330 All trees:  
331 Char. 72: 1 --> 0  
332 Char. 113: 1 --> 0  
333 Char. 150: 2 --> 1  
334 Node 139 :  
335 All trees:  
336 Char. 64: 0 --> 1  
337 Char. 132: 1 --> 0  
338 Char. 137: 0 --> 1  
339 Char. 143: 0 --> 1  
340 Char. 226: 2 --> 1  
341 Char. 233: 0 --> 1  
342 Node 140 :  
343 All trees:  
344 Char. 219: 0 --> 1  
345 Node 141 :  
346 All trees:  
347 Char. 223: 2 --> 1  
348 Char. 260: 0 --> 2  
349 Node 142 :  
350 All trees:  
351 Char. 13: 0 --> 1  
352 Char. 44: 0 --> 1  
353 Char. 73: 0 --> 1  
354 Char. 127: 0 --> 1  
355 Char. 201: 1 --> 0  
356 Char. 209: 0 --> 2  
357 Char. 236: 0 --> 1  
358 Char. 241: 1 --> 3

359 Char. 244: 0 --> 1  
360 Char. 261: 0 --> 1  
361 Node 143 :  
362 All trees:  
363 Char. 64: 1 --> 0  
364 Char. 72: 0 --> 1  
365 Char. 113: 0 --> 1  
366 Char. 132: 0 --> 1  
367 Char. 159: 1 --> 3  
368 Char. 186: 3 --> 0  
369 Char. 187: 0 --> 2  
370 Char. 220: 0 --> 1  
371 Char. 221: 1 --> 0  
372 Char. 222: 0 --> 1  
373 Char. 225: 1 --> 0  
374 Char. 229: 0 --> 1  
375 Char. 258: 0 --> 1  
376 Char. 259: 1 --> 0  
377 Char. 267: 1 --> 2  
378 Node 144 :  
379 All trees:  
380 Char. 232: 0 --> 1  
381 Node 145 :  
382 All trees:  
383 Char. 153: 0 --> 1  
384 Char. 157: 1 --> 2  
385 Char. 245: 0 --> 1  
386 Node 146 :  
387 All trees:  
388 Char. 196: 1 --> 0  
389 Char. 208: 1 --> 2  
390 Node 147 :  
391 All trees:  
392 Char. 147: 1 --> 0

393 Node 148 :  
394 All trees:  
395 Char. 146: 0 --> 1  
396 Node 149 :  
397 All trees:  
398 Char. 151: 4 --> 5  
399 Node 150 :  
400 All trees:  
401 Char. 133: 0 --> 1  
402 Char. 264: 1 --> 0  
403 Node 151 :  
404 All trees:  
405 Char. 10: 0 --> 2  
406 Char. 64: 0 --> 2  
407 Char. 86: 0 --> 1  
408 Char. 103: 0 --> 1  
409 Char. 104: 0 --> 1  
410 Char. 105: 1 --> 0  
411 Some trees:  
412 Char. 178: 0 --> 1  
413 Node 152 :  
414 All trees:  
415 Char. 157: 1 --> 0  
416 Char. 158: 2 --> 1  
417 Char. 163: 2 --> 1  
418 Some trees:  
419 Char. 5: 0 --> 1  
420 Char. 60: 0 --> 1  
421 Char. 122: 0 --> 1  
422 Char. 151: 4 --> 2  
423 Char. 167: 1 --> 0  
424 Char. 169: 1 --> 0  
425 Char. 220: 1 --> 2  
426 Node 153 :

