Trophic niche of invasive murid rodents in urban areas in South Africa: insights from stable isotope analysis

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Supplementary material

Effect of tissue type on isotopic niche

Tissue type had a statistically significant effect on the mean $\delta^{15}N$ and $\delta^{13}C$ values of the three *Rattus* species across the four sampled localities (Table S1). Muscle tissue was the most $\delta^{15}N$-enriched relative to other tissues for *R. norvegicus*, in contrast, to liver tissue *R. rattus* and *R. tanezumi*. Hair tissue was the most $\delta^{13}C$-enriched relative to other tissues.

Table S1: Stable isotopes of nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) values of different tissues (hair, liver muscle) and estimates of isotopic niche area (sample size-corrected standard ellipse area [SEAc]) of *Rattus norvegicus*, *R. rattus* and *R. tanezumi* urban and peri-urban areas of Gauteng Province, South Africa.

Species	site	Tissue type	$\delta^{15}N$	$\delta^{13}C$
Rattus norvegicus	Alexandra Township	Liver	6.9‰ ± 0.5	-16.9‰ ± 1.0
		Muscle	7.1‰ ± 0.5	-15.6‰ ± 1.0
		Hair	6.5‰ ± 0.6	-15.2‰ ± 1.0
	Tembisa Township	Liver	6.6‰ ± 0.7	-16.7‰ ± 1.3
		Muscle	6.9‰ ± 0.7	-16.3‰ ± 1.1
		Hair	6.8‰ ± 0.6	-14.8‰ ± 1.1
Rattus rattus	UP Experimental Farm	Liver	9.0‰ ± 0.7	-14.9‰ ± 0.8
		Muscle	8.3‰ ± 0.6	-14.5‰ ± 1.0
		Hair	8.3‰ ± 0.5	-13.4‰ ± 1.7
Rattus tanezumi	Hammanskraal	Liver	7.0‰ ± 1.6	-17.7‰ ± 3.1
		Muscle	8.6‰ ± 1.8	-19.2‰ ± 2.3
		Hair	7.0‰ ± 0.7	-19.4‰ ± 2.2

Table S2: Test for significant differences of stable isotopes of nitrogen ($\delta^{15}N$) and carbon ($\delta^{13}C$) values based on sex, age and season for populations of *Rattus norvegicus* from Alexandra and Tembisa Townships, *R. rattus* from the University of Pretoria Experimental Farm, and *R. tanezumi* from Hammanskraal Township in Gauteng Province, South Africa.

R. norvegicus (Alexandra)

```
-- ANOVA for N ---
model_Nitrogen <- aov(N ~ Sex * Age, data = df)
summary(model_Nitrogen)
            Df Sum Sq Mean Sq F value  Pr(>F)
Sex          1  0.396  0.3957   1.462 0.23012
Age          2  3.615  1.8077   6.677 0.00205 **
Sex:Age      2  0.403  0.2016   0.745 0.47798
Residuals   83 22.469  0.2707
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

# --- ANOVA for C ---
model_Carbon <- aov(C ~ Sex * Age, data = df)
summary(model_Carbon)
            Df Sum Sq Mean Sq F value Pr(>F)
Sex          1   0.63   0.629   0.616 0.4349
Age          2   6.65   3.327   3.258 0.0435 *
Sex:Age      2   2.53   1.265   1.239 0.2950
Residuals   83  84.78   1.021
```

