This is an electronic appendix to the paper by Stenseth *et al*. 2002 Interaction between seasonal density-dependence structures and length of the seasons explain the geographical structure of the dynamics of voles in Hokkaido: an example of seasonal forcing. *Proc. R. Soc. Lond.* B **269**, 1853—1863.

Electronic appendix A.

Contents

Supplementary table 1 (the stations used and the predicted τ)

Supplementary tables 2 and 3 (together with some background methodological text): the linear approximation based upon the simplifying assumption of Stenseth *et al.* (1998).

Supplementary table 1: Relative length of summer season [τ; equations (2b) and (2c)] and mean estimates (*i.e*., mean of posterior distributions) of direct (α_1) and delayed (α_2) annual density dependence. (The direct and delayed density dependence are estimated from equation (1) incorporating a statistical observation model (and thus accounting for sampling variance; see equations (A1)-(A3)). Estimates are given for each of 189 sites within eight groups (see figure 1). The location of each population is indicated by altitude (h) and positions in the west-to-east (g_{we}) and south-to-north (g_{sn}) direction (the unit of which being 1 corresponding to 2 km for g_{we} and g_{sn} and 10 m for h). 'Group' is the variable into which each time series is grouped according to topography (see Fig. 1).

Code	Office	Group	g_{we}	g_{sn}	h	τ	α_1	α_2
101	Wakkanai	1	74.3	222.5	75	0.4042	0.0591	0.4166
201	Hamatonbetsu	2	89.5	213.5	100	0.4046	-0.3765	-0.4411
202	Onishibetsu	2	82.7	220.0	200	0.4035	0.3570	0.0151
203	Shirikibetsu	2	81.2	226.0	50	0.4006	-0.3328	0.0150
205	Asagino	2	83.8	213.9	50	0.4063	-0.0517	-0.1153
301	Nakatonbetsu	2	93.4	206.3	150	0.4062	0.0910	-0.4517
302	Shimotonbetsu	2	90.8	208.2	100	0.4065	0.3439	-0.4062
303	Usotan	2	98.2	209.5	300	0.4031	0.3241	-0.2148
304	Heian	2	96.4	204.0	100	0.4059	0.0404	-0.6334
401	Esashi	2	103.2	204.6	300	0.4027	-0.5572	-0.6042
402	Utanobori	2	100.0	202.9	100	0.4047	-0.0316	-0.3141
403	Ketobetsu	2	96.7	196.1	200	0.4087	-0.0637	-0.4431
404	Shibiutan	2	103.2	193.3	400	0.4061	-0.3343	-0.3079
410	Esashi2	2	106.6	189.0	350	0.4054	-0.2215	-0.2453
501	Teshio	1	74.6	201.5	50	0.4170	0.4593	-0.0317
502	Oshinnai	1	79.9	196.6	100	0.4173	0.2432	-0.1941
503	Horonobe	1	80.0	209.1	150	0.4103	0.0463	0.3024

