SUPPLEMENTARY MATERIAL

for

Phenotypic integration and modularity drives skull shape divergence in the Arctic fox (*Vulpes lagopus*) from the Commander islands

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Supplementary Results

Although there is not strong sexual size dimorphism in the Arctic fox (29), we performed a Procrustes ANOVA to explore if differences in the number of males/females among populations affected the strength of integration and modularity. The Procrustes ANOVA revealed that differences in the number of males and females among populations does not bias patterns of integration and modularity (Table S5).

Supplementary Figures and Tables

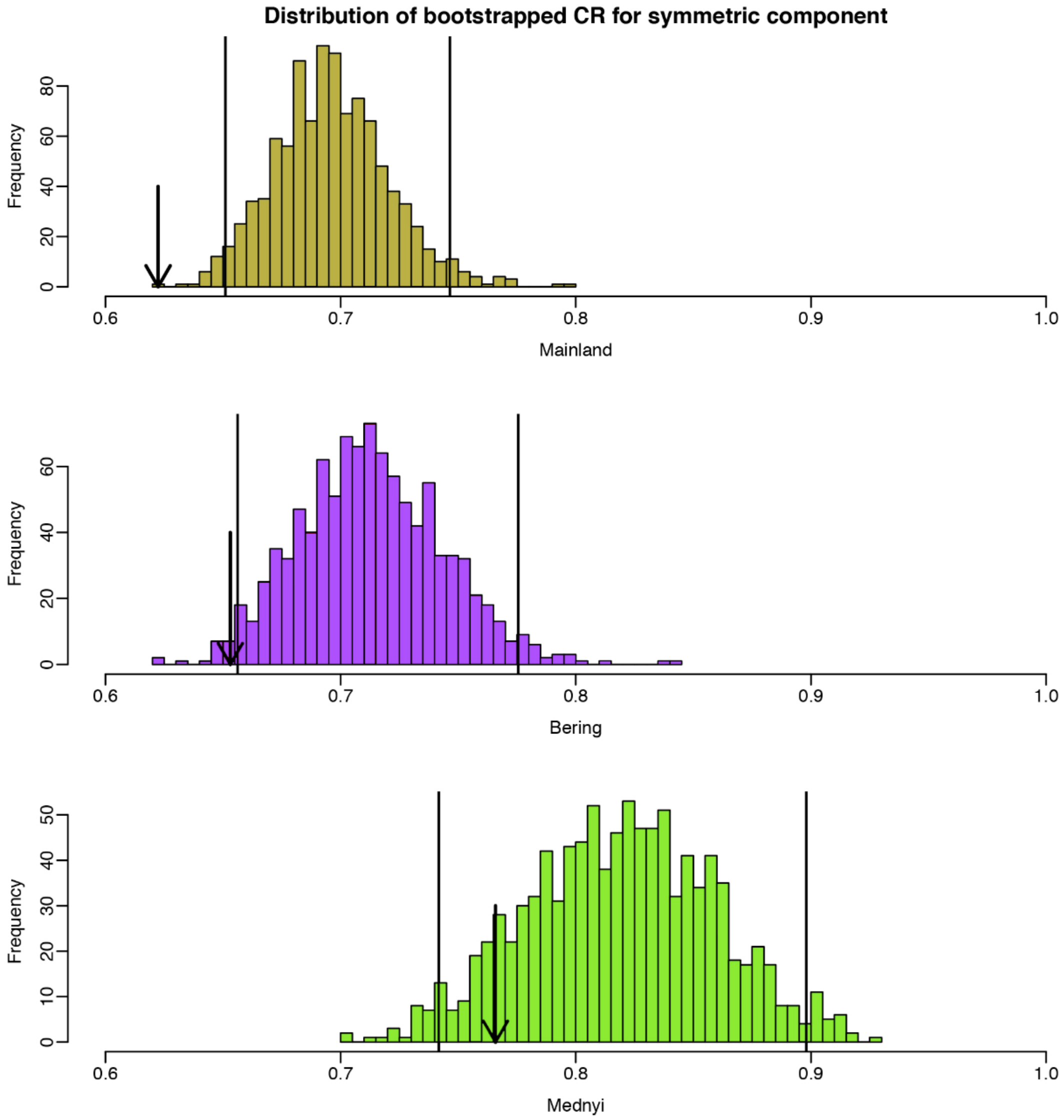

Figure S1. Histograms obtained from the bootstrap analyses on CR values for the symmetric component of shape. Each graph shows the distribution of CR values (1000 iterations) for each population. Black arrows indicate the observed CR values and the vertical lines indicate the 95% of confidence intervals.