R. norvegicus (Tembisa)

```
model_Nitrogen <- aov(N ~ Sex * Age * Season, data = df)
summary(model_Nitrogen)
               Df Sum Sq Mean Sq F value Pr(>F)
Sex             1  1.638  1.6381   4.159 0.0548 .
Age             2  0.089  0.0447   0.114 0.8932
Season          1  0.137  0.1369   0.348 0.5620
Sex:Age         2  0.122  0.0610   0.155 0.8574
Sex:Season      1  0.064  0.0644   0.164 0.6902
Age:Season      1  0.010  0.0100   0.025 0.8748
Sex:Age:Season  1  0.192  0.1918   0.487 0.4933
Residuals      20  7.877  0.3938
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

# --- ANOVA for C ---
model_Carbon <- aov(C ~ Sex * Age * Season, data = df)
summary(model_Carbon)
               Df Sum Sq Mean Sq F value Pr(>F)
Sex             1  8.541   8.541   7.003 0.0155 *
Age             2  3.086   1.543   1.265 0.3039
Season          1  0.229   0.229   0.188 0.6693
Sex:Age         2  1.852   0.926   0.759 0.4811
Sex:Season      1  0.176   0.176   0.144 0.7080
Age:Season      1  0.004   0.004   0.003 0.9571
Sex:Age:Season  1  0.058   0.058   0.048 0.8290
```

```
Residuals       20 24.395   1.220
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Rattus rattus (UP Experimental Farm)

```
model_Nitrogen <- aov(N ~ Sex * Age * Season, data = df)
> summary(model_Nitrogen)
            Df Sum Sq Mean Sq F value Pr(>F)
Sex          1  1.360  1.3600   6.069 0.0255 *
Age          2  1.306  0.6531   2.914 0.0833 .
Season       1  0.269  0.2691   1.201 0.2893
Sex:Age      2  0.789  0.3947   1.761 0.2035
Age:Season   2  0.084  0.0420   0.188 0.8308
Residuals   16  3.586  0.2241
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> # --- ANOVA for C ---
> model_Carbon <- aov(C ~ Sex * Age * Season, data = df)
> summary(model_Carbon)
            Df Sum Sq Mean Sq F value Pr(>F)
Sex          1   4.57   4.571   1.249  0.280
Age          2   1.73   0.867   0.237  0.792
Season       1   1.51   1.509   0.412  0.530
Sex:Age      2   0.54   0.269   0.073  0.930
Age:Season   2   0.32   0.159   0.043  0.958
Residuals   16  58.56   3.660
```

R. tanezumi (Hammanskraal)

