

Table S1. Data collection periods for the analysis.

Site	Year	Start date (UTC)	End date (UTC)
AW	2018	20/08/2018 16:56	26/09/2018 10:07
	2019	18/08/2019 14:26	03/10/2019 9:55
	2023	22/08/2023 14:45	17/09/2023 11:00
	2024	21/08/2024 19:06	16/09/2024 12:06
MI	2018	28/08/2018 18:51	27/09/2018 11:09
	2019	25/08/2019 18:00	06/10/2019 9:30
OS	2023	18/08/2023 19:15	04/10/2023 9:30
	2024	19/08/2024 7:55	05/10/2024 5:40

AW, MI, and OS indicate Awashima Island, Mikurajima Island, and Oshima Island, respectively.

Table S2. Morphological traits by breeding site.

Site	Sex	Body		Bill		Head		Tarsus		Wing		Bill	
		mass		length		length		length		length		depth	
		Mean (g)	SD	Mean (mm)	SD	Mean (mm)	SD	Mean (mm)	SD	Mean (mm)	SD	Mean (mm)	SD
AW	f	498.28	43.79	48.20	1.82	98.26	2.62	51.50	1.80	312.90	7.89	11.37	0.55
	m	593.65	47.97	51.49	1.91	104.36	2.30	53.05	1.67	320.23	6.66	12.92	0.59
MI	f	466.00	35.42	47.21	1.39	96.19	2.27	50.78	1.09	306.90	5.22	11.01	0.61
	m	565.83	53.50	51.18	1.42	101.99	1.57	52.33	1.16	313.29	6.94	12.82	0.49
OS	f	488.42	50.80	47.80	2.13	97.30	2.38	51.20	1.17	313.35	7.30	10.92	0.30
	m	612.50	69.41	52.37	1.38	105.16	2.14	53.48	1.58	322.56	5.85	12.64	0.48

Mean and standard deviation values of morphological traits (body mass, bill length, head length, tarsus length, wing length and bill depth) by breeding site. SD indicates standard deviation. AW, MI, and OS indicate Awashima Island, Mikurajima Island, and Oshima Island, respectively.

Table S3. Bayesian model summaries for external morphological traits.

	Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Body mass	Intercept	497.37	5.51	486.66	508.33	1.00	5328.89	5865.65
	sexm	94.17	7.90	78.60	109.66	1.00	5194.17	5803.78
	study_siteMI	-31.40	15.82	-62.44	-0.90	1.00	6921.92	6105.72
	study_siteOS	-5.15	12.34	-29.14	18.91	1.00	7392.97	6098.60
	sexm:study_siteMI	5.59	19.34	-32.75	43.35	1.00	6437.44	6171.97
	sexm:study_siteOS	29.17	20.47	-10.43	69.00	1.00	7139.46	6268.14
	sigma	36.10	2.30	31.90	40.84	1.00	3008.10	4785.04
Bill length	Intercept	48.23	0.25	47.73	48.74	1.00	1780.05	2651.44
	sexm	3.42	0.36	2.72	4.13	1.00	1816.22	3127.58
	study_siteMI	-1.01	0.61	-2.21	0.21	1.00	2130.28	3229.70
	study_siteOS	-0.43	0.50	-1.39	0.56	1.00	2096.77	3738.96
	sexm:study_siteMI	0.54	0.75	-0.92	2.04	1.00	2042.92	3367.10
	sexm:study_siteOS	1.15	0.81	-0.46	2.72	1.00	1967.62	3620.39
	sigma	0.86	0.14	0.64	1.18	1.00	594.13	1167.41
Head length	Intercept	98.16	0.32	97.52	98.77	1.00	2141.24	3212.00
	sexm	6.27	0.46	5.38	7.15	1.00	1944.26	3281.25
	study_siteMI	-1.94	0.79	-3.53	-0.39	1.00	2353.12	3815.31

