Supplementary material for: Berteaux D., Thierry A.-M., Alisauskas R., Angerbjörn A., Buchel E., Doronina L., Ehrich D., Eide N.E., Erlandsson R., Flagstad Ø., Fuglei E., Gilg O., Goltsman M., Henttonen H., Ims R.A., Killengreen S.T., Kondratyev A., Kruchenkova E., Kruckenberg H., Kulikova O., Landa A., Lang J., Menyushina I., Mikhnevich J., Niemimaa J., Norén K., Ollila T., Ovsyanikov N., Pokrovskaya L., Pokrovsky I., Rodnikova A., Roth J.D., Sabard B., Samelius G., Schmidt N.M., Sittler B., Sokolov A.A., Sokolova N.A., Stickney A., Unnsteinsdóttir E.R. & White P.A. 2017. Harmonizing circumpolar monitoring of Arctic fox: benefits, opportunities, challenges and recommendations. *Polar Research 36.* Contact: Dominique Berteaux, Canada Research Chair on Northern Biodiversity and Centre for Northern Studies, Université du Québec à Rimouski, 300 Allée des Ursulines, Rimouski, Québec G5L 3A1, Canada. E-mail: dominique_berteaux@uqar.ca

Supplementary Table S1. Summary of Arctic fox monitoring sites with geographic characteristics and indicators of monitoring effort. Values indicating monitoring effort were averaged across the monitoring period when they varied through time. Sites are mapped in Fig. 1.

Site reference number and name	Area	Country	Coordinates	Climate zone[a]				Size of study area (km^2)	Number of known dens[b]	Monitoring period	Fieldwork season	Number of person days/year in the field
				High Arctic	Low Arctic	Sub-Arctic	Montane/alpine					
1. East Iceland	Eastern regions of Iceland[c]	Iceland	65°N, 18°W		●	●		82000	1000	1979–ongoing	all year round	NA[d]
2. West Iceland	Western regions of Iceland[c]	Iceland	65°N, 21°W		●	●		21000	500	1979–ongoing	all year round	NA[d]

3. Hornstrandir	Westfjords	Iceland	66°N, 22°W		●	●	77	40	1998–ongoing	Jun–Aug	110
4. Kap Rink	Hochstetter Forland	Greenland	75°N, 20°W	●			38	4	2010–ongoing	1 Jul–10 Aug	180
5. Zackenberg Valley	Wollaston Forland	Greenland	74°N, 21°W	●			50	17	1996–ongoing	mid-May–late Oct	330
6. Karupelv Valley	Traill Island	Greenland	72°N, 24°W	●			75	8	1988–ongoing	25 Jun–5 Aug	240
7a. Bylot Island	Nunavut	Canada	73°N, 80°W	●			200	30	1993–2003	1 Jun–5 Aug	100
7b. Bylot Island	Nunavut	Canada	73°N, 80°W	●			600	100	2004–ongoing	10 May–5 Aug	330
8a. Churchill	Manitoba	Canada	59°N, 94°W		●	●	600	100	1994–97	Apr, June–Aug	80
8b. Churchill	Manitoba	Canada	59°N, 94°W		●	●	700	110	2010–ongoing	Apr, Jun, Aug	200
9. Karrak Lake	Nunavut	Canada	67°N, 100°W		●		70	12	2000–ongoing	10–31 May	60
10. Egg River	Northwest Territories	Canada	72°N, 124°W	●			75	28	1995–98	June	120
11. Prudhoe Bay	Alaska	USA	70°N, 148°W		●		792	51	2005–2014	late Jun–mid-Jul	43
12. Pribilof Islands	Pribilof Islands	USA	57°N, 170°W			●	125	100	1988–ongoing	May–Sep or Jul	30