```
# --- ANOVA for N ---
> model_Nitrogen <- aov(N ~ Sex * Age * Season, data = df)
> summary(model_Nitrogen)
            Df Sum Sq Mean Sq F value Pr(>F)
Sex          1  6.147   6.147   7.137  0.116
Age          2 12.470   6.235   7.239  0.121
Season       2  3.126   1.563   1.815  0.355
Sex:Age      2  1.014   0.507   0.589  0.629
Residuals    2  1.722   0.861
> # --- ANOVA for C ---
> model_Carbon <- aov(C ~ Sex * Age * Season, data = df)
> summary(model_Carbon)
            Df Sum Sq Mean Sq F value Pr(>F)
Sex          1  17.06  17.056   2.247  0.273
Age          2  24.48  12.242   1.613  0.383
Season       2   7.77   3.883   0.512  0.662
Sex:Age      2  32.58  16.289   2.146  0.318
Residuals    2  15.18   7.590
```

Table S3: Stable isotope values ($\delta^{15}N$ and $\delta^{13}C$) of *Rattus norvegicus* and *R. rattus* with reference to sex, age, and season sampled from Alexandra and Tembisa Townships, and the University of Pretoria (UP) Experimental Farm, Gauteng Province, South Africa.

Rat ID	Species	Tissue	Sex	Age	Season	Location	N	C
3	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.6	-15.46
4	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.74	-14.99
6	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.31	-14.02
8	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.62	-16.12
9	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	7.92	-14.61
12	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.18	-16.5
16	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.28	-14.89
20	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	6.02	-16.23
21	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.77	-13.72
26	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	7.51	-15.3
28	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.64	-13.87
30	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	5.76	-16.49
31	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.66	-17.43
35	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	6.2	-17.1
36	R. norvegicus	Hair	Male	Juvenile	Winter	Alexandra	5.96	-13.45
47	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	5.81	-15.94
48	R. norvegicus	Hair	Female	Subadult	Winter	Alexandra	6.3	-17
49	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.57	-14.66
55	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.5	-16
57	R. norvegicus	Hair	Female	Subadult	Winter	Alexandra	6.4	-13.8
60	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	5.82	-14.24
61	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	6.5	-15
62	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	6.7	-13.9
64	R. norvegicus	Hair	Male	Juvenile	Winter	Alexandra	7.16	-14.59
65	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.79	-14.19
66	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	6.1	-15.1
67	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.2	-14.6
68	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.3	-15.76
70	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.25	-14.96
71	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.23	-15.55
74	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.75	-13.42
75	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	5.98	-17.02
86	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	7.45	-14.06
89	R. norvegicus	Hair	Female	Subadult	Winter	Alexandra	5.8	-16.1
91	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.02	-16.62
92	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.57	-15.43
94	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	7.03	-15.39
100	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.69	-14.12
102	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.59	-16.91
103	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.45	-14.26
105	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.74	-15.69
106	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	7.05	-15.57

Rat ID	Species	Tissue	Sex	Age	Season	Location	N	C
109	R. norvegicus	Hair	Female	Subadult	Winter	Alexandra	6.5	-14.5
110	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	6.2	-14.7
111	R. norvegicus	Hair	Female	Subadult	Winter	Alexandra	6.4	-14.9
112	R. norvegicus	Hair	Male	Juvenile	Winter	Alexandra	8.25	-13.92
113	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	6.4	-14.2
114	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	6.91	-16.29
115	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	6.1	-14.2
119	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.2	-15.95
120	R. norvegicus	Hair	Female	Subadult	Winter	Alexandra	5.75	-15.88
121	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.66	-16.92
122	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	5.71	-14.72
126	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.47	-14.08
128	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.29	-15.25
129	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.51	-15.88
130	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.24	-14.59