427 All trees:  
428 Char. 172: 1 --> 0  
429 Char. 183: 0 --> 2  
430 Char. 187: 2 --> 1  
431 Some trees:  
432 Char. 47: 0 --> 2  
433 Char. 48: 0 --> 2  
434 Char. 120: 0 --> 1  
435 Char. 129: 0 --> 1  
436 Char. 131: 0 --> 1  
437 Char. 137: 0 --> 1  
438 Char. 178: 1 --> 0  
439 Char. 218: 3 --> 2  
440 Node 154 :  
441 All trees:  
442 Char. 11: 1 --> 0  
443 Char. 16: 0 --> 1  
444 Char. 21: 1 --> 2  
445 Char. 49: 1 --> 2  
446 Char. 50: 0 --> 2  
447 Char. 54: 0 --> 1  
448 Char. 65: 0 --> 1  
449 Char. 75: 1 --> 0  
450 Char. 80: 1 --> 0  
451 Char. 83: 1 --> 2  
452 Char. 99: 0 --> 2  
453 Char. 101: 0 --> 1  
454 Char. 108: 0 --> 1  
455 Char. 118: 0 --> 1  
456 Char. 125: 0 --> 1  
457 Char. 156: 1 --> 0  
458 Char. 189: 0 --> 1  
459 Char. 190: 0 --> 1  
460 Char. 202: 2 --> 1

461 Char. 204: 1 --> 2  
462 Char. 224: 0 --> 1  
463 Some trees:  
464 Char. 214: 0 --> 1  
465 Char. 248: 1 --> 2  
466 Node 155 :  
467 All trees:  
468 Char. 27: 0 --> 2  
469 Char. 43: 0 --> 1  
470 Char. 111: 1 --> 0  
471 Char. 131: 1 --> 0  
472 Char. 132: 1 --> 0  
473 Node 156 :  
474 Some trees:  
475 Char. 3: 0 --> 1  
476 Char. 14: 1 --> 2  
477 Char. 17: 0 --> 1  
478 Char. 116: 0 --> 1  
479 Char. 134: 0 --> 1  
480 Char. 147: 2 --> 0  
481 Char. 164: 0 --> 2  
482 Char. 168: 1 --> 0  
483 Char. 173: 1 --> 0  
484 Node 157 :  
485 All trees:  
486 Char. 248: 2 --> 1  
487 Some trees:  
488 Char. 60: 0 --> 1  
489 Char. 114: 0 --> 1  
490 Char. 189: 0 --> 1  
491 Char. 244: 2 --> 1  
492 Char. 269: 1 --> 0  
493 Node 158 :  
494 All trees:



495 Char. 52: 1 --> 2  
496 Char. 158: 1 --> 2  
497 Char. 178: 1 --> 0  
498 Char. 192: 0 --> 1  
499 Some trees:  
500 Char. 156: 0 --> 2  
501 Char. 260: 0 --> 1  
502 Char. 269: 0 --> 1  
503 Node 159 :  
504 All trees:  
505 Char. 43: 0 --> 1  
506 Char. 203: 1 --> 0  
507 Some trees:  
508 Char. 113: 1 --> 0  
509 Node 160 :  
510 All trees:  
511 Char. 196: 1 --> 0  
512 Node 161 :  
513 All trees:  
514 Char. 158: 2 --> 1  
515 **Node 162 (Euelasmosaurida):**  
516 All trees:  
517 Char. 4: 0 --> 1  
518 Char. 49: 2 --> 3  
519 Char. 154: 0 --> 2  
520 Char. 201: 1 --> 0  
521 Char. 254: 1 --> 2  
522 Node 163 :  
523 All trees:  
524 Char. 55: 0 --> 1  
525 Char. 62: 1 --> 0  
526 Char. 66: 1 --> 0  
527 Char. 114: 1 --> 0  
528 Char. 138: 0 --> 2