504	Toyotomi	1	79.1	212.9	100	0.4084	0.2557	0.1685
601	Nayoro	2	106.6	174.9	400	0.4091	-0.2771	-0.2278
602	Nakagawa	1	84.0	196.2	250	0.4153	0.6056	-0.1166
603	Saku	1	83.6	191.8	100	0.4178	-0.0743	-0.7437
604	Kyowa	1	88.2	187.5	200	0.4172	-0.1098	-0.3913
605	Yamato	1	86.0	183.9	300	0.4204	0.2258	-0.0550
607	Furen	2	106.8	165.1	400	0.4116	0.2258	-0.0550
701	Maesanru	2	109.8	174.2	100	0.4069	0.1223	0.2874
702	Mikuruma	2	112.5	175.7	250	0.4045	0.0738	0.0946
703	Okusanru	2	114.9	177.6	300	0.4024	-0.1280	-0.1991
704	Ninohashi	2	113.5	168.4	400	0.4052	-0.0801	-0.5030
705	Panke	2	112.3	165.6	300	0.4067	0.1479	-0.2533
800	Shin	2	113.1	171.7	400	0.4049	-0.0563	-0.3114
801	Shikaribetsu	2	115.3	175.0	300	0.4026	-0.0607	-0.3610
802	Ichinohashi	2	115.3	172.3	300	0.4030	-0.5482	-0.5370
901	Onnebetsu	2	94.7	163.3	250	0.4228	-0.0713	0.0506
902	Wassamu	2	102.8	154.4	300	0.4184	0.2894	0.0888
903	Kamishibetsu	2	106.4	161.0	300	0.4130	0.1530	-0.1043
1001	Kitashibetsu	2	110.3	160.6	300	0.4096	0.1671	-0.1265
1003	Mitsumata	2	111.6	156.6	400	0.4092	-0.0174	-0.5932
1005	Nisama	2	118.0	159.6	200	0.4027	0.0584	-0.1842
1006	Nakateshio	2	115.0	156.2	500	0.4061	-0.1278	-0.3199
1101	Kamikawa	5	117.8	147.5	500	0.4046	0.1220	-0.2552
1104	Kiyokawa	5	124.2	140.0	700	0.3985	0.0063	-0.1254
1110	Kamikawa2	5	124.0	147.3	500	0.3982	0.1245	0.1292
1202	Rubeshinai	5	130.2	134.0	1000	0.3918	0.2052	-0.2750
1204	Ishikari	5	125.4	131.9	1000	0.3976	0.2196	-0.3931
1302	Etanbetsu	5	95.8	146.5	200	0.4283	0.3474	-0.1199
1304	Aibetsu	5	111.3	150.0	250	0.4110	-0.4243	-0.2292
1310	Asahikawa2	5	106.5	151.1	600	0.4156	-0.5658	-0.3635
1401	Nishikagura	5	100.8	132.5	300	0.4276	-0.3858	-0.1449
1402	Kamuikotan	5	97.4	137.7	500	0.4299	-0.2908	-0.2792
1501	Ebishima	1	83.2	145.8	200	0.4424	0.6423	-0.3636
1503	Fukagawa	1	80.0	137.6	100	0.4505	0.1639	0.0430
1601	Takatomari	1	89.9	146.3	200	0.4348	0.6252	-0.6047
1602	Horokanai	1	89.7	152.4	400	0.4322	0.1321	-0.3464
1604	Seiwa	1	89.3	157.0	500	0.4305	0.2108	0.5553
1605	Shumarinai	1	88.9	168.1	400	0.4258	0.1560	0.3577
1701	Rubeshibe	5	102.9	126.9	500	0.4268	0.1892	0.3940
1703	Biei	5	115.7	124.7	800	0.4107	0.3246	-0.2063
1801	Furano	5	103.7	120.0	800	0.4278	-0.0586	-0.4047
1803	Furebetsu	5	114.3	119.1	700	0.4135	0.1234	-0.2228
1901	Kanayama	5	106.6	102.7	500	0.4285	0.1117	-0.2691
1903	Nishishimcup	5	104.7	99.3	600	0.4325	0.2426	-0.4982
1904	Higashishimcup	5	108.9	98.9	500	0.4259	-0.0555	-0.3743
1905	Soshubetsu	5	112.2	95.5	500	0.4213	0.3792	-0.0778
1906	Niniu	5	104.3	93.4	500	0.4349	0.2251	-0.3216
2001	Ikutora	5	111.2	104.8	500	0.4209	-0.1113	-0.5024
2002	Ochiai	5	117.1	102.2	700	0.4123	0.6200	0.0164
2003	Okuochiai	5	117.3	114.4	750	0.4101	0.2918	-0.1599
2004	Kamitomamu	5	114.9	99.4	800	0.4162	0.3496	0.1452
2005	Shimotomam	5	112.8	102.1	500	0.4190	-0.0225	-0.5667
2201	Shimokinen	1	81.2	151.2	150	0.4416	0.3554	0.2388