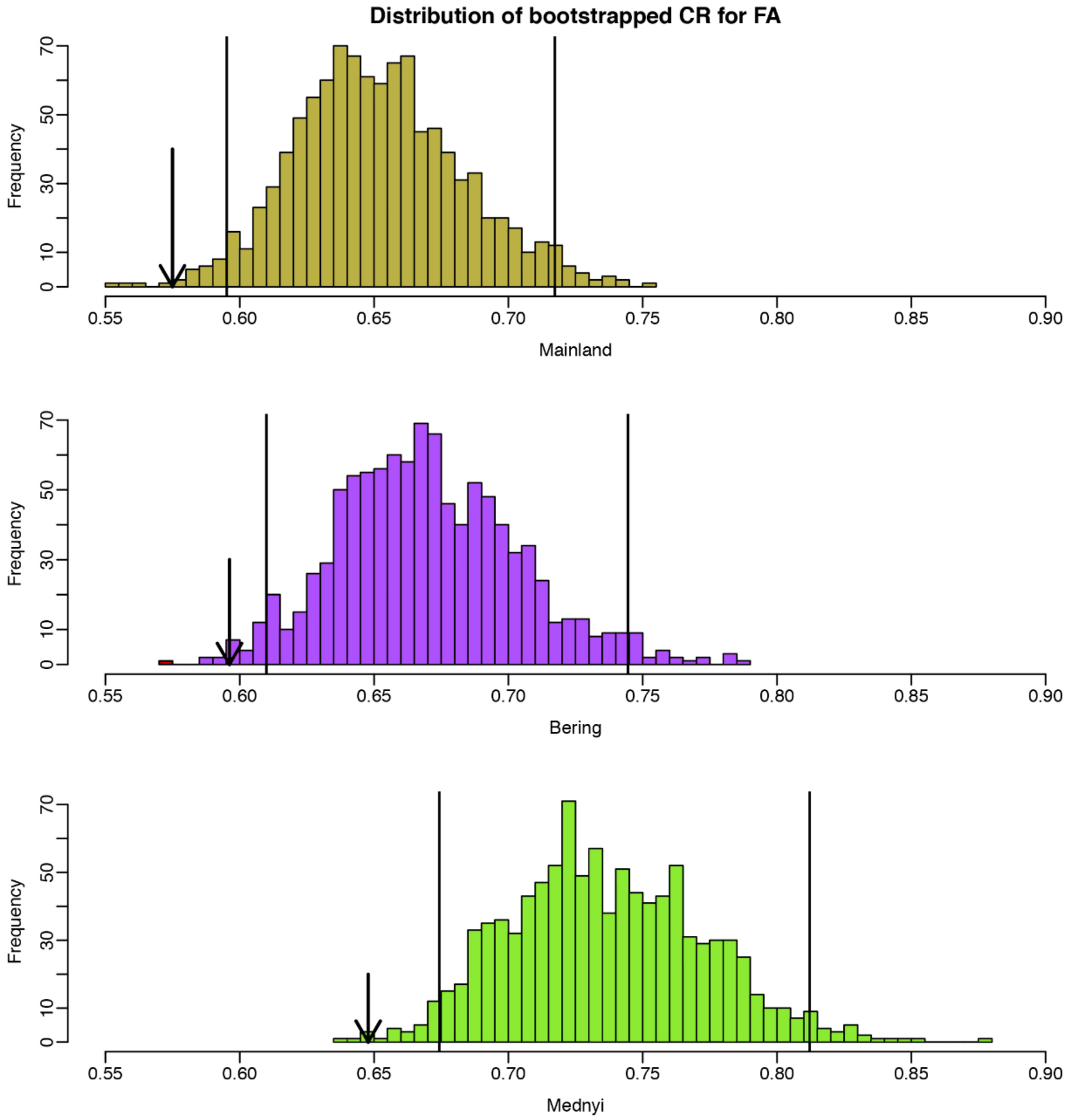

Figure S2. Histograms obtained from the bootstrap analyses on CR values for FA. Each graph shows the distribution of CR values (1000 iterations) for each population. Black arrows indicate the observed CR values and the vertical lines indicate the 95% of confidence intervals.