529 Char. 139: 1 --> 0  
530 Char. 157: 1 --> 2  
531 Char. 204: 0 --> 1  
532 Char. 244: 1 --> 2  
533 Node 164 :  
534 All trees:  
535 Char. 208: 1 --> 2  
536 Char. 218: 3 --> 1  
537 Node 165 :  
538 All trees:  
539 Char. 204: 2 --> 0  
540 Char. 244: 0 --> 1  
541 **Node 166 (Elasmosauridae):**  
542 All trees:  
543 Char. 152: 1 --> 2  
544 Char. 153: 0 --> 1  
545 Char. 164: 0 --> 1  
546 Char. 207: 0 --> 13  
547 Char. 243: 2 --> 3  
548 Node 167 :  
549 All trees:  
550 Char. 60: 0 --> 1  
551 Char. 132: 1 --> 0  
552 Char. 196: 1 --> 0  
553 Char. 250: 2 --> 3  
554 Char. 253: 2 --> 1  
555 **Node 168 (Weddellonectia):**  
556 Some trees:  
557 Char. 30: 0 --> 1  
558 Char. 71: 0 --> 1  
559 Char. 98: 2 --> 0  
560 Char. 132: 1 --> 0  
561 Char. 218: 1 --> 3  
562 Char. 232: 0 --> 1

563 Char. 244: 2 --> 1  
564 Char. 247: 0 --> 1  
565 Char. 270: 0 --> 1  
566 Char. 275: 1 --> 0  
567 Char. 282: 0 --> 1  
568 Node 169 :  
569 All trees:  
570 Char. 17: 0 --> 2  
571 Char. 18: 2 --> 1  
572 **Node 170 (Aristonectinae):**  
573 All trees:  
574 Char. 121: 1 --> 0  
575 Char. 122: 0 --> 1  
576 Char. 137: 0 --> 2  
577 Char. 152: 2 --> 1  
578 Char. 172: 1 --> 2  
579 Char. 254: 2 --> 1  
580 Some trees:  
581 Char. 113: 2 --> 3  
582 Char. 144: 1 --> 0  
583 Char. 153: 1 --> 0  
584 Char. 188: 0 --> 2  
585 Char. 190: 1 --> 2  
586 Char. 271: 0 --> 1  
587 Char. 273: 0 --> 1  
588 Node 171 :  
589 All trees:  
590 Char. 111: 1 --> 2  
591 Some trees:  
592 Char. 220: 12 --> 2  
593 Char. 231: 0 --> 2  
594 Char. 243: 3 --> 4  
595 Char. 250: 2 --> 3  
596 Char. 252: 0 --> 1

597 Char. 276: 1 --> 0  
598 Char. 278: 0 --> 2  
599 Node 172 :  
600 All trees:  
601 Char. 158: 1 --> 2  
602 Node 173 :  
603 All trees:  
604 Char. 281: 0 --> 1  
605 Node 174 :  
606 All trees:  
607 Char. 178: 1 --> 0  
608 Char. 203: 0 --> 2  
609

610 The strict consensus tree of the inclusion of MN 7820-V in the phylogenetic  
611 analysis is in **Supplementary Figure 3**. In both ordered and unordered character (chr.  
612 155) the topology was the same.

613

614 **Normality tests.** The VLI values of the cervical vertebrae in the dataset are not  
615 normally distributed (**Supplementary Figure 4**). Although the osteologically juvenile  
616 ‘*Cimoliasaurus*’-grade, adult early elasmosaurids, juvenile *Styxosaurus* and juvenile  
617 *Aristonectes* + *Morturneria* complex showed a normal distribution isolated, these  
618 groups are marked by small sample sizes and the histograms corroborate the non-  
619 normal distribution. The distribution of the dataset of dorsal vertebrae show that only  
620 elasmosaurines is significantly normal (**Supplementary Figure 5**). However, as in the  
621 cervical vertebral samples, the dorsal vertebrae dataset histograms suggests a non-  
622 normal distribution. Therefore, we employed non-parametric methods.