2202	Tappu	1	79.3	155.0	200	0.4414	-0.0146	0.3861
2203	Takishita	1	82.9	153.7	300	0.4385	0.1697	0.1874
2204	Kawakami	1	84.9	156.7	400	0.4349	0.0697	-0.0584
2301	Kotanbetsu	1	78.5	161.8	150	0.4382	-0.1488	0.0763
2302	Okukotan	1	83.6	161.2	300	0.4338	-0.3111	-0.2757
2303	Sankei	1	77.2	159.2	200	0.4409	0.4752	0.0971
2304	Okusankei	1	80.8	159.5	300	0.4374	-0.0543	0.1874
2401	Haboro	1	78.7	167.8	100	0.4345	0.1538	0.3442
2403	Chikubetsu	1	78.9	172.2	100	0.4318	0.1850	0.1341
2404	Okuchikubetsu	1	80.6	175.2	200	0.4288	-0.1734	0.1653
2405	Shosanbetsu	1	79.1	176.9	200	0.4290	-0.1202	0.0757
2406	Toyomisaki	1	79.1	179.9	250	0.4272	0.1722	-0.1389
2501	Enbetsu	1	78.8	187.9	200	0.4228	0.4459	0.2948
2502	Nishienbetsu	1	82.8	178.5	300	0.4253	0.2714	0.3176
10103	Yuni	4	82.3	93.6	150	0.4718	0.6848	-0.2944
10303	Kaede	4	94.0	93.7	400	0.4520	0.4575	0.0429
10304	Keiritsu	4	89.1	92.9	150	0.4606	0.3578	-0.1575
10305	Maeyubari	4	94.6	99.9	600	0.4485	0.4381	-0.3271
10308	Yubaridake	4	98.8	99.5	500	0.4419	-0.2142	-0.1092
10309	Nanbu	4	95.7	96.8	400	0.4480	0.1428	-0.3509
10310	Kawabata	4	92.1	89.9	300	0.4569	0.2367	-0.5086
10311	Shimizusawa	4	91.4	96.0	200	0.4554	0.5109	-0.7676
10401	Mitsuiwa	7	107.9	85.1	600	0.4310	-0.1486	-0.2176
10402	Hidaka	7	110.2	91.2	500	0.4256	0.2735	0.0234
10403	Chiroro	7	115.7	85.9	750	0.4172	0.1289	-0.7292
10404	Senei	7	116.9	91.3	1000	0.4143	0.1633	0.0204
10405	Nissho	7	119.1	94.6	1000	0.4102	0.3710	-0.0313
10407	Nukabira	7	110.5	82.9	200	0.4269	0.3870	-0.0160
10501	Furenai	7	105.9	82.8	400	0.4352	-0.0025	-0.2909
10502	Niseu	7	105.4	86.4	400	0.4350	0.3861	0.0768
10503	Horoshiri	7	114.6	83.5	800	0.4195	-0.0281	-0.2131
10504	Shukushubetsu	7	111.7	78.6	750	0.4257	0.1115	-0.0680
10505	Nukibetsu	7	102.7	76.3	150	0.4429	0.1789	-0.5925
10601	Atsuga	7	104.4	65.2	200	0.4431	0.3129	-0.0951
10604	Miu	7	108.7	71.7	500	0.4329	-0.0757	-0.4726
10701	Nishigvoen	7	119.7	66.4	500	0.4127	0.0083	-0.4315
10702	Higashigvoen	7	116.6	70.1	500	0.4181	0.0015	-0.3853
10703	Okushizunai	7	125.3	71.3	900	0.4016	0.4246	-0.1386
10801	Nisha	7	129.5	62.2	300	0.3939	-0.5390	-0.4140
10804	Utafue	7	122.5	64.0	500	0.4075	0.0482	-0.1005
10901	Tomakomai	6	72.6	78.2	50	0.4984	0.3233	-0.0457
10902	Itoi	6	71.2	76.4	150	0.5022	0.2624	-0.5202
10903	Kitashikotsu	6	61.1	80.9	500	0.5177	0.0686	-0.2996
10904	Hobetsu	7	98.5	80.8	200	0.4492	-0.1767	-0.0689
10906	Tominai	7	101.5	85.7	400	0.4421	-0.0790	-0.2443
10907	Maruyama	6	68.5	80.0	100	0.5048	0.2457	0.1270
11001	Tarumae	6	67.3	73.8	300	0.5114	0.0744	-0.4340
11002	Shiraoi	6	61.4	74.0	400	0.5226	-0.5273	-0.1107
11003	Takeura	6	57.9	68.0	400	0.5342	0.2551	0.4910
11101	Eniwa	6	64.4	84.5	400	0.5090	-0.0662	0.3189
11204	Hiroshima	6	71.8	95.8	50	0.4881	0.0652	-0.0756
11207	Shiraigawa	6	52.3	92.9	500	0.5233	0.4360	0.3295
11209	Nishimisumai	6	57.9	88.9	500	0.5170	-0.1711	0.2453