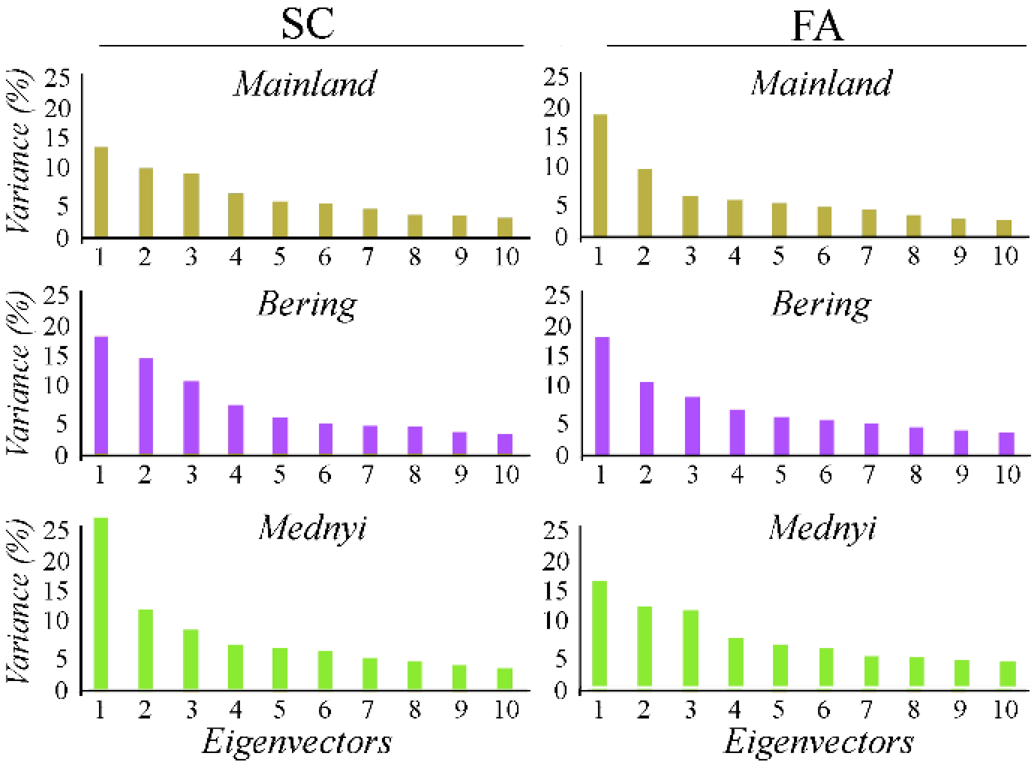

Figure S3. Histograms showing the percentage of variance explained for by each eigenvector obtained from the PCAs of the symmetric component (SC) and of fluctuating assymetry (FA) of shape. See also Table S9.

Table S1. Museum numbers. sex and population of the skulls analysed in this article.

Museum number	Sex	Population
S-5923	Female	Bering
S-11963	Female	Bering
S-11965	Female	Bering
S-11970	Female	Bering
S-11974	Female	Bering
S-11991	Male	Bering
S-12059	Female	Bering
S-12060	Female	Bering
S-30339	Female	Bering
S-30355	Female	Bering
S-30356	Female	Bering
S-30361	Male	Bering
S-30367	Male	Bering
S-30371	Female	Bering
S-30378	Male	Bering
S-42779	Female	Bering
S-166344	Male	Bering
S-166345	Female	Bering
S-166362	Male	Bering
S-166406	Male	Bering
S-166427	Female	Bering
S-166449	Male	Bering
S-166464	Male	Bering
S-166496	Female	Bering