13. Shemya Island	Aleutian Islands	USA	52°N, 174°E			●	15	15	2006, 2008, 2011–ongoing	Jan–Feb or Jun–Jul	21
14. Wrangel Island	Chukotka	Russia	71°N, 179°E	●			800	82	1980-2014	May-Sep	140
15. Mednyi Island	Commander Islands	Russia	54°N, 167°E			●	50	45	1976, 1978, 1994–2012	Jun–Aug	320
16. Sabetta	Yamal Peninsula	Russia	71°N, 71°E	●	●		160	29	2012–ongoing	Jul–Sep	35
17. Belyi Island	Yamal Peninsula	Russia	73°N, 70°E	●			40	11	2013, 2015–ongoing	Jul	14
18. Erkuta	Yamal Peninsula	Russia	68°N, 69°E		●		230	56	1989, 1998, 2007–ongoing	nearly year round	400
19. Nenetsky	Nenets Autonomous Okrug	Russia	68°N, 53°E		●		100	12	2007–2011	20 Jun–20 Aug	120
20a. Kolguev Island	Nenets Autonomous Okrug	Russia	69°N, 48°E		●		350	50	2006–08, 2011–12	20 May–15 Aug	540
20b. Kolguev Island	Nenets Autonomous Okrug	Russia	69°N, 48°E		●		350	80	2013, 2015	20 Jun–20 Aug	180

21. Longyear-byen	Svalbard	Norway	78°N, 17°E	●				900	32	1982–1989, 1997–ongoing	25 Jun–27 Jul	60
22. Ny-Ålesund	Svalbard	Norway	79°N, 11°E	●				221	10	1993–ongoing	25 Jun–27 Jul	25
23. Finnish Lapland	Lapland	Finland[e]	69˚N, 21-27˚E				●	5000	320	1960–ongoing	Apr–Aug	40
24. Helags	Jämtland	Sweden[e]	63˚N, 13˚E				●	1920	100	1985–ongoing	Apr, 1 Jul–15 Aug	315
25. Borga	Jämtland/ Västbotten	Sweden[e]	65˚N, 15˚E				●	1676	50	1985–ongoing	Apr, 1 Jul–15 Aug	165
26. Vindel-fjällen/Arjeplog	Västerbotten/ Norrbotten	Sweden[e]	66˚N, 16˚E				●	2600	130	1985–ongoing	Apr, 1 Jul–15 Aug	315
27. Norrbotten	Norrbotten	Sweden[e]	67-69˚N, 17-21˚E			●	●	6000	150	1985–ongoing	Apr, 1 Jul–15 Aug	165
28. Varanger	Varanger Peninsula	Norway[e]	70°N, 29°E		●	●		2000	40	2001–ongoing	28 Jun–18 Jul, 31 Aug–5 Sep, 15 Mar–1 Apr	200
29. Ifjordfjellet/ Reisa/Dividalen	Troms/ Finnmark	Norway[e]	66-70°N, 15-27°E			●	●	15000	163	2001–ongoing	Feb–May late Jun–mid- Aug	21
30. Saltfjellet	Nordland	Norway[e]	66°N, 15°E				●	2500	58	1972–1994,	Feb–May	40

								2001–ongoing	late Jun–mid- Aug	
31. Børgefjell	Nordland/Nord-Trøndelag	Norway[e]	66°N, 15°E		●	2000	43	1977–ongoing	Feb–May late Jun–mid Aug.	110
32. Lierne/ Sylane	Nord Trøndelag/Sør Trøndelag	Norway[e]	63-65°N, 11-14°E		●	6000	164	2001–ongoing	Feb–May late Jun–mid- Aug.	55
33. Snøhetta/ Knutshø/Finse	Sør-Trøndelag/ Oppland/ Buskerud	Norway[d]	60-62°N, 7-11°E		●	7000	151	1989–ongoing	Feb - May late Jun–mid- Aug	273
34. Hardanger-vidda	Buskerud/Sogn/ Hordaland	Norway[d]	60°N, 7°E		●	5000	205	1956–1975, 1999–ongoing	Feb–May late Jun–mid- Aug	40