11212	Ishiyama	6	65.2	91.1	200	0.5026	0.7243	0.1190
11301	Yoichi	6	37.7	104.0	300	0.5365	0.3123	-0.2033
11303	Meiji	6	47.6	94.0	600	0.5303	-0.8599	-0.3991
11305	Furubira	6	33.3	101.9	500	0.5457	0.3302	-0.0504
20105	Hokuyu	3	124.2	173.9	400	0.3960	0.0353	-0.4149
20202	Konomai	3	131.1	171.4	350	0.3907	0.1394	-0.4223
20301	Shirataki	3	134.4	148.3	750	0.3874	-0.0460	-0.1637
20303	Okushirataki	3	129.9	148.7	800	0.3920	-0.0211	0.1833
20401	Taki	3	138.8	147.2	500	0.3828	0.0711	-0.1998
20402	Muri	3	135.8	142.6	600	0.3856	0.0953	0.0116
20601	Ankoku2	3	147.0	155.8	400	0.3758	-0.1213	-0.0800
20705	Tanno	3	161.3	154.8	300	0.3622	0.5843	-0.1298
20902	Tsunemoto	3	145.2	136.6	800	0.3746	-0.3136	-0.2883
20903	Katsuyama	3	145.8	131.0	500	0.3730	0.0403	-0.0017
20904	Asahi2	3	139.5	132.7	800	0.3807	-0.3106	-0.2792
21003	Satomi	3	173.7	134.7	600	0.3420	-0.0218	-0.2724
21004	Motogi	3	168.9	133.1	300	0.3467	0.1432	-0.2573
21005	Aioi	3	168.1	130.3	500	0.3466	0.1202	-0.0813
21101	Abashiri	3	174.4	158.7	100	0.3518	-0.1845	-0.4461
21103	E-mokoto	3	176.3	144.1	300	0.3434	-0.0149	-0.4535
21106	Tokusahara	3	183.2	145.8	200	0.3373	0.1082	-0.7589
21200	Satsugen	3	189.7	144.3	200	0.3300	0.1374	-0.1024
21201	Kiyosato2	3	192.9	145.7	500	0.3277	0.0710	-0.3595
21302	Koshikawa	3	197.1	151.1	250	0.3271	-0.2118	-0.1393
40101	Ozawa	6	38.6	91.2	300	0.5483	-0.0677	0.0782
40102	Tomari	6	31.2	96.9	400	0.5546	0.4025	0.1920
40103	Kamuenai	6	28.6	101.0	300	0.5542	-0.0394	-0.3677
40201	Kucchan	6	43.0	90.2	500	0.5417	-0.1076	-0.4426
40202	Kyogoku	6	49.4	88.2	800	0.5325	0.4227	-0.1863
40203	Rusutsu	6	52.1	74.5	500	0.5399	-0.0852	0.1286
40204	Kimobetsu	6	54.4	80.9	600	0.5300	-0.1120	0.0920
40205	Futaba	6	57.3	76.9	500	0.5280	-0.1320	-0.0071
40301	Date	6	50.0	62.2	600	0.5550	0.3362	0.3140
40302	Noboribetsu	6	54.2	64.3	500	0.5447	-0.2420	0.2581
40303	Ootaki	6	56.4	72.4	500	0.5335	0.2505	-0.2039
40304	Sobetsu	6	50.0	70.7	500	0.5473	0.2257	-0.1537
40401	Kuromatsunai	8	19.7	69.9	300	0.6061	0.4814	-0.1073
40402	Suttsu	8	18.4	74.2	300	0.6033	0.5445	-0.0997
40403	Nagatoyo	8	16.8	70.0	300	0.6114	0.8131	-0.3097
40404	Motomachi	8	11.3	68.9	900	0.6230	1.0280	-0.2359
40501	Imagane	8	16.2	62.5	400	0.6217	0.1253	0.0830
40502	Hanaishi	8	19.7	65.3	700	0.6116	0.7448	0.0291
40602	E-setana	8	9.3	62.7	500	0.6346	0.6862	-0.1954
40603	Wakamatsu	8	9.9	51.0	200	0.6482	0.8422	0.0085
40604	Futamata	8	4.3	53.1	350	0.6565	0.0507	-0.5805
40702	Yakumo	8	19.5	44.7	400	0.6362	0.6968	-0.1797
40703	Ozeki	8	16.3	51.0	400	0.6353	0.4026	-0.1887
40704	Oshamanbe	8	22.9	63.9	350	0.6071	0.5405	0.2786
40801	Mori	8	33.1	38.3	400	0.6142	0.9372	0.1560
40802	Komagatake	8	40.3	38.4	600	0.5982	0.3288	-0.2445
40803	Rakube	8	28.5	38.3	400	0.6243	0.5987	-0.0274
40804	Nanae	8	43.0	32.7	400	0.5976	0.8632	0.0558
40805	Oono	8	34.1	33.8	550	0.6166	0.1338	-0.1088