	study_siteOS	-0.87	0.65	-2.16	0.42	1.00	2322.28	3609.48
	sexm:study_siteMI	-0.50	0.97	-2.36	1.41	1.00	2128.23	3415.40
	sexm:study_siteOS	1.60	1.04	-0.42	3.67	1.00	2539.08	3557.59
	sigma	1.06	0.18	0.77	1.47	1.01	633.24	1290.48
Tarsus length	Intercept	51.42	0.22	51.00	51.84	1.00	6173.83	6300.07
	sexm	1.91	0.31	1.29	2.51	1.00	5801.92	5848.38
	study_siteMI	-0.64	0.55	-1.72	0.45	1.00	5914.17	5952.47
	study_siteOS	-0.22	0.44	-1.07	0.66	1.00	6438.61	6034.62
	sexm:study_siteMI	-0.36	0.67	-1.69	0.98	1.00	5606.40	6005.38
	sexm:study_siteOS	0.38	0.71	-1.01	1.77	1.00	6461.86	5591.33
	sigma	1.20	0.16	0.92	1.55	1.00	627.24	1175.93
Wing length	Intercept	312.61	1.31	310.04	315.19	1.00	7966.50	6702.09
	sexm	7.03	1.87	3.33	10.66	1.00	7352.89	5953.22
	study_siteMI	-5.69	3.54	-12.58	1.36	1.00	6878.98	6473.21
	study_siteOS	0.74	2.80	-4.69	6.06	1.00	8293.81	6571.96
	sexm:study_siteMI	-0.67	4.27	-8.87	7.77	1.00	6247.89	6409.20
	sexm:study_siteOS	2.11	4.58	-6.79	11.05	1.00	7721.32	6433.36
	sigma	9.54	0.64	8.29	10.80	1.00	3281.13	5196.41

Bill depth	Intercept	11.36	0.08	11.20	11.52	1.00	4908.37	5599.30
	sexm	1.59	0.11	1.36	1.81	1.00	4911.12	5395.92
	study_siteMI	-0.35	0.20	-0.74	0.04	1.00	4872.47	5769.65
	study_siteOS	-0.44	0.16	-0.76	-0.12	1.00	5934.91	6127.86
	sexm:study_siteMI	0.22	0.25	-0.27	0.70	1.00	4899.46	5603.34
	sexm:study_siteOS	0.13	0.27	-0.40	0.65	1.00	5777.14	6259.69
	sigma	0.42	0.06	0.31	0.55	1.00	685.91	1318.08

For each trait (body mass, bill length, head length, tarsus length, wing length, and bill depth), sex and study site were included as fixed effects, and repeated measurements from the same individuals were accounted for using a random intercept. The table reports posterior means (Estimate), standard errors (Est.Error), and 95% credible intervals (l-95% CI, u-95% CI). Positive coefficients represent larger values relative to the reference categories (female for sex and AW for study site). Interaction terms describe how sex differences vary among study sites. The parameter sigma denotes the residual standard deviation. Convergence diagnostics include Rhat (values ≤ 1.01 indicate good convergence) and effective sample sizes for the bulk and tail of the posterior distribution (Bulk_ESS, Tail_ESS). AW, MI, and OS indicate Awashima Island, Mikurajima Island, and Oshima Island, respectively.

Table S4. Sex differences in movement, space use, and behavior by site and year.

Site	Year	Trip duration	Total travel distance	Proportion of ARS	Duration of ARS / Total trip time	Proportion of directed flight	Duration of directed flight / Total trip time
AW	2018	N.S.	m>f	m<f	N.S.	N.S.	m>f
	2019	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	2023	N.S.	m>f	m<f	N.S.	N.S.	N.S.
	2024	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
MI	2018	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	2019	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
OS	2023	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	2024	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.

“m>f” indicates that males had higher values than females; “m<f” indicates that males had lower values than females; “N.S.” indicates no significant difference. Bold text denotes statistically significant sex differences. AW, MI, and OS indicate Awashima Island, Mikurajima Island, and Oshima Island, respectively.

Table S5. Summary statistics of trip-level behavioral parameters by site and year.

