Timing of resource availability drives divergent social systems and home range dynamics in ecologically similar tree squirrels

Mazzamuto et al.

Supplementary material 1. Conifer seed production and energy contents in the study areas.

SM 1.1 Cone and seed count methodology

ERS

For our sites in the Italian Alps, we counted new (current year) maturing cones in the canopy of sample trees of all conifer species (described in detail in (Salmaso et al. 2009, Di Pierro et al. 2010, Romeo et al. 2010) each year between last week of July – first week of August. Based on species-specific energy values per cone (kJ/cone) and data on tree species composition and density (Salmaso et al. 2009), these counts allowed us to estimate the average yearly tree seed-energy production for the entire study area. Since these procedures are not the main argument of this paper, we refer to Romeo et al. 2010 and Di Pierro et al. 2011 for details.

MGRS

In our Pinaleño Mountains sites, seed production is estimated via seed traps. Seed trap plots (n = 20) are distributed randomly across our monitored areas in both mixed conifer and spruce-fir sites. At each site 3, 0.25 m^2 seed traps are placed within a 10 m x 10 m plot. We constructed traps from window screen, stapled at the corners to form a shallow square tray, and covered with 3/8 inch (0.95 cm) hardware cloth (similar to, formed into a 0.25m x 0.25 m lid by shaping over a wooden form, and then staked into place over each screen bottom to prevent seed removal by rodents and birds. We collected the contents of each trap, representing the previous years' seed fall, annually in June. We then sorted the contents of each trap in the laboratory, where we identify seeds to species (corkbark fir, Douglas-fir, and Engelmann spruce). We counted the number of seeds per trap and averaged across the three traps to obtain an average seed fall estimate for each plot. We then extrapolated the seed fall per m^2 and per hectare for our mixed conifer and spruce-fir sites each year. Based on the seed-specific energy values per seed and per cone (kJ seed, kJ cone; (Miller and Yoder 2009) we estimated the seed energy available to MGRS (kJ hectare $^{-1}$) each year for both forest types.

SM1.2 Seed and cone characteristics of conifers present in the study areas of Eurasian red squirrel (ERS) and Mount Graham red squirrel (MGRS). Energy-contents (kJ) per seed and per cone. From Salmaso et al. 2009; Miller & Yoder 2009; and authors own data.

Alps (ERS)		**Seed-energy**	**Seeds/cone**	**Cone-energy**
Tree species	**Common name**			
Pinus mugo	Mountain pine	0.214 kJ	28	6.0 kJ
Pinus sylvestris	Scots pine	0.227 kJ	33	7.5 kJ
Abies alba	Silver fir	1.187 kJ	123	146 kJ
Picea abies	Norway spruce	0.220 kJ	232	51 kJ
Larix decidua	Larch	0.107 kJ	88	9.4 kJ
Pinus cembra	Arolla pine	1.680 kJ	72	121 kJ
Mt. Graham (MGRS)				
Abies lasiocarpa var *arizonica*	Corkbark fir	0.221 kJ	150	33.1 kJ
Abies concolor	White fir	0.546 kJ	185	101.0 kJ
Pseudotsuga menziesii var *glauca*	Rocky Mt. Douglas fir	0.255 kJ	25	6.4 kJ
Picea engelmannii	Engelmann spruce	0.108 kJ	139	15.0 kJ

Timing of resource availability drives divergent social systems and home range dynamics in ecologically similar tree squirrels

Mazzamuto et al.

SM 1.3 Mean annual conifer seed production across study areas on the Alps (ERS) and on Mt. Graham (MGRS) expressed in kJ/ha. A generalized linear model (GLM) with ln-transformed food-energy availability (ln kJ/ha) as dependent variable indicated that overall, food availability was higher on the Alps than on Mt. Graham (area effect $F_{1, 14} = 25.1$; $p = 0.0002$) but that the year effect was statistically not significant ($F_{22, 14} = 1.31$; $p = 0.30$) despite large annual fluctuations in tree-seed productivity.

Year	Alps	Mt. Graham
1993		765892
1994		138326
1995		1451442
1996		146809
1997		381478
1998		222479
1999	1497338	205750
2000	203788	30712
2001	1667006	1555280
2002	685693	62998
2003	911394	592583
2004	1588809	83251
2005	670766	39616
2006	986890	1014118
2007	1137490	105716
2008	557748	62710
2009	3358447	155423
2010	1580828	320756
2011	2034546	22278
2012	381714	878748
2013	1038604	185322
2014		152474
2015		31632
Mean	1220071	374165
SE	203888	94687

Timing of resource availability drives divergent social systems and home range dynamics in ecologically similar tree squirrels

Mazzamuto et al.

Supplementary material 2. Sample size used to calculate home ranges per area, year, season and sex.