40901	Otsube	8	22.2	36.0	200	0.6405	0.5336	-0.3471
40902	Sakaehama	8	19.3	37.7	250	0.6447	0.5142	0.2730
40903	Kumaishi	8	16.3	41.1	450	0.6471	0.2617	0.3721
40904	Taisei	8	8.8	46.0	500	0.6566	0.6317	0.2137
41101	Kaminokuni	8	22.0	23.1	300	0.6553	0.8720	-0.3101
41102	Yunotai	8	25.2	21.4	250	0.6499	0.4549	-0.3762
41103	Shinmyo	8	26.4	20.2	300	0.6485	0.2894	-0.5052
41104	Okuyunotai	8	23.2	15.4	600	0.6611	0.4530	-0.6020
41201	Kikonai	8	29.0	20.7	250	0.6420	1.2780	-0.2699
41202	Yoshibari	8	26.9	16.1	100	0.6517	1.0110	-0.0660
41203	Shiriuchi	8	24.7	11.3	200	0.6620	0.7278	0.0506
41301	Kamiiso	8	33.6	28.2	400	0.6236	0.4241	-0.1417
41302	Moheji	8	32.1	23.4	200	0.6320	0.4006	0.3636

Analysis based on the simplifying assumption of Stenseth *et al.* (1998)

Assuming spring-densities to be mapped on to autumn-densities (as did Stenseth *et al.* 1998), we may approximate the annual model according to:

$$N_t = const \bullet N_{t-1} \bullet \exp[(-a_{s1}x_{t-1} - a_{s2}x_{t-2})\tau] \bullet \exp[(-a_{w1}x_{t-1} - a_{w2}x_{t-2})(1-\tau)] \qquad \text{(I)}$$

where N_t is the density corresponding to x_t [*i.e.*, $x_t = \log(N_t)$], and '*const*' is some scaling parameter of no interest to us in the present context. Note that positive values for the parameters $a_{.1}$ and $a_{.2}$ represent negative (*i.e.*, typical) density-dependence.

Based on equation (I) the annual density-dependencies may be re-parameterised so as to incorporate the seasonal components [direct density dependence during summer (a_{s1}) and during winter (a_{w1}), and delayed density dependence during summer (a_{s2}) and during winter (a_{w2})]:

$$\alpha_1 = 1 - a_{w1} + (a_{w1} - a_{s1})\tau \qquad \text{(II)}$$

$$\alpha_2 = - a_{w2} + (a_{w2} - a_{s2})\tau \qquad \text{(III)}$$

[See Stenseth *et al.* (1998) for derivations].

Simplifying equations (II) and (III) gives:

$$\alpha_1 = c_0 + c_1 \tau \qquad \text{(IV)}$$

$$\alpha_2 = d_0 + d_1 \tau \qquad \text{(V)}$$

We computed τ for a large number of b_2-b_3 combinations and estimated c_0, c_1, d_0 and d_1 for each combination using linear regression, as described in Appendix B. As the optimisation criterion for finding the parameters b_2 and b_3 we have essentially used one of three: either the R^2-product for equations (IV) and (V) or the corresponding average of the R^2's; however, since we really want the overall dependency the former is to be preferred (see supplementary table 3 and figure B2; pubs.royalsoc web-site).