Site	Sex	Year	Trip duration	Maximum flight distance from the colony				Total flight distance						
				Mean	SD	Minimum	Maximum	Mean (km)	SD	Minimum	Maximum			
				(hour)										
AW	Female	2018	33.54	32.87	6.25	177.50	116.23	125.90	15.90	779.78	353.74	415.42	26.62	2206.15
	Male	2018	37.56	37.39	11.75	166.75	179.35	223.41	18.82	955.45	505.82	636.41	44.52	2799.88
	Female	2019	91.82	84.27	11.25	307.25	299.38	240.41	9.42	793.21	1028.05	901.85	46.36	2917.14
	Male	2019	87.32	89.20	12.75	422.75	338.25	302.97	13.80	964.88	1091.32	1079.78	36.66	4386.00
	Female	2023	37.26	32.66	6.50	117.00	91.72	91.86	5.83	457.36	313.36	327.79	32.28	1447.52
	Male	2023	56.53	63.92	12.75	232.00	222.80	326.71	9.44	1011.44	652.51	886.93	53.56	2817.98
	Female	2024	126.09	135.18	14.50	517.50	346.73	260.25	34.93	891.89	1222.78	1123.91	72.39	3717.30
	Male	2024	87.65	92.63	14.50	302.75	336.87	351.36	23.30	1001.65	1039.03	1192.70	69.65	3512.69
MI	Female	2018	81.70	92.24	6.25	304.00	391.98	492.05	7.40	1323.52	1117.42	1413.33	7.86	4026.79
	Male	2018	77.31	101.99	7.75	349.00	352.10	483.12	6.17	1280.31	1003.95	1425.22	5.91	4102.53

	Female	2019	148.82	166.99	10.75	400.00	547.05	591.24	23.42	1485.72	1943.14	2185.45	101.79	5344.62
	Male	2019	87.61	109.09	6.75	425.75	446.74	494.49	14.39	1339.86	1275.32	1506.83	57.91	4776.88
OS	Female	2023	56.01	43.75	13.00	213.25	110.45	60.60	16.06	329.31	444.09	307.97	51.90	1660.08
	Male	2023	63.99	67.46	14.00	280.75	112.01	194.24	9.64	1365.44	506.63	691.52	30.88	3898.70
	Female	2024	57.64	71.32	8.75	445.50	127.37	169.75	0.00	1508.38	517.86	675.21	57.47	4429.75
	Male	2024	57.27	76.29	13.25	356.00	192.29	407.62	0.00	1772.38	618.04	1048.38	21.66	4416.00

Mean, standard deviation, minimum, and maximum values of behavioral parameters (trip duration, maximum distance from the colony, and total flight distance) by breeding site and year. SD indicates standard deviation. AW, MI, and OS indicate Awashima Island, Mikurajima Island, and Oshima Island, respectively.

Table S6. Bayesian gamma model summaries of sex differences in trip characteristics.

	Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Trip durations	Intercept	4.03	0.35	3.33	4.71	1.00	1043.66	1235.94

Sexm	0.06	0.19	-0.34	0.40	1.01	1215.87	1281.64
SiteMI	0.68	0.63	-0.48	2.07	1.00	1445.88	1408.50
SiteOS	0.02	0.62	-1.22	1.31	1.00	1389.96	1491.28
Sexm:SiteMI	-0.32	0.39	-1.04	0.42	1.00	1496.38	1182.91
Sexm:SiteOS	0.02	0.34	-0.61	0.71	1.00	1409.33	1180.57
shape	1.20	0.04	1.12	1.29	1.00	4546.82	3417.84

Maximun

flight distance

Intercept	5.13	0.35	4.45	5.80	1.00	1026.21	1334.54
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from the

colony

Sexm	0.33	0.20	-0.09	0.72	1.00	1581.46	1572.15
SiteMI	1.05	0.66	-0.09	2.32	1.00	1297.59	1075.48
SiteOS	-0.36	0.62	-1.56	0.88	1.00	1109.39	1052.44
Sexm:SiteMI	-0.47	0.37	-1.20	0.27	1.00	1719.19	1462.54
Sexm:SiteOS	-0.17	0.37	-0.89	0.57	1.00	1652.30	1763.26
shape	0.98	0.04	0.92	1.05	1.00	4104.36	2964.00