S-166528	Female	Bering
S-166531	Female	Bering
S-166539	Male	Bering
S-166551	Male	Bering
S-166556	Male	Bering
S-166595	Female	Bering
S-166609	Male	Bering
S-166611	Male	Bering
S-166618	Male	Bering
S-166621	Male	Bering
S-166623	Male	Bering
S-166634	Male	Bering
S-166636	Male	Bering
S-166642	Male	Bering
S-166645	Male	Bering
S-166646	Female	Bering
S-166648	Female	Bering
S-166652	Female	Bering
S-166654	Male	Bering
S-166659	Female	Bering
S-166664	Male	Bering
S-166665	Female	Bering
S-166668	Female	Bering
S-166669	Female	Bering
S-166670	Male	Bering
S-167009	Male	Bering
S-167017	Male	Bering

S-5928	Female	Mednyi
S-5929	Female	Mednyi
S-5930	Female	Mednyi
S-5931	Female	Mednyi
S-5932	Male	Mednyi
S-5934	Male	Mednyi
S-6166	Male	Mednyi
S-6168	Female	Mednyi
S-6169	Male	Mednyi
S-6170	Female	Mednyi
S-12007	Male	Mednyi
S-12010	Male	Mednyi
S-12015	Male	Mednyi
S-12025	Male	Mednyi
S-12026	Male	Mednyi
S-12027	Male	Mednyi
S-12030	Male	Mednyi
S-12031	Male	Mednyi
S-12033	Male	Mednyi
S-12034	Male	Mednyi
S-12037	Female	Mednyi
S-12038	Female	Mednyi
S-12041	Male	Mednyi
S-12043	Male	Mednyi
S-12045	Male	Mednyi
S-12046	Female	Mednyi
S-12049	Female	Mednyi

S-12050	Male	Mednyi
S-12051	Female	Mednyi
S-12053	Male	Mednyi
S-12056	Male	Mednyi
S-69547	Female	Mednyi
S-167038	Female	Mednyi
S-170790	Female	Mednyi
S-179789	Female	Mednyi
S-179792	Female	Mednyi
S-179793	Male	Mednyi
S-188218	Male	Mednyi
S-191289	Male	Mednyi
S-191488	Female	Mednyi
S-97487	Male	Mainland
S-97518	Male	Mainland
S-97523	Male	Mainland
S-97524	Male	Mainland
S-97526	Male	Mainland
S-97531	Male	Mainland
S-97533	Male	Mainland
S-97534	Male	Mainland
S-97545	Male	Mainland
S-97546	Male	Mainland
S-97547	Male	Mainland
S-97548	Male	Mainland
S-97553	Male	Mainland
S-97559	Male	Mainland

S-97564	Female	Mainland
S-97567	Female	Mainland
S-97572	Female	Mainland
S-97577	Female	Mainland
S-97578	Female	Mainland
S-97581	Female	Mainland
S-97584	Female	Mainland
S-97586	Female	Mainland
S-97603	Female	Mainland
S-97606	Female	Mainland
S-97614	Male	Mainland
S-97617	Female	Mainland
S-97624	Male	Mainland
S-97629	Female	Mainland
S-97630	Female	Mainland
S-97638	Female	Mainland
S-97641	Female	Mainland
S-97643	Male	Mainland
S-97650	Female	Mainland
S-97667	Male	Mainland
S-97669	Male	Mainland
S-97671	Male	Mainland
S-97689	Female	Mainland
S-97693	Male	Mainland
S-97694	Male	Mainland
S-97695	Female	Mainland
S-97734	Female	Mainland

S-97739	Male	Mainland
S-97741	Female	Mainland
S-97743	Female	Mainland
S-97744	Male	Mainland
S-97746	Female	Mainland
S-97747	Male	Mainland
S-97748	Male	Mainland
S-97751	Female	Mainland
S-97760	Female	Mainland

Table S2. **Anatomical criteria used in this article to digitize de 52 LMs on the Artic fox skulls. See also Figure S1.**