Using equations (II) and (III) we can, through linear regression, obtain the seasonal density-dependent components. We obtain: $a_{w1} = 1 - c_0$, $a_{s1} = 1 - c_1 - c_0$, $a_{w2} = - d_0$ and $a_{s2} = - d_1 - d_0$. The corresponding variances, from which we obtain the standard errors of the estimates, are given as: $\text{var}(a_{w1}) = \text{var}(c_0)$, $\text{var}(a_{s1}) = \text{var}(c_0) + \text{var}(c_1) - 2\text{cov}(c_0,c_1)$, $\text{var}(a_{w2}) = \text{var}(d_0)$, and $\text{var}(a_{s2}) = \text{var}(d_0) + \text{var}(d_1) - 2\text{cov}(d_0,d_1)$.

Supplementary table 2: Estimating the seasonal density-dependent structure from the relationships between the annual density-dependent structure and the relative length of the summer, assuming that the spring densities can be mapped on to the autumn densities. (Apart from this simplifying assumption, this table corresponds to table 2 in the article. Results from the linear regression of α_i on τ, where c_0 and d_0 are the estimated intercepts and c_1 and d_1 the estimated slopes of the regression equations corresponding to equations (IV) and (V) respectively (see, *e.g.*, Sokal & Rohlf 1995). Reported values are from the best model given by the average of the two R^2 values. (When the R^2 product was maximized instead, the estimated values for c_0, c_1, d_0 and d_1 were 0.69, 1.58, -0.54, and 0.74, respectively). Values for a_{wi} and a_{si} (for i = 1,2) were calculated using the relationships described under 'A seasonal model: re-parameterising the annual model and seasonal forcing'. Confidence intervals are based on estimates +/- 1.96 standard errors.)

(1) Direct density dependencies (α_1 regressed on τ).
(Residual error = 0.284; df = 187; R^2 = 0.264; $F_{1,187}$ = 67.23; p = 0; n = 189.)

Parameters	Estimate	S.E.	Lower 95% C.I.	Upper 95% C.I.	*t*-value	*P*-value
c_0	-0.7848	0.1174	-1.015	-0.555	-6.684	0.000

c_1	2.0188	0.2462	1.536	2.501	8.1995	0.000
Predicted seasonal density-dependent structure:						
a_{w1}	1.785	0.117	1.556	2.014	15.256	0.000
a_{s1}	-0.234	0.362	-0.944	0.476	-0.646	0.519

(2) Delayed density dependencies (α_2 regressed on τ).
(Residual error = 0.270 ; $df = 187$; $R^2 = 0.0262$; $F_{1,187} = 5.034$; $p = 0.0260$; $n = 189$.)

Parameters	Estimate	S.E.	Lower 95% C.I.	Upper 95% C.I.	*t*-value	*P*-value
d_0	-0.3879	0.1114	-0.606	-0.170	-3.483	0.0006
d_1	0.524	0.2335	0.066	0.982	2.2437	0.026
Predicted seasonal density-dependent structure:						
a_{w2}	0.388	0.111	0.170	0.606	3.495	0.001
a_{s2}	-0.912	0.344	-1.586	-0.238	-2.651	0.009

Supplementary table 3: Optimum values found for the parameters b_2-b_3 when maximizing the product (left column) and the average (right column) of the R^2 values of the two regressions $\alpha_1 = c_0 + c_0\tau$ and $\alpha_2 = d_0 + d_0\tau$. (See Appendix B for further explanation. The resulting estimates of c_0, c_1, d_0 and d_1 are given in supplementary table 2.)

	Criterion	
	R^2 product	R^2 average
Optimum values of b_0-b_3		
b_0	0.915	0.999
b_1	$-8.01 \cdot 10^{-3}$	$-10.77 \cdot 10^{-3}$
b_2	$6.01 \cdot 10^{-4}$	$-5.99 \cdot 10^{-3}$
b_3	$-1.08 \cdot 10^{-5}$	$4.62 \cdot 10^{-5}$
R^2 for regressions (equations g_{we} and g_{sn})		
	intercept const.	regression coeff.
$\alpha_1 = c_0 + c_0\tau$	0.190	0.260
$\alpha_2 = d_0 + d_0\tau$	0.062	0.026