Total flight distance	Intercept	6.36	0.39	5.64	7.20	1.00	901.65	853.24
	Sexm	0.24	0.19	-0.21	0.58	1.00	1264.14	1282.69
	SiteMI	0.92	0.67	-0.44	2.19	1.00	1081.02	1010.81
	SiteOS	-0.20	0.63	-1.54	1.06	1.00	1345.28	1599.95
	Sexm:SiteMI	-0.48	0.36	-1.15	0.28	1.00	1477.23	1433.50
	Sexm:SiteOS	-0.10	0.34	-0.77	0.65	1.00	1578.94	1767.50
	shape	0.92	0.03	0.86	0.99	1.00	4929.20	3139.85

Each model included sex (Sex), breeding site (Site), and their interaction (Sex $\times$ Site) as fixed effects. To account for interannual and site-specific variation in sex differences, the colony–year combination (Site_year) was included as a grouping factor with a random intercept and a random slope for sex (1 + Sex | Site_year). Bird identity (Logger) was included as a random intercept to account for repeated measurements of individuals. Estimates represent posterior means on the linear predictor scale (log scale for gamma models), accompanied by standard errors and 95% credible intervals (l-95% CI, u-95% CI). Positive coefficients indicate higher values relative to the reference categories (female for Sex and Awashima Island for Site).

The parameter shape denotes the gamma shape parameter estimated from the posterior.

Model convergence diagnostics include the potential scale-reduction factor (Rhat; values ≤ 1.01 indicate good convergence) and effective sample sizes for the bulk and tail of the posterior distributions (Bulk_ESS, Tail_ESS). MI and OS indicate Mikurajima Island, and Oshima Island, respectively.

Table S7. Bayesian Gaussian model summaries of sex differences in HMM-derived behaviors.

	Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
Propotion of ARS	Intercept	0.52	0.04	0.43	0.61	1.00	700.93	567.90
	Sexm	-0.03	0.02	-0.08	0.02	1.00	1089.19	1306.96
	SiteMI	-0.03	0.08	-0.18	0.13	1.00	843.23	581.60
	SiteOS	0.03	0.08	-0.11	0.22	1.00	718.97	328.86
	Sexm:SiteMI	-0.02	0.04	-0.11	0.06	1.00	1687.07	1795.54
	Sexm:SiteOS	0.02	0.04	-0.07	0.10	1.00	1216.95	1245.72
	sigma	0.15	0.00	0.14	0.15	1.00	3256.42	2984.53
Duration of ARS / Total trip time	Intercept	0.69	0.04	0.62	0.77	1.00	1716.74	1764.90
	Sexm	-0.03	0.03	-0.08	0.02	1.00	1898.47	1788.92
	SiteMI	-0.04	0.07	-0.18	0.10	1.00	2210.35	1971.00
	SiteOS	0.03	0.07	-0.11	0.15	1.00	2192.55	1860.72
	Sexm:SiteMI	0.01	0.06	-0.10	0.12	1.00	2584.74	2256.98
	Sexm:SiteOS	0.05	0.05	-0.05	0.15	1.00	2222.69	2341.05

	sigma	0.18	0.00	0.17	0.19	1.00	4166.84	2628.15
Proportion of								
directed	Intercept	0.23	0.03	0.17	0.30	1.00	1436.66	1589.50
flight								
	Sexm	0.03	0.02	-0.01	0.07	1.00	1844.24	1814.93
	SiteMI	0.04	0.06	-0.09	0.16	1.00	1886.52	1938.76
	SiteOS	-0.02	0.06	-0.14	0.09	1.00	1406.11	1299.90
	Sexm:SiteMI	-0.02	0.05	-0.11	0.07	1.00	2431.03	2676.93
	Sexm:SiteOS	-0.06	0.04	-0.14	0.02	1.00	1782.43	2262.42
	sigma	0.15	0.00	0.14	0.16	1.00	5518.64	3321.62
Duration of								
directed								
flight / Total	Intercept	0.20	0.03	0.15	0.26	1.00	1993.56	2176.15
trip time								
	Sexm	0.04	0.02	0.00	0.08	1.00	1874.65	1931.11
	SiteMI	0.06	0.05	-0.03	0.17	1.00	2753.09	2322.06
	SiteOS	-0.02	0.05	-0.10	0.08	1.00	2033.39	1869.13
	Sexm:SiteMI	-0.04	0.04	-0.12	0.05	1.00	2346.10	1920.50