		Mt. Graham, AZ, USA			Alps, Italy		
year	*season*	*n tot*	*M*	*F*	*n tot*	*M*	*F*
2000	breeding	-	-	-	13	8	5
	seed	-	-	-	0	0	0
2002	breeding	0	0	0	0	0	0
	seed	21	7	14	12	8	4
2003	breeding	23	10	13	15	10	5
	seed	17	8	9	15	8	7
2004	breeding	35	18	17	12	6	6
	seed	36	24	12	10	4	6
2005	breeding	47	24	23	5	3	2
	seed	34	15	19	3	1	2
2006	breeding	33	19	14	9	6	3
	seed	21	11	10	11	7	4
2007	breeding	40	22	18	12	7	5
	seed	35	20	15	13	7	6
2008	breeding	31	12	19	5	3	2
	seed	28	10	18	4	3	1
2009	breeding	20	8	12	-	-	-
	seed	15	7	8	-	-	-
2010	breeding	18	8	10	-	-	-
	seed	13	5	8	-	-	-
2011	breeding	25	8	17	-	-	-
	seed	19	6	13	-	-	-
2012	breeding	30	14	16	-	-	-
	seed	25	9	16	-	-	-
2013	breeding	27	12	15	-	-	-
	seed	30	10	20	-	-	-
2014	breeding	24	9	15	-	-	-
	seed	18	9	9	-	-	-
2015	breeding	19	8	11	-	-	-
	seed	20	8	12	-	-	-
2016	breeding	16	8	8	-	-	-
	seed	0	0	0	-	-	-

Timing of resource availability drives divergent social systems and home range dynamics in ecologically similar tree squirrels

Mazzamuto et al.

Supplementary material 3. Core area size analyses and results

SM 3.1 Average core area size (ha, mean ± SD, sample size between brackets) of male and female European red squirrels and Mount Graham red squirrels per season and independent of season (Total).

Period	European Red Squirrel		Mount Graham Red Squirrel	
	Males	Females	Males	Females
Breeding	(43) 19.55 ± 20.44	(28) 9.34 ± 5.11	(181) 6.05 ± 9.55	(209) 3.48 ± 4.88
Seed mature	(38) 14.37 ± 9.70	(30) 7.95 ± 5.57	(150) 2.34 ± 3.29	(183) 3.55 ± 8.36
Total	(81) 17.11 ± 16.42	(58) 8.62 ± 5.35	(331) 4.37 ± 7.62	(392) 3.52 ± 6.72

SM 3.2 LMM for squirrel core-area size (ln transformed). See methods for details.

Parameter	Estimates	t-value (df)	P
Intercept	2.59 ± 0.13	18.9 (79)	<0.0001
Species[1]	-1.13 ± 0.13	8.99 (498)	<0.0001
Sex[2]	-0.50 ± 0.15	3.40 (454)	0.0007
Season[3]	-0.34 ± 0.10	3.54 (605)	0.0004
Species * sex		1.78 (405)	0.076
Species * season		0.87 (599)	0.38
Sex * season		4.70 (561)	<0.0001

[1] ERS held as reference value, [2] Male held as reference value, [3] Breeding season held as reference value. (n = 862).

Overall, ERS used larger core-areas than MGRS and core-area size of males was larger than of females (Tables S4.1 and S4.2). Squirrels used larger core-areas in the breeding than in the seed season but there was a significant sex by season interaction and a nearly significant species by sex interaction (Tables S4.1 and S4.2). The species by sex interaction revealed that males tended to use larger core-areas than females in ERS (DLSM = 0.34 ± 0.14; t_{413} = 2.36; p = 0.087), while there was no difference between the sexes in MGRS (DLSM = 0.05 ± 0.08; t_{301} = 0.63; p = 0.92). Comparing core areas per sex, both male (DLSM = 1.17 ± 0.12; t_{392} = 10.2; p < 0.0001) and female (DLSM 0.88 ± 0.13; t_{427} = 6.93; p < 0.0001) ERS have larger core areas than MGRS. Finally, only male squirrels increased their core area during the breeding season (DLSM breeding vs seed season = 0.39 ± 0.06; t_{593} = 6.37; p < 0.0001) while females do not (DLSM breeding vs seed season = 0.06 ± 0.06; t_{573} = 0.97; p = 0.77). Consequently, males have larger core areas than females in the breeding season (DLSM = 0.36 ± 0.09; t_{468} = 4.04; p = 0.0004) but not in the season of seed caching and consumption (DLSM = 0.03 ± 0.09; t_{491} = 0.34; p = 0.99).

Timing of resource availability drives divergent social systems and home range dynamics in ecologically similar tree squirrels

Mazzamuto et al.

Supplementary Material 4. Core-area overlap analyses

SM 4.1 LMM for ERS core area overlap (squareroot transformed). See methods for details.