[a] Climate zones follow figure 1 in CAFF (2013). [b] Arctic and red fox dens are included when the two species live in the study area. [c] East Iceland includes the Northwestern Region, Northeastern Region, Eastern Region and Southern Region. West Iceland includes the Capital Region, Southern Peninsula, Western Region and Westfjords. [d] The field part of this monitoring project relies mostly on ca. 35 people who hunt Arctic foxes at their dens, all year round but mostly from late winter to late summer, and send fox carcasses and associated information to researchers. [e] In Fennoscandia, Arctic fox distribution is fragmented into >25 units (Herfindal et al. 2010). Our identification of 12 monitoring sites in Fennoscandia reflects our attempt to identify monitoring units that are rather homogeneous in terms of monitoring effort and management regime, and that can be compared to other Arctic fox monitoring sites. The overlap between these nine monitoring sites and the clusters identified in Herfindal et al. (2010) is as follows: Finnish Lapland (clusters 20, 22, 26, 27), Helags (6, 7), Borga (12, 13), Vindelfjällen/Arjeplog (14, 15, 16), Norrbotten (17, 18, 20), Varanger (cluster 28), Ifjordfjellet/Reisa/Dividalen (clusters 15, 18, 19, 20, 21, 22, 24, 23, 25), Saltfjellet (cluster 16), Børgefjell (cluster 13), Lierne/Sylane (clusters 4, 5, 6, 8, 9, 10), Snøhetta/Knutshø/Finse (cluster 3, northern part of cluster 1), Hardangervidda (cluster 1).

Supplementary Table S2. Features of Arctic fox monitored populations, with emphasis on population size and trends, multi-annual fluctuations, competition with red fox, diet components and interference from humans. Grey-coloured cells reflect expert opinion rather than quantitative results obtained from data analyses.

Ref. no.	No. of monitored dens[a]	Number of Arctic fox breeding pairs[b]		Long-term population trend	Multi-annual fluctu-ations	Number of red fox breeding pairs[b]		Main diet components[c]												Main human interferences[6]: Negative						Main human interferences[6]: Positive				
		Min	Max			Min	Max	Lemmings	Voles	Hares and muskrats	Large mammal carcasses	Seabirds	Geese	Other waterfowl	Other birds	Seals	Other marine food[d]	Conservation feeding[e]	Other feeding[e]	Trapping	Hunting	Killing as pest	Disease from pets	Contaminants	Industrial development	Conservation feeding[e]	Other feeding[e]	Removal of competitors	Release of captive bred	Land protection[g]
1	750	190	750	increase	none	0	0				3		1		2							1								
2	750	95	750	increase	none	0	0					1			3		2					1								
3	40	9	13	stable	none	0	0					1			3		2													1
4	4	0	2	stable	strong	0	0	1					2		3															
5	17	0	5	stable	none	0	0	1			3				2															
6	8	0	6	unclear	strong	0	0	1					3		2															
7a	30	1	10	stable	strong	0	1	1					2			3				1										
7b	100	3	33	stable	strong	0	1	1					2			3				1										

8a	100	3	35	stable	strong	3	9	1					2			3					1									
8b	110	4	40	stable	unclear	3	9	1					2			3					1									
9	12	0	6	stable	strong	0	0	1					2		3															
10	28	1	17	stable	strong	0	0	1					2																	
11	51	1	11	decrease	strong	2	15	1						3					2	2							1			
12	100	20	55	decrease	none	0	0					2				1	3					1	2	3						
13	14	8	14	stable	none	0	0					3					1		2					2			1			
14	82	2	74	stable	strong	0	0	1					2			3														1
15	45	8	14	stable	none	0	0					1				3	2						2	3						1
16	21	0	14	unclear	strong	0	0	1	3					2							2				1		3			
17	9	1	1	unclear	unclear	0	0	2			3			1																
18	33	0	8	stable	weak	0	2	3	1	2				2	4					2	1						3			
19	12	1	4	stable	weak	1	1	2	1						3												1			2
20a	50	6	14	stable	strong	0	1				2		1				3										1			
20b	80	11	25	stable	strong	0	1				2		1				3										1			
21	32	3	16	stable	none	0	0				1	2	3							1										
22	10	0	9	stable	none	0	0				1	2	3							1										
23	220	0	1	stable	strong	30	100	1	3		2																	1		2
24	100	0	30	increase	strong	0	30	1	2									3								1		2		3
25	60	0	25	increase	strong	0	30	1	2									3								1		2		
26	100	0	30	increase	strong	0	30	1	2									3								1		2		3