Sexm:SiteOS	-0.07	0.04	-0.14	0.01	1.00	2160.24	1825.96
sigma	0.14	0.00	0.13	0.14	1.00	4166.94	3048.93

Each model included sex (Sex), breeding colony (Site), and their interaction (Sex $\times$ Site) as fixed effects. To account for interannual and colony-specific variation in sex differences, the colony–year combination (Site_year) was included as a grouping factor with a random intercept and a random slope for sex (1 + Sex | Site_year). Logger identity was included as an additional random intercept to account for repeated measurements of individuals (not shown). Estimates represent posterior means on the linear predictor scale, accompanied by standard errors and 95% credible intervals (l-95% CI, u-95% CI). Positive coefficients indicate higher values relative to the reference categories (female for Sex and Awashima Island for Site). Interaction terms (Sex $\times$ Site) describe how sex differences vary among breeding colonies relative to the reference colony. The parameter sigma denotes the residual standard deviation. Model convergence diagnostics include the potential scale-reduction factor (Rhat; values ≤ 1.01 indicate good convergence) and effective sample sizes for the bulk and tail of the posterior distributions (Bulk_ESS, Tail_ESS). MI and OS indicate Mikurajima Island, and Oshima Island, respectively.

Table S8. Oceanographic conditions within 95% and 50% utilization distributions.

Site	year	Sex	Chl-a (mg/m ³)		SST (°C)	
			Mean	SD	Mean	SD

95% UD	AW	2018	Female	0.41	0.01	24.17	0.01
		2018	Male	0.51	0.01	22.68	0.01
		2019	Female	0.39	0.01	23.85	0.01
		2019	Male	0.68	0.01	22.69	0.01
		2023	Female	0.21	0.00	28.50	0.01
		2023	Male	0.44	0.01	26.00	0.02
		2024	Female	0.44	0.03	25.70	0.02
		2024	Male	0.75	0.02	24.30	0.03
	MI	2018	Female	0.50	0.01	22.87	0.03
		2018	Male	0.53	0.01	22.73	0.02
		2019	Female	0.39	0.01	22.14	0.03
		2019	Male	0.38	0.01	23.41	0.01
	OS	2023	Female	1.60	0.04	28.27	0.00
		2023	Male	0.73	0.03	27.44	0.02
		2024	Female	0.57	0.02	28.10	0.01

		2024	Male	0.65	0.02	25.30	0.03
50% UD	AW	2018	Female	0.41	0.01	24.17	0.01
		2018	Male	0.51	0.01	22.68	0.01
		2019	Female	0.39	0.01	23.85	0.01
		2019	Male	0.68	0.01	22.69	0.01
		2023	Female	0.21	0.00	28.50	0.01
		2023	Male	0.44	0.01	26.00	0.02
		2024	Female	0.44	0.03	25.70	0.02
		2024	Male	0.75	0.02	24.30	0.03
	MI	2018	Female	0.50	0.01	22.87	0.03
		2018	Male	0.53	0.01	22.73	0.02
		2019	Female	0.39	0.01	22.14	0.03
		2019	Male	0.38	0.01	23.41	0.01
	OS	2023	Female	1.60	0.04	28.27	0.00
		2023	Male	0.73	0.03	27.44	0.02
		2024	Female	0.57	0.02	28.10	0.01

2024 Male 0.65 0.02 25.30 0.03

Mean and standard deviation of oceanographic parameters (sea surface temperature and chlorophyll a concentration) within the 95% and 50% utilization distributions (UDs).AW indicates Awasima, MI indicates Mikurajima, OS indicates Oshima, SST indicates sea surface temperature, Chl-a indicates chlorophyll-a concentration, and SD indicates standard deviation. AW, MI, and OS indicate Awashima Island, Mikurajima Island, and Oshima Island, respectively.