623           **Statistical analyses of cervical vertebrae.** The regressions with BI vs HI and  
624 VLI vs both BI and HI to adult elasmosaurid morphotypes are in **Supplementary**  
625 **Figures 6-8.**

626           The multivariate analyses of the adult elasmosaurid morphotypes are in  
627 **Supplementary Figure 9 and 10.**

628           All the LBR to cervical vertebrae at genus-level are in **Supplementary Figure**  
629 **11-14.**

630           **Statistical analyses of dorsal vertebrae.** The regression with HI vs BI is  
631 available in **Supplementary Figure 15.**

632           The regression with BI vs VLI available in **Supplementary Figure 16.**

633           The regression with HI vs VLI available in **Supplementary Figure 17.**

634           The LDA evaluating the adult morphotypes of elasmosaurines and early  
635 weddellonectians are available in **Supplementary Figure 18.** The preliminary LDA  
636 analysis at generic level revealed a wide overlap between them and it failed in segregate  
637 them. The PCA shows this overlap in **Supplementary Figure 19.**

638

639

640 **SUPPLEMENTARY FIGURES**

641 **Supplementary Figure 1.** Photographed sites where crops out the Snow Hill Island  
642 Formation in Santa Marta Cove. Outcrops of AF-6P2C in (A-C), with stratigraphic  
643 profile in (C). View of the sites Site AF-6P1 and AF-6P2 in (D). Site AF-6P2b (E), in  
644 which the elasmosaurine vertebrae were collected. The elasmosaurine silhouettes marks  
645 where they were recovered in the outcrop. View of the Shark Stream (F). Site AF-2 (G-  
646 H). Elasmosaurine silhouettes in (A and F) indicates the direction of the site in which  
647 the specimen was recovered. Silhouette from PhiloPic, drawn by Frank Denota (CC0  
648 1.0; <https://creativecommons.org/publicdomain/zero/1.0/>).

649

650 **Supplementary Figure 2.** Strict consensus tree from 30 MTPs of 1518 steps using the  
651 dataset of O’Gorman (2019a) with the codification of *Jucha* from Fischer *et al.* (2020),  
652 without the wildcard OTUs *Alxandronectes* and *Lagenectes*, and MN 7080-V.

653

654 **Supplementary Figure 3.** Strict consensus tree obtained from the phylogenetic  
655 analyses with the inclusion of MN 7820-V.

656

657 **Supplementary Figure 4.** Distribution of the VLI of cervical vertebrae dataset. The *p*  
658 values in **bold** are significant.

659

660 **Supplementary Figure 5.** Distribution of the VLI of dorsal vertebrae dataset. The *p*  
661 values in **bold** are significant.

662

663 **Supplementary Figure 6.** LBR between BI and HI of adult elasmosaurid cervical  
664 vertebral morphotypes. The silhouette of the cervicals indicates the deformation along  
665 the axes.

666

667 **Supplementary Figure 7.** LBR between BI and VLI of adult elasmosaurid cervical  
668 vertebral morphotypes. The silhouette of the cervicals indicates the deformation along  
669 the axes.

670

671 **Supplementary Figure 8.** LBR between HI and VLI of adult elasmosaurid cervical  
672 vertebral morphotypes. The silhouette of the cervicals indicates the deformation along  
673 the axes.

674

675 **Supplementary Figure 9.** PCA of adult elasmosaurid cervical vertebral morphotypes.  
676 The silhouette of the cervicals indicates the deformation along the axes.

677

678 **Supplementary Figure 10.** LDA of adult elasmosaurid cervical vertebral morphotypes.  
679 The silhouette of the cervicals indicates the deformation along the axes.

680

681 **Supplementary Figure 11.** LBR of juvenile and adult cervical vertebrae of the early  
682 elasmosaurid '*Cimoliasaurus*'-grade. The silhouette of the cervicals indicates the  
683 deformation along the axes.

684

685 **Supplementary Figure 12.** LBR of juvenile and adult cervical vertebrae of the  
686 elasmosaurine *Styxosaurus*. The silhouette of the cervicals indicates the deformation  
687 along the axes.

688

689 **Supplementary Figure 13.** LBR of juvenile and adult cervical vertebrae of the early  
690 weddellonectian *Tuarangisaurus*. The silhouette of the cervicals indicates the  
691 deformation along the axes.

692

693 **Supplementary Figure 14.** LBR of juvenile and adult cervical vertebrae of the  
694 aristonectine genus complex *Aristonectes* + *Morturneria*. The silhouette of the cervicals  
695 indicates the deformation along the axes.