Lm	***Definition***
0	Occiput
1	Junction of parietal and frontal sutures at the sagittal crest.
2	Tip of the right postorbital process.
3	Tip of the left postorbital process.
4	Most ventral point of the right lacrimal foramen.
5	Most ventral point of the left lacrimal foramen.
6	Most anterior point of the junction of both nasal bones suture.
7	Prostion.
8	Tip of the right preorbital process.
9	Tip of the left preorbital process.
10	Posteroventral point of the rigth jugal and squamosal bones.
11	Posteroventral point of the left jugal and squamosal bones.
12	Posteroventral point of both palatine bones.
13	Posteroventral point of the left third molar.
14	Interdental gap between the second and third left molars
15	Interdental gap between the first and second left molars
16	Interdental gap between the left third premolar and first molar
17	Interdental gap between the left second premolar and third premolar
18	Interdental gap between the left first premolar and second premolar
19	Interdental gap between the left first premolar and the canine
20	Most antero-dorsal point of the left canine
21	Most postero-dorsal point of the left third incisive
22	Most postero-dorsal point of the right third incisive
23	Most antero-dorsal point of the right canine
24	Interdental gap between the right first premolar and the canine
25	Interdental gap between the right first premolar and second premolar
26	Interdental gap between the right second premolar and third premolar
27	Interdental gap between the right third premolar and first molar
28	Interdental gap between the first and second right molars
29	Interdental gap between the second and third right molars
30	Posteroventral point of the right third molar.

31	Posterior margin of the right incisive foramen at the premaxilar bone.
32	Posterior margin of the left incisive foramen at the premaxilar bone.
33	Anterior margin of the right lacerum foramen of the tympanic bulla.
34	Anterior margin of the left lacerum foramen of the tympanic bulla.
35	Ventral junction of the right paracondylar process and the tympanic bulla.
36	Ventral junction of the left paracondylar process and the tympanic bulla.
37	Ventral junction of the right and left occipital condyles.
38	Dorsal margin of the left infraorbital foramen.
39	Dorsal margin of the right infraorbital foramen.
40	Ventral tip of the left postglenoid process.
41	Ventral tip of the right postglenoid process.
42	Most lateral point of the left glenoid fossa.
43	Most lateral point of the right glenoid fossa.
44	Ventral margin of the left auditory meatus.
45	Dorsal point of the left auditory meatus.
46	Ventral margin of the right auditory meatus.
47	Dorsal point of the right auditory meatus.
48	Most medial point of the left glenoid fossa.
49	Most medial point of the right glenoid fossa.
50	Ventral margin of the left optic foramen.
51	Ventral margin of the right optic foramen.

Table S3. Skull shape asymmetry for each population of Artic foxes. The analysis of variance was performed from the residuals of shape on size obtained for each population. Abbreviations: *ind*. individuals; side. effect of directional asymmetry; *ind:side*. effect of fluctuating asymmetry; *ind:side:replicate*. effects of differences between replicates (error). We used a separate permutation test to determine statistical significance of each effect.

	Df	***SS***	***MS***	***Rsq***	***F***	***Z***	***Pr(>F)***
Mainland							
ind	50	52.791	1.0558	0.49649	2.2058	-4.0091	0.001
side	1	12.763	12.7634	0.12004	26.6658	8.8106	0.001
ind:side	50	23.932	0.4786	0.22508	2.899	28.4328	0.001
ind:side:replicate	102	16.841	0.1651	0.15839			
Total	203	106.327					
Bering							
ind	50	47.209	0.9442	0.44192	2.2512	-0.5915	0.001
side	1	13.312	13.3123	0.12462	31.7411	9.6361	0.001
ind:side	50	20.97	0.4194	0.1963	1.6885	25.5619	0.001
ind:side:replicate	102	25.335	0.2484	0.23716			
Total	203	106.827					
Mednyi							
ind	31	26.825	0.8653	0.37339	1.5389	-6.4092	0.001
side	1	13.558	13.558	0.18872	24.1123	7.1988	0.001
ind:side	31	17.431	0.5623	0.24263	2.5654	25.1085	0.001
ind:side:replicate	64	14.027	0.2192	0.19525			
Total	127	71.841					

Table S4. Results of the integration test for the symmetric component of shape (SC) and for fluctuating asymmetry (FA) obtained from 2B-PLS for each population of Artic foxes. P-values of the two-sample Z-tests using the pooled standard error from the sampling distributions of the PLS analyses. For the effect sizes (Z-scores) of each population see text.

SC				**FA**		
	Mainland	***Bering***	***Mednyi***	***Mainland***	***Bering***	***Mednyi***
Mainland	-	0.00	0.00	-	0.000	0.000
Bering	0.00	-	0.33	0.000	-	0.325
Mednyi	0.00	0.33	-	0.000	0.325	-

Table S5. Analyses of variance for sexes for the symmetric component of shape (SC) and fluctuating asymmetry (FA). Abbreviation: *Sex*. effect of differences between sexes; *Pop*. effect of different populations; *Sex:Pop*. interaction between sexes and populations.