27	50	0	10	unclear	strong	0	30	1	2		3		3		1
28	40	0	4	unclear	strong	5	20	1		2			2		
29	62	0	5	decrease	strong	0	≥17	1	2	3					
30	43	0	10	increase	strong	0	≥3	1	2	3	3	1		1	
31	26	0	14	stable	strong	0	≥3	1	2	3					
32	48	0	13	increase	strong	0	≥5	1	2	3	3	1	2		
33	100	0	23	increase	strong	0	≥5	1	2	3	3	2		1	
34	37	0	2	increase	strong	0	≥7	1	2	3	3	2		1	

[a] The number of monitored dens can differ from the number of known dens reported in Supplementary Table S1 if only a proportion of known dens were monitored. Monitored dens include reproductive and non-reproductive dens, as well as active and inactive dens. [b] Minimum and maximum numbers can reflect multi-annual fluctuations, long-term changes in fox abundance, or variation in monitoring effort. [c] Each monitoring team ranked a maximum of three diet components (1 = main diet component). [d] Includes marine invertebrates and all beachcast marine edibles. [e] Conservation feeding includes regular provisioning of significant quantities of food to enhance fox reproduction and survival. Contribution of conservation feeding to the diet of foxes is not quantified, but is known to be higher when rodents are rare. Other feeding includes provisioning of significant quantities of food with no aim to enhance fox reproduction and survival (e.g., allowing access to human garbage, providing large quantities of baits to attract foxes, providing reindeer carcasses through husbandry practices). Note that “Other feeding” can have negative effects on fox populations, for example, through disease or contaminant transfer. [f] Each monitoring team ranked a maximum of three human interferences (1 = main human interference). We considered humans to interfere with Arctic foxes if they had some measured or suspected effects on population size or trend. To simplify the table, we did not consider distant anthropogenic influences such as climate change or artificial increases in goose densities. [g] Land protection (e.g., national park or reserve) was considered as human interference only if it had measured or suspected effects on Arctic fox population size.

Supplementary Table S3. Monitoring objectives, variables, techniques, and local knowledge at 34 Arctic fox monitoring sites. A variable was considered as monitored when data collection followed a protocol and sample sizes allow data interpretation. The list of variables and techniques is not exhaustive. Standardization of protocols across study sites was not fully assessed. Open circles indicate partial monitoring of a given variable. Partial monitoring was subjectively defined as monitoring during less than 50% of the study period, monitoring on less than 50% of the known dens, or monitoring over less than 50% of the study area, as appropriate.

Sites

		1. East Iceland	2. West Iceland	3. Hornstrandir	4. Kap Rink	5. Zackenberg	6. Karupelv	7a. Bylot Island	7b. Bylot Island	8a. Churchill	8b. Churchill	9. Karrak Lake	10. Egg River	11. Prudhoe Bay	12. Pribilof Islands	13. Shemya Island	14. Wrangel Island	15. Mednyi Island	16. Sabetta	17. Belyi Island	18. Erkuta	19. Nenetsky	20a. Kolguev Island	20b. Kolguev Island	21. Longyearbyen	22. Ny-Ålesund	23. Finnish Lapland	24. Helags	25. Borga	26. Vindelfjällen/Arjeplog	27. Norrbotten	28. Varanger	29. Ifjordfjellet/Reisa/Dividalen	30. Saltfjellet	31. Børgefjell	32. Lierne/Sylane	33. Snøhetta/Knutshø/Finse	34. Hardangervidda
1. Monitoring objectives[a]																																						
Scientific		2	2	1	●	●	●	●	●	●	●	●	●	●	1	2	●	●	●	●	●	●	●	●	2	2	2	2	2	2	2	2	1	2	1	2	1	2
Management		1	1	2											2	1									1	1	1	1	1	1	1	1	1	1	1	1	1	1
2. Monitored variables	3. Monitoring techniques																																					