696

697 **Supplementary Figure 15.** LBR of BI x HI of adult vertebrae focused on  
698 elasmosaurines and early weddellonectians only. The silhouette of the cervicals  
699 indicates the deformation along the axes.

700

701 **Supplementary Figure 16.** LBR of BI x VLI of adult dorsal vertebrae focused on  
702 elasmosaurines and early weddellonectians only. The silhouette of the cervicals  
703 indicates the deformation along the axes.

704

705 **Supplementary Figure 17.** LBR of HI x VLI of adult dorsal vertebrae focused on  
706 elasmosaurines and early weddellonectians only. The silhouette of the cervicals  
707 indicates the deformation along the axes.

708

709 **Supplementary Figure 18.** LDA of elasmosaurines (*Elasmosaurus* and *Fluvionectes*)  
710 and early weddellonectians (*Futabasaurus*, *Kawanectes* and *Vegasaurus*).

711

712 **Supplementary Figure 19.** PCA of elasmosaurines (*Elasmosaurus* and *Fluvionectes*)  
713 and early weddellonectians (*Futabasaurus*, *Kawanectes* and *Vegasaurus*). The  
714 silhouette of the cervical in graphs indicates the deformation along the axes.

715

716

717

718

719

720

721

722

723

724

725

726 **SUPPLEMENTARY TABLES**727 **Supplementary Table 1.** Specimens used in the statistical analysis to the cervical  
728 vertebrae.

Morphotype	Taxon	Specimen	N	Ontogenetic stage	Reference
?	Indet.	MLP 11-II-20-4	1	Adult	(O’Gorman 2012)
Early elamosaurid	<i>Callawayasaurus colombiensis</i>	UCMP 38349	11	Adult	(O’Keefe and Hiller 2006)
Early elamosaurid	‘ <i>Cimoliasaurus magnus</i> ’	AMNH 2554	10	Adult	(Otero 2016)
Early elamosaurid	‘ <i>Cimoliasaurus maccoyi</i> ’	AM F9630-9928	19	Juvenile	(O’Gorman <i>et al.</i> 2013)
Early elamosaurid	<i>Thalassomedon haningtoni</i>	CMNH 1588	57	Adult	(O’Keefe and Hiller 2006)
Early elamosaurid	<i>Jucha squalea</i>	UPM 2756/1-53	21	Adult	(Fischer <i>et al.</i> 2020)
Early elamosaurid	<i>Jucha</i> cf.	UPM NV 15	18	Adult	(Fischer <i>et al.</i> 2020)
Early elamosaurid	<i>Libonectes morgana</i>	SMUMP 69120	38	Adult	(Welles 1949)
Elamosaurine	<i>Albertonectes vanderveldei</i>	TMP 2007.011.0001	7	Adult	(Kubo <i>et al.</i> 2012)