Table S9. Bayesian model summaries of sex differences in oceanographic conditions within utilization distributions.

		Parameter	Estimate	Est.Error	l-95% CI	u-95% CI	Rhat	Bulk_ESS	Tail_ESS
95%UD	SST	Intercept	26.42	0.97	24.49	28.43	1.00	1106.37	1486.26
		sexm	-0.48	0.16	-0.78	-0.16	1.00	1804.40	1435.05
		siteMI	-0.62	1.84	-4.42	3.11	1.00	1600.19	1625.85
		siteOS	2.02	1.78	-1.61	5.50	1.00	1403.88	2167.34
		sexm:siteMI	0.87	0.35	0.20	1.54	1.00	2777.04	2203.15
		sexm:siteOS	0.23	0.28	-0.31	0.76	1.00	1953.89	1540.26
		sigma	1.40	0.03	1.34	1.46	1.00	5679.50	2716.31
	Chl-a	Intercept	0.37	0.16	0.05	0.68	1.00	889.26	676.79
		sexm	0.00	0.13	-0.27	0.25	1.00	935.90	835.52

		siteMI	-0.04	0.28	-0.60	0.53	1.00	1224.37	1439.17
		siteOS	0.86	0.27	0.34	1.42	1.00	1383.06	1083.46
		sexm:siteMI	-0.08	0.24	-0.58	0.40	1.00	1112.70	1186.03
		sexm:siteOS	-0.55	0.24	-1.00	-0.10	1.00	1093.89	976.10
		sigma	0.51	0.01	0.49	0.54	1.00	6122.37	2793.48
50%UD	SST	Intercept	26.23	1.08	24.12	28.52	1.00	1105.52	1333.79
		sexm	-0.71	0.21	-1.13	-0.31	1.00	2509.41	2064.61
		siteMI	-1.23	1.91	-5.21	2.37	1.00	1867.20	1791.14
		siteOS	2.26	1.95	-1.63	6.15	1.00	1324.32	1330.19
		sexm:siteMI	1.20	0.46	0.27	2.13	1.00	3743.71	2518.34
		sexm:siteOS	0.38	0.37	-0.32	1.12	1.00	2934.27	2110.98
		sigma	2.00	0.04	1.92	2.09	1.00	6591.09	3059.80
	Chl-a	Intercept	0.33	0.27	-0.22	0.84	1.00	1444.19	1421.61
		sexm	0.10	0.17	-0.22	0.48	1.00	1781.01	1137.94
		siteMI	0.09	0.49	-0.83	1.12	1.00	1662.12	1695.31
		siteOS	0.90	0.45	0.03	1.83	1.00	1970.66	2239.14
		sexm:siteMI	-0.17	0.32	-0.86	0.46	1.00	1945.09	2092.85
		sexm:siteOS	-0.66	0.30	-1.29	-0.12	1.00	2172.91	2059.17

sigma	0.65	0.01	0.62	0.68	1.00	8950.49	3024.74
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For each environmental variable and UD scale, Gaussian models were fitted with sex (Sex), breeding site (Site), and their interaction ($\text{Sex} \times \text{Site}$) as fixed effects. To account for interannual and site-specific variation in sex differences, the colony-year combination (Site_year) was included as a grouping factor with a random intercept and a random slope for sex ($1 + \text{Sex} \mid \text{Site_year}$). Bird identity (Logger) was included as an additional random intercept to account for repeated measurements of individuals (not shown). Estimates represent posterior means on the original response scale, accompanied by standard errors and 95% credible intervals (l-95% CI, u-95% CI). Positive coefficients indicate higher values relative to the reference categories (female for Sex and Awashima Island for Site). Interaction terms ($\text{Sex} \times \text{Site}$) describe how sex differences in experienced environmental conditions vary among breeding sites relative to the reference site. The residual standard deviation is denoted by sigma. Model convergence diagnostics include the potential scale-reduction factor (Rhat; values ≤ 1.01 indicate good convergence) and effective sample sizes for the bulk and tail of the posterior distributions (Bulk_ESS, Tail_ESS). MI, and OS indicate, Mikurajima Island, and Oshima Island, respectively.