Arctic foxes																																						
Abundance	Total census of dens in study area			●	●	●	●		●	●	●	○	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●
	Proportion of active dens in summer			●	●	●	●	●	●	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●
	Proportion of active dens in winter									●	●														●		●	○	○	○	○	●	●	●	●	●	●	●
	Capture–mark–recapture								●			●			●	●		●																			●	
	Number of observed foxes														●	●	●	●									○	●	●	●			●	●	●	●	●	●
	Number of foxes per sampling effort	●	●		●	●	●						●																									
Reproductive effort	Proportion of reproductive dens	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	○	●	●	●	●	●	●	●
	Number of fetuses/placental scars	●	●												●	●					○				●	●							●	●	●	●	●	●
Litter size	Visual observations	●	●	●	●	●	●	●	●			○		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●
	Automatic cameras				○	●			○		○								○	○	○	○	○	○	●	●	●	○	○	○	○	●		○	○	○	●	○
Age structure	Tooth condition of live individuals								●			●			●	●																						
	Programme of carcass collection	●	●			○				●	●				●	●					○				●	●							●	●	●	●	●	●
	Harvest statistics	●	●							●	●														●	●												

	Annual registration of tagged foxes																	●																				
Date of pup emergence	Visual observations	●	●			●			●						●	●	●	●										●	●	●								
	Automatic cameras					●			○		○																				○	●		○	○	○	○	○
Cub survival	Visual observations	●	●	●	●	●	●		●						●	●	●	●				○	○	○			●	●	●	●							●	
	Automatic cameras				●	●			○													○	○	○			●					●					●	
Parental attendance at active dens	Visual observations			●					●			○			●		●	●			○							●	●	●							○	
	Automatic cameras				●	●			○		○											○	○	○	●	●	●					●					○	
Phenology of molting	Visual observations	●	●	●													●											●	●	●								
	Automatic cameras					●																			●	●		●	●	●		●						
Genetic parameters	DNA sampling (live individuals)								●			○			●	●		●										●	●	●	○	●					●	
	DNA sampling (carcasses)	●	●			●									●	●		●							●	●					○		○	○	○	○	○	○
	DNA sampling (hair, faeces)																														○		●	●	●	●	●	●
Body mass	Live captures								●			●			●	●		●						○	○	○		●	●	●							●	
	Programme of carcass collection	●	●							●	●				●	●					○				●	●											●	
Morphology	Live captures								●						●	●																					●	
	Programme of carcass collection	●	●								●				●	●		●							●	●											●	

Home range size	Marking and re-observations								○						●	●	●	●						○				●	●	●							●	
	VHF telemetry	○	○	●			○								●																						○	
	Satellite telemetry			○					○															○	○													
Winter activity	Automatic cameras										○										●	○						●	●	●		●		○	●	●	○	○
	Satellite telemetry								○																●													
Diet	Prey remains at dens	●	●	●	●	●	●			○	○			●	●	●	●	●	●	●	●	●	●	●	●	●							○	○	○	○	●	●
	Faeces analyses	●	●		●	●	●				●						○	●			○	○		●				●	●	●			○	○	○	○	●	●
	Stable isotope ratios	○	○			●			●	●	●	○			○	○	○				●	○			●	●		○	○	○		●			●			
	Stomach contents	●	●												●	●					○				●	●							○	○	○	○	○	○
	DNA barcoding				○	○	○																															
	Behavioural observations						○	○	○						●	●		●										○	○	○								
Level of contamination	Blood samples from live individuals														○	○		○						○														
	Hair samples from live individuals					●											○	●				○	○	○				○	○	○							●	●
	Programme of carcass collection	●	●			●									○	○		○							●	●							●	●	●	●	●	●
Level of parasitism	Programme of carcass collection	●	●			●					○				○	○		○							●	●							●	●	●	●	●	●
	Feces analyses	●	●		●	●	●					○						○							●	●							●	●	●	●	●	●
Disease exposure	Serology											○			●	●		○							●	●												