Elasmosaurine	<i>Elasmosaurus platyurus</i>	ANSP 1801	4 7	Adult	(O'Keefe and Hiller 2006)
Elasmosaurine	<i>Fluvionectes sloanae</i>	TMP 2009.037.0068/1990.046.0001/0002	2	Adult	(Campbell <i>et al.</i> 2021)
Elasmosaurine	<i>Hydrotherosaurus alexandrae</i>	UCMP 33912	3 6	Adult	(O'Keefe and Hiller 2006)
Elasmosaurine	<i>Nakonanectes bradti</i>	MOR 3072	2 1	Adult	(Serratos <i>et al.</i> 2017)
Elasmosaurine	<i>Styxosaurus</i> sp.	AMNH 1495	5 3	Adult	(Otero 2016)
Elasmosaurine	<i>Styxosaurus</i> sp.	SDSM 451	4 2	Adult	(O'Keefe and Hiller 2006)
Elasmosaurine	<i>Styxosaurus browni</i>	AMNH 5385	5 5	Adult	(Otero 2016)
Elasmosaurine	<i>Styxosaurus glendowerensis</i>	QMF 3567	2 4	Juvenile	(Sachs 2004)
Elasmosaurine	<i>Terminonator ponteixensis</i>	RSM P214	3	Adult	(Sato 2003)
Early weddellonectian	<i>Futabasaurus suzukii</i>	NSM PV 15025	1 3	Adult	(Sato <i>et al.</i> 2006)
Early weddellonectian	<i>Kawanectes lafquenianum</i>	MCS Pv 4	1 2	Adult	(O'Gorman 2016a)
Early weddellonectian	<i>Kawanectes lafquenianum</i>	MLP 71-II 13-1	6	Adult	(O'Gorman 2016a)
Early weddellonectian	<i>Kawanectes lafquenianum</i>	MUC Pv 92	1	Adult	(O'Gorman 2016a)
Early weddellonectian	<i>Kawanectes lafquenianum</i>	MPEF 1155	7	Adult	(O'Gorman 2019)
Early weddellonectian	<i>Tuarangisaurus keyesi</i>	NZGS CD 426	8	Adult	(Wiffen and Moislely 1986)
Early weddellonectian	<i>Tuarangisaurus keyesi</i> cf.	CM Zfr 115	3 9	Juvenile	(O'Keefe and Hiller 2006)
Early weddellonectian	<i>Vegasaurus molyi</i>	MLP 93-I-5-1	4 2	Adult	(O'Gorman <i>et al.</i> 2015)
Aristonectine	<i>Aristonectes</i> cf.	MLP 89-III-3-1	1 1	Adult	(O'Gorman <i>et al.</i> 2019)
Aristonectine	<i>Aristonectes</i> sp.	MLP 14-I-20-16	2	Adult	(O'Gorman <i>et al.</i> 2018)
Aristonectine	<i>Aristonectes parvidens</i>	MLP 40-XI-14-6	1 7	Adult	(O'Gorman 2016b)
Aristonectine	<i>Aristonectes quiriquinensis</i>	SGO.PV.957	1 7	Adult	(Otero <i>et al.</i> 2014)

Aristonectine	<i>Aristonectes</i> cf. <i>parvidens</i>	MLP 89-III-3-2	1	Juvenile	(O’Gorman <i>et al.</i> 2013)
Aristonectine	<i>Aristonectes</i> cf. <i>parvidens</i>	MML PV 192	3	Juvenile	(O’Gorman <i>et al.</i> 2013)
Aristonectine	<i>Aristonectes</i> cf. <i>parvidens</i>	MUCPv 131	3	Juvenile	(O’Gorman <i>et al.</i> 2013)
Aristonectine	<i>Morturneria seymourensis</i>	TTU P 9219	6	Juvenile	(O’Gorman <i>et al.</i> 2013)
Aristonectine	<i>Wunyelfia maulensis</i>	SGO.PV.6507	8	Adult	Otero and Soto-Acuña (2021)

729 **Abbreviations:** N, number of analyzed vertebrae.

730

731

732

733

734 **Supplementary Table 2.** Specimens used in the statistical analysis to the adult dorsal  
735 vertebrae.

Group	Taxon	Specimen	N	Reference
Early elasmosaurid	<i>Jucha squalea</i>	UPM 2756/1-53	5	(Fischer <i>et al.</i> 2020)
Elasmosaurine	<i>Albertonectes vanderveldei</i>	TMP 2007.011.0001	1	(Kubo <i>et al.</i> 2012)
Elasmosaurine	<i>Elasmosaurus platyurus</i>	ANSP 18001	7	
Elasmosaurine	<i>Fluvionectes sloanae</i>	TMP 2009.037.0068/1990.046.0001/.0002	22	(Campbell <i>et al.</i> 2021)
Weddellonectian	<i>Futabasaurus suzukii</i>	NSM PV 15025	17	(Sato <i>et al.</i> 2006)
Weddellonectian	<i>Kawanectes lafquenianum</i>	MCS Pv 4	14	(O’Gorman 2016a)
Weddellonectian	<i>Kawanectes lafquenianum</i>	MLP 71-II-13-1	3	(O’Gorman 2016a)
Weddellonectian	<i>Kawanectes lafquenianum</i>	MUC Pv 92	3	(O’Gorman 2016a)
Weddellonectian	<i>Kawanectes lafquenianum</i>	MPEF 1155	8	(O’Gorman 2019)
Weddellonectian	<i>Vegasaurus molyi</i>	MLP 93-I-5-1	9	(O’Gorman <i>et al.</i> 2015)

736 **Abbreviations:** N, number of analyzed vertebrae.