SC							
	Df	**SS**	**MS**	**Rsq**	**F**	**Z**	**Pr(>F)**
Sex	1	0.001778	0.001778	0.01531	2.99	2.8738	0.005
Pop	2	0.036402	0.018201	0.31333	30.6059	11.6281	0.001
Sex:Pop	2	0.001879	0.00094	0.01617	1.5799	4.0659	0.001
Residuals	128	0.07612	0.000595	0.6552			
Total	133	0.116179					
FA							
	Df	**SS**	**MS**	**Rsq**	**F**	**Z**	**Pr(>F)**
Sex	1	0.000353	0.000353	0.00697	0.9498	-0.071	0.505
Pop	2	0.001748	0.000874	0.03457	2.3543	4.5033	0.001
Sex:Pop	2	0.00095	0.000475	0.01879	1.2799	1.5775	0.055
Residuals	128	0.04751	0.000371	0.93967			
Total	133	0.05056					

Table S6. Results of disparity analysis (Procrustes variance) for each population of Arctic foxes. P-values of the pairwise comparisons of disparity values among populations for both the symmetric component of shape (SC) and for fluctuating asymmetry (FA). For disparity values of each population see text.

	SC			**FA**		
	Mainland	***Bering***	***Mednyi***	***Mainland***	***Bering***	***Mednyi***
Mainland	-	0.285	0.014	-	0.419	0.001
Bering	0.285	-	0.001	0.419	-	0.001
Mednyi	0.014	0.001	-	0.001	0.001	-

Table S7. Angles between the first three eigenvectors obtained from a PCA per population for SC and FA. The p-values for the pairwise comparisons between eigenvectors are given within parentheses. Non-significant p-values indicate that both eigenvectors are orthogonal. and therefore. the shape variation accounted for by them is different.

SC	**Bering PC1**	**Bering PC2**	**Bering PC3**
Mainland PC1	67.537 (0.00056)	52.302 (<0.00001)	76.853 (0.04522)
Mainland PC2	65.400 (0.00015)	79.143 (0.09865)	57.461 (<0.00001)
Mainland PC3	50.023 (<0.00001)	70.181 (0.00239)	68.667 (0.00106)
	MednyiPC1	**MednyiPC2**	**MednyiPC3**
Mainland PC1	48.600 (<0.00001)	75.697 (0.02922)	88.900 (0.86753)
Mainland PC2	81.487 (0.19588)	59.248 (<.00001)	74.472 (0.01781)
Mainland PC3	66.266 (0.00026)	87.809 (0.73971)	79.470 (0.10927)
	MednyiPC1	**MednyiPC2**	**MednyiPC3**
Bering PC1	87.549 (0.71002)	51.909 (<.00001)	66.604 (0.00032)
Bering PC2	67.675 (0.00060)	81.269 (0.18461)	76.993 (0.04757)
Bering PC3	83.877 (0.35262)	65.981 (0.00022)	69.411 (0.00159)
FA	**Bering PC1**	**Bering PC2**	**Bering PC3**
Mainland PC1	42.278 (<0.00001)	72.138 (0.00831)	83.686 (0.35430)
Mainland PC2	65.848 (0.00033)	61.855 (0.00003)	88.080 (0.77843)
Mainland PC3	80.535 (0.16447)	87.093 (0.67001)	89.250 (0.91249)
	MednyiPC1	**MednyiPC2**	**MednyiPC3**
Mainland PC1	46.019 (<0.00001)	85.088 (0.47131)	87.919 (0.76039)
Mainland PC2	82.197 (0.29868)	79.902 (0.13788)	72.435 (0.00947)
Mainland PC3	88.013 (0.77088)	83.868 (0.36839)	88.250 (0.79757)
	MednyiPC1	**MednyiPC2**	**MednyiPC3**
Bering PC1	48.114 (<.00001)	72.078 (0.00809)	77.781 (0.07226)
Bering PC2	79.428 (0.12026)	80.373 (0.15730)	72.813 (0.01115)
Bering PC3	83.332 (0.32797)	89.114 (0.89667)	69.740 (0.00269)

Table S8. Percentages of variance explained for by each eigenvector obtained from the PCAs performed for each population separately from SC and FA. See also Figure 3.