Ecosystem structure																																						
Mammals																																						
Red fox abundance	Proportion of dens used by red foxes							●	●	●	●			●							●	●	●	●			●	●	●	●		●	●	●	●	●	●	●
	Automatic cameras with baits																				●	○						●	●	●		●			●	●		
Other mammal predators abundance (e.g., wolf, wolverine, lynx)	Number of observed individuals, active den counts				●	●	●										●																●	●	●	●	●	●
Small rodent abundance	Snap trapping		○	○				●	●			●	●						●	●	●	●					○	●	●	●		●	○	●	●		●	●
	Live trapping		○		●		○		●	●	●																											
	Surveys of signs of abundance				●	●	●	●	●		●				●	●	●		●		●							●	●	●		●		●	●		●	●
Hare abundance	Transect and area counts					●																						○	○	○		●					○	
Large mammal carcasses	Transect and area counts				●	●	●										●								●	●		●	●	●								
Seal rookeries	Visual counts at rookeries	●	●												●			●							●	●												
Birds																																						
Geese abundance	Aerial survey							●	●								●					●	●	●	●	●												
	Direct counts	○	○		●	●	●				○	●	●													●												

Waterfowl abundance	Counts on lakes																				○																	
Ptarmigan abundance	Transect counts	●	●																						●		○	●	●	●				○		○	○	○
	Nest and territory census				●	●	●																															
Seabird abundance	Colony counts	●	●	○	○	○	○				●				●			●							●	●												
Shorebird abundance	Transect counts								●																							●						
	Nest census			○	●	●	●																															
	Point counts					●															○																	
	Nest searches of focal species																				○																	
Passerine bird abundance	Transect and point counts																				○							○	○	○		●						
	Nest and territory census					●			●																													
Avian predators abundance (e.g., falcons, snowy owls, jaegers, gulls)	Nest census				●	●	●		●			●	●				●		●	●	●	●	●	●	○	○	○	○	○	○		●	○	○	●	○	○	○
Other																																						
Scavenger abundance	Automatic cameras with bait																				●				○							●			●	●		
Herbivore activity	Faeces counts on permanent plots										●								●	●	●	●		●	○	○						●			●		○	
	Transect and area counts					●		●	●																													

Tourist numbers and activities	Total counts			●		●												○							●	●	○										○	○
Weather and snow conditions	Various methods	●	●		●	●	●	●	●		●	●	●	○	●	●	●				●	●	●	●	●	●	●					●		●	●		●	●
Sea ice extent and phenology	Sea-ice maps				●	●	●								●	●	●								●	●												
Ecosystem function																																						
Predation by Arctic foxes on ground-nesting bird nests	Predation on artificial bird nests								●								●				●	●			○							○						
	Predation on real nests				●	●	●		○												○																	
Plant productivity	Various methods					●		○	●		○											●			●	●		●	●	●		●			○		○	
Plant phenology	Various methods					●		○	●								●															●						
Bird phenology (spring arrival)	Various methods			●		○		○	●					○			●								●													
Bird phenology (egg laying/hatching)	Various methods				●	●	●	○	●		●	●	●				●																					
4. Local knowledge from people other than scientists																																						
Substantial local knowledge exists about the studied population		●	●					●	●					●				●			●	●	●	●	●	●	●	●	●	●	●							

Substantial local knowledge was collected about the studied population					•		•	•			•			
Local knowledge is collected repeatedly as a monitoring technique	•	•	•											

[a] Monitoring objectives are categorized as scientific when the focus is on developing an understanding of the monitored system, and management when the goal is to inform management decisions. If both objectives were followed, their importance was ranked (1 = higher importance).

References

Herfindal I., Linnell J.D.C., Elmhagen B., Andersen R., Eide N.E., Frafjord K., Henttonen H., Kaikusalo A., Mela M., Tannerfeldt M., Dalén L., Strand O., Landa A. & Angerbjörn A. 2010. Population persistence in a landscape context: the case of endangered Arctic fox populations in Fennoscandia. *Ecography 33*, 932–941.

Meltofte H. (ed.) 2013. *Arctic biodiversity assessment. Status and trends in Arctic biodiversity*. Akureyri: CAFF.