737

738

739

740

741

742

743

744

745

746

747

748

749

750 **SUPPLEMENTARY REFERENCES**

751 FISCHER, V., ZVERKOV, N. G., ARKHANGELSKY, M. S., STENSHIN, I. M.,

752 BLAGOVETSHENSKY, I. V and USPENSKY, G. N. 2020. A new

753 elasmosaurid plesiosaurian from the Early Cretaceous of Russia marks an early

754 attempt at neck elongation. *Zoological Journal of the Linnean Society*, **zlaa103**,

755 1–28.

756 KUBO, T., MITCHELL, M. T. and HENDERSON, D. M. 2012. Albertonectes

757 vanderveldei, a new elasmosaur (Reptilia, Sauropterygia) from the Upper

758 Cretaceous of Alberta. *Journal of Vertebrate Paleontology*, **32**, 557–572.

759 O’GORMAN, J. P. 2012. The oldest elasmosaurs (Sauropterygia, Plesiosauria) from

760 Antarctica, Santa Marta Formation (upper Coniacian? Santonian–upper  
761 Campanian) and Snow Hill Island Formation (upper Campanian–lower  
762 Maastrichtian), James Ross Island. *Polar Research*, **31**, 11090.

763 O’GORMAN, J. P. 2016a. A Small Body Sized Non-Aristonectine Elasmosaurid  
764 (Sauropterygia, Plesiosauria) from the Late Cretaceous of Patagonia with  
765 Comments on the Relationships of the Patagonian and Antarctic Elasmosaurids.  
766 *Ameghiniana*, **53**, 245–268.

767 O’GORMAN, J. P. 2016b. New insights on the *Aristonectes parvidens* (Plesiosauria,  
768 Elasmosauridae) holotype: news on an old specimen. *Ameghiniana*, **53**, 397–417.

769 O’GORMAN, J. P. 2019. First record of *Kawanectes lafquenianum* (Plesiosauria,  
770 Elasmosauridae) from the La Colonia Formation of Argentina, with comments on  
771 the mandibular morphology of elasmosaurids. *Alcheringa: An Australasian*  
772 *Journal of Palaeontology*, **44**, 176–193.

773 O’GORMAN, J. P. 2020. Elasmosaurid phylogeny and paleobiogeography, with a  
774 reappraisal of *Aphrosaurus furlongi* from the Maastrichtian of the Moreno  
775 Formation. *Journal of Vertebrate Paleontology*, **35**, e1692025.

776 O’GORMAN, J. P., GASPARINI, Z. and SALGADO, L. 2013. Postcranial morphology  
777 of *Aristonectes* (Plesiosauria, Elasmosauridae) from the Upper Cretaceous of  
778 Patagonia and Antarctica. *Antarctic Science*, **25**, 71–82.

779 O’GORMAN, J. P., SALGADO, L., OLIVERO, E. B. and SERGIO, A. 2015.  
780 *Vegasaurus molyi*, gen. et sp. nov. (Plesiosauria, Elasmosauridae), from the Cape  
781 Lamb Member (Lower Maastrichtian) of the Snow Hill Island Formation, Vega  
782 Island, Antarctica, and remarks on Wedellian Elasmosauridae. *Journal of*  
783 *Vertebrate Paleontology*, **35**, e931285.