PC	SC Mainland	SC Bering	SC Mednyi	FA Mainland	FA Bering	FA Mednyi
1	13.74000	16.99000	25.08000	19.07900	17.06700	16.14000
2	10.49100	13.83700	11.74000	10.88800	10.65300	12.15700
3	9.82500	10.48300	8.70100	6.84700	8.36400	11.61000
4	6.73600	7.09400	6.51300	6.24100	6.60800	7.31600
5	5.59800	5.30900	5.97500	5.68600	5.63500	6.26700
6	5.26900	4.39500	5.53700	5.09300	5.10800	5.76800
7	4.58100	4.09200	4.50100	4.76000	4.62200	4.52400
8	3.63500	4.00900	4.10800	3.94800	4.14600	4.36200
9	3.45600	3.25700	3.42500	3.40800	3.57700	4.00000
10	3.15500	2.93500	3.04400	3.19900	3.27500	3.72500
11	2.95600	2.73300	2.55300	2.86400	2.94900	3.34000
12	2.62400	2.43400	2.20900	2.63200	2.57900	2.57000
13	2.39300	2.12700	1.95400	2.30000	2.37900	2.21100
14	2.34900	1.91900	1.83500	2.26000	2.24100	2.14900
15	2.16800	1.77900	1.56300	1.98000	1.99200	1.95300
16	1.92100	1.59800	1.43000	1.81800	1.92600	1.71300
17	1.82100	1.36300	1.31500	1.71700	1.56000	1.46900
18	1.58100	1.24500	1.28000	1.61900	1.45800	1.29100
19	1.49400	1.09300	1.11400	1.44600	1.37800	1.24600
20	1.42500	0.99100	1.00100	1.40000	1.34200	1.01800
21	1.31200	0.87700	0.89500	1.22800	1.27800	0.86600
22	1.12400	0.84800	0.76700	1.16100	1.13700	0.78300
23	1.08800	0.78100	0.74300	1.03600	0.95800	0.67200
24	1.00500	0.73900	0.58400	0.85900	0.88300	0.62000
25	0.87600	0.68900	0.51000	0.73500	0.83800	0.50800
26	0.76500	0.64000	0.41700	0.71600	0.70400	0.48900
27	0.70500	0.60800	0.34700	0.66200	0.67800	0.38500
28	0.62700	0.54700	0.32800	0.59600	0.62900	0.29500
29	0.55200	0.52300	0.31600	0.54800	0.57500	0.22500
30	0.53800	0.49700	0.21600	0.47100	0.56500	0.18000
31	0.48400	0.41200	0.00000	0.45000	0.48100	0.14700
32	0.44300	0.37100	0.00000	0.43700	0.43700	0.00000
33	0.40300	0.34300	0.00000	0.34200	0.36800	0.00000
34	0.36900	0.30300	0.00000	0.28800	0.32200	0.00000
35	0.31400	0.29700	0.00000	0.24900	0.29700	0.00000
36	0.31000	0.25100	0.00000	0.21700	0.25800	0.00000
37	0.28700	0.23900	0.00000	0.19800	0.21500	0.00000
38	0.25200	0.20400	0.00000	0.18100	0.14500	0.00000
39	0.22100	0.19700	0.00000	0.12700	0.12000	0.00000
40	0.21100	0.16900	0.00000	0.11300	0.11500	0.00000
41	0.17700	0.14800	0.00000	0.09700	0.07000	0.00000

42	0.15000	0.12500	0.00000	0.05500	0.04900	0.00000
43	0.12700	0.11000	0.00000	0.02700	0.01400	0.00000
44	0.10500	0.10000	0.00000	0.01500	0.00200	0.00000
45	0.10100	0.08800	0.00000	0.01000	0.00000	0.00000
46	0.09000	0.07500	0.00000	0.00000	0.00000	0.00000
47	0.06700	0.06100	0.00000	0.00000	0.00000	0.00000
48	0.04300	0.04800	0.00000	0.00000	0.00000	0.00000
49	0.03500	0.02300	0.00000	0.00000	0.00000	0.00000