Parameter	Estimates	t-value (df)	P
Intercept	0.36 ± 0.13	2.80 (15)	0.0132
FM[1]	1.04 ± 0.1	10.47 (172)	<0.0001
MF[1]	0.46 ± 0.10	4.39 (228)	<0.0001
MM[1]	0.58 ± 0.10	5.53 (228)	<0.0003
Season[2]	0.07 ± 0.11	0.63 (211)	0.53
FM * season_seed[3]	-0.49 ± 0.14	-3.46 (172	0.0007
MF * season_seed[3]	-0.14 ± 0.14	-0.99 (219)	0.32
MM * season_seed[3]	-0.30 ± 0.14	-2.14 (220)	0.034

[1] FF held as reference value, [2] Breeding season held as reference value, [3] Breeding season held as reference value (n = 284).

Pairwise comparisons of 2-factor interactions analysed using the differences of least square means with Tukey p-value adjustment for multiple comparisons.

Contrasts	Estimates	t-value (df)	P
FF,breeding - FM,breeding	-1.04 ± 0.1	-10.47 (172)	<0.0001
FF,breeding - MF,breeding	-0.46 ± 0.11	-4.39 (228)	0.0005
FF,breeding - MM,breeding	-0.58 ± 0.11	-5.53 (228)	<0.0001
FF,breeding - FF,seed	-0.07 ± 0.11	-0.63 (211)	0.998
FM,breeding - MF,breeding	0.58 ± 0.11	5.53 (228)	<0.0001
FM,breeding - MM,breeding	0.46 ± 0.11	4.38 (228)	0.0005
FM,breeding - FM,seed	0.42 ± 0.11	4.03 (209)	0.0020
MF,breeding - MM,breeding	-0.12 ± 0.08	-1.48 (172)	0.817
MF,breeding - MF,seed	0.07 ± 0.09	0.75 (211)	0.995
FF,seed - FM,seed	-0.55 ± 0.1	-5.5 (172)	<0.0001
FF,seed - MF,seed	-0.33 ± 0.11	-2.95 (237)	0.067
FF,seed - MM,seed	-0.29 ± 0.11	-2.58 (238)	0.168
FM,seed - MF,seed	0.23 ± 0.11	2.08 (234)	0.431
FM,seed - MM,seed	0.27 ± 0.11	2.42 (236)	0.237
MF,seed - MM,seed	0.04 ± 0.09	0.44 (173)	1.000

SM 4.2 LMM for MGRS core area overlap (squareroot transformed). See methods for details.

Parameter	Estimates	t-value (df)	P
Intercept	1.208 ± 0.11	11.34 (19)	< 0.0001
FM[1]	-0.09 ± 0.05	-1.98 (1292)	0.0476
MF[1]	-0.23 ± 0.06	-3.73 (816)	0.0002
MM[1]	0.07 ± 0.06	1.1 (816)	0.27
Season[2]	0.01 ± 0.05	0.32 (1414)	0.75
FM * season_seed[3]	0.01 ± 0.07	-0.21 (1292)	0.83
MF * season_seed[3]	0.03 ± 0.07	0.41 (1407)	0.68
MM * season_seed[3]	0.005 ± 0.07	-0.07 (1407)	0.94

[1] FF held as reference value, [2] Breeding season held as reference value, [3] Breeding season held as reference value (n = 1654).

Pairwise comparisons of 2-factor interactions analysed using the differences of least square means with Tukey p-value adjustment for multiple comparisons.

Contrasts	Estimate	t-value (df)	P
FF,breeding - FM,breeding	0.09 ± 0.05	1.98 (1292)	0.494
FF,breeding - MF,breeding	0.23 ± 0.06	3.74 (816)	0.005
FF,breeding - MM,breeding	-0.07 ± 0.06	-1.10 (816)	0.958
FF,breeding - FF,seed	-0.02 ± 0.05	-0.32 (1414)	1
FM,breeding - MF,breeding	0.14 ± 0.06	2.26 (816)	0.318
FM,breeding - MM,breeding	-0.16 ± 0.06	-2.56 (816)	0.171
FM,breeding - FM,seed	0 ± 0.05	-0.03 (1414)	1
MF,breeding - MM,breeding	-0.3 ± 0.05	-5.97 (1292)	< 0.0001
MF,breeding - MF,seed	-0.04 ± 0.05	-0.84 (1407)	0.991
MM,breeding - MM,seed	-0.01 ± 0.05	-0.19 (1407)	0.991
FF,seed - FM,seed	0.11 ± 0.05	2.27 (1292)	0.313
FF,seed - MF,seed	0.2 ± 0.06	3.22 (852)	0.029
FF,seed - MM,seed	-0.06 ± 0.06	-1.003 (852)	0.974
FM,seed - MF,seed	0.1 ± 0.06	1.55 (852)	0.777
FM,seed - MM,seed	-0.17 ± 0.06	-2.67 (852)	0.133
MF,seed - MM,seed	-0.27 ± 0.05	-5.18 (1292)	< 0.0001