784 O’GORMAN, J. P., SANTILLANA, S., OTERO, R. and REGUERO, M. 2019. A giant  
785 elasmosaurid (Sauropterygia; Plesiosauria) from Antarctica: New information on  
786 elasmosaurid body size diversity and aristonectine evolutionary scenarios.  
787 *Cretaceous Research*, **102**, 37–58.

788 O’GORMAN, J. P., PANZERI, K. M., FERNÁNDEZ, M. S., SANTILLANA, S.,  
789 MOLY, J. J. and REGUERO, M. 2018. A new elasmosaurid from the upper  
790 Maastrichtian López de Bertodano Formation: new data on weddellonectian  
791 diversity. *Alcheringa*, **42**, 575–586.

792 O’KEEFE, F. R. and HILLER, N. 2006. Morphologic and ontogenetic patterns in  
793 elasmosaur neck length, with comments on the taxonomic utility of neck length  
794 variables. *Paludicola*, **5**, 206–229.

795 OTERO, R. A. 2016. Taxonomic reassessment of *Hydralmosaurus* as *Styxosaurus*: new  
796 insights on the elasmosaurid neck evolution throughout the Cretaceous. *PeerJ*, **4**,  
797 e1777.

798 OTERO, R. A. and SOTO-ACUÑA, S. 2021. *Wunyelfia maulensis* gen. et sp. nov., a  
799 new basal aristonectine (Plesiosauria, Elasmosauridae) from the Upper Cretaceous  
800 of central Chile. *Cretaceous Research*, **118**, 104651.

801 OTERO, R. A., SOTO-ACUÑA, S., O’KEEFE, F. R., O’GORMAN, J. P.,  
802 WOLFGANG, S., SUÁREZ, M. E., RUBILAR-ROGERS, D., SALAZAR, C. and  
803 QUINZIO-SINN, L. A. 2014. *Aristonectes quiriquinensis*, sp. nov., a new highly  
804 derived elasmosaurid from the Upper Maastrichtian of Central Chile. *Journal of*  
805 *Vertebrate Paleontology*, **34**, 100–125.

806 SACHS, S. 2004. Redescription of *Woolungasaurus glendowerensis* (Plesiosauria:  
807 Elasmosauridae) from the Lower Cretaceous of Northeast Queensland. *Memoirs of*

- 808           *the Queensland Museum*, **49**, 713–731.
- 809   SACHS, S. 2005. Redescription of *Elasmosaurus Platyurus* Cope 1868 (Plesiosauria:  
810       Elasmosauridae) from the Upper Cretaceous (Lower Campanian) of Kansas,  
811       U.S.A. *Paludicola*, **5**, 92–106.
- 812   SATO, T. 2003. *Terminonatator ponteixensis*, a new elasmosaur (Reptilia;  
813       Sauropterygia) from the Upper Cretaceous of Saskatchewan. *Journal of Vertebrate*  
814       *Paleontology*, **23**, 89–103.
- 815   SATO, T., HASEGAWA, Y. and MANABE, M. 2006. A new elasmosaurid plesiosaur  
816       from the Upper Cretaceous of Fukushima, Japan. *Palaeontology*, **49**, 467–484.
- 817   SERRATOS, D. J., DRUCKENMILLER, P. and BENSON, R. B. J. 2017. A new  
818       elasmosaurid (Sauropterygia, Plesiosauria) from the Bearpaw Shale (Late  
819       Cretaceous, Maastrichtian) of Montana demonstrates multiple evolutionary  
820       reductions of neck length within Elasmosauridae. *Journal of Vertebrate*  
821       *Paleontology*, **37**, e1278608.
- 822   WELLES, S. P. 1949. A new elasmosaur from the Eagle Ford Shale of Texas. *Fondren*  
823       *Science Series*, **1**: 1–28.
- 824   WIFFEN, J. and MOISLEY, W. L. 1986. Late cretaceous reptiles (families  
825       Elasmosauridae and Pliosauridae) from the Mangahouanga Stream, North Island,  
826       New Zealand. *New Zealand Journal of Geology and Geophysics*, **29**, 205–252.
- 827