145	R. norvegicus	Hair	Female	Subadult	Winter	Alexandra	5.39	-16.16
146	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	5.75	-15.24
153	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.31	-14.48
157	R. norvegicus	Hair	Female	Subadult	Winter	Alexandra	5.67	-16.16
168	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.58	-13.81
178	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.92	-15.9
184	R. norvegicus	Hair	Female	Subadult	Winter	Alexandra	6	-14.9
185	R. norvegicus	Hair	Female	Juvenile	Winter	Alexandra	7.39	-13.4
190	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	7.62	-16.7
197	R. norvegicus	Hair	Female	Subadult	Winter	Alexandra	6.84	-14.06
198	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.53	-16.64
202	R. norvegicus	Hair	Female	Juvenile	Winter	Alexandra	6.64	-14.96
205	R. norvegicus	Hair	Female	Juvenile	Winter	Alexandra	6.5	-15.2
211	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.44	-15.56
214	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.95	-15.19
215	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	5.8	-16.27
217	R. norvegicus	Hair	Female	Adult	Winter	Alexandra	6.07	-15.65
220	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	6.74	-16.76
223	R. norvegicus	Hair	Female	Subadult	Winter	Alexandra	5.97	-15.93
229	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	7.49	-14.37
236	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.51	-15.88
241	R. norvegicus	Hair	Male	Adult	Winter	Alexandra	6.66	-14.91
249	R. norvegicus	Hair	Female	Subadult	Winter	Alexandra	6.84	-14.93
257	R. norvegicus	Hair	Female	Juvenile	Winter	Alexandra	6.38	-16.4
263	R. norvegicus	Hair	Male	Juvenile	Winter	Alexandra	6.2	-14.9
266	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	6.04	-15.9
268	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	6.11	-15.44
270	R. norvegicus	Hair	Female	Subadult	Winter	Alexandra	6.28	-14.11
271	R. norvegicus	Hair	Male	Juvenile	Winter	Alexandra	8.6	-12.5
279	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	6.65	-13.94
280	R. norvegicus	Hair	Female	Subadult	Winter	Alexandra	6.79	-14.5
281	R. norvegicus	Hair	Male	Subadult	Winter	Alexandra	6	-15.2

Rat ID	Species	Tissue	Sex	Age	Season	Location	N	C
27	R. norvegicus	Hair	Male	Subadult	Summer	Tembisa	6.7	-15.79
28	R. norvegicus	Hair	Male	Adult	Summer	Tembisa	6.68	-15.66
29	R. norvegicus	Hair	Male	Juvenile	Summer	Tembisa	6.66	-16.44
30	R. norvegicus	Hair	Male	Juvenile	Summer	Tembisa	6.76	-16.54
31	R. norvegicus	Hair	Male	Juvenile	Summer	Tembisa	6.74	-16.7
40	R. norvegicus	Hair	Female	Adult	Summer	Tembisa	6.43	-13.87
41	R. norvegicus	Hair	Female	Adult	Summer	Tembisa	7.05	-13.36
42	R. norvegicus	Hair	Female	Adult	Summer	Tembisa	5.83	-17.1
43	R. norvegicus	Hair	Male	Adult	Summer	Tembisa	8.55	-16.15
44	R. norvegicus	Hair	Female	Subadult	Summer	Tembisa	6.68	-13.2
45	R. norvegicus	Hair	Female	Adult	Summer	Tembisa	6.26	-14.09
46	R. norvegicus	Hair	Male	Adult	Summer	Tembisa	6.41	-13.84
47	R. norvegicus	Hair	Female	Adult	Summer	Tembisa	6.09	-15.37
48	R. norvegicus	Hair	Female	Juvenile	Summer	Tembisa	6.59	-14.76
49	R. norvegicus	Hair	Female	Adult	Summer	Tembisa	6.6	-12.06
50	R. norvegicus	Hair	Male	Adult	Summer	Tembisa	7.08	-14.33
52	R. norvegicus	Hair	Female	Subadult	Summer	Tembisa	6.79	-13.97
54	R. norvegicus	Hair	Female	Adult	Summer	Tembisa	7.71	-14.3
55	R. norvegicus	Hair	Male	Juvenile	Summer	Tembisa	7.18	-14.28
59	R. norvegicus	Hair	Female	Adult	Summer	Tembisa	6.19	-14.72
71	R. norvegicus	Hair	Female	Subadult	Autumn	Tembisa	6.03	-13.59
72	R. norvegicus	Hair	Male	Subadult	Autumn	Tembisa	6.37	-15.49
73	R. norvegicus	Hair	Female	Subadult	Autumn	Tembisa	6.42	-14.01
74	R. norvegicus	Hair	Male	Adult	Autumn	Tembisa	7.32	-14.77
75	R. norvegicus	Hair	Male	Adult	Autumn	Tembisa	7.32	-14.83
76	R. norvegicus	Hair	Male	Adult	Autumn	Tembisa	7.49	-14.7
77	R. norvegicus	Hair	Male	Subadult	Autumn	Tembisa	7.63	-15.1
78	R. norvegicus	Hair	Female	Adult	Autumn	Tembisa	6.37	-14.38
79	R. norvegicus	Hair	Male	Adult	Autumn	Tembisa	6	-15.6
80	R. norvegicus	Hair	Male	Adult	Autumn	Tembisa	6.65	-14.07
6	R. rattus	Hair	Male	Adult	Summer	UP Experimental Farm	7.923448372	-12.70715537
7	R. rattus	Hair	Female	Juvenile	Summer	UP Experimental Farm	8.057799283	-13.28685987
8	R. rattus	Hair	Male	Juvenile	Summer	UP Experimental Farm	8.104375044	-13.33432954
9	R. rattus	Hair	Male	Juvenile	Summer	UP Experimental Farm	8.294526547	-13.45909471
11	R. rattus	Hair	Male	Subadult	Autumn	UP Experimental Farm	7.750261246	-13.7572488
12	R. rattus	Hair	Male	Juvenile	Summer	UP Experimental Farm	8.832683318	-14.10597729
13	R. rattus	Hair	Female	Adult	Summer	UP Experimental Farm	9.277380912	-11.89306633
14	R. rattus	Hair	Male	Juvenile	Autumn	UP Experimental Farm	8.418178988	-13.38344696
16	R. rattus	Hair	Male	Adult	Summer	UP Experimental Farm	7.608434615	-13.90261698
17	R. rattus	Hair	Male	Juvenile	Winter	UP Experimental Farm	8.067537826	-14.97348032
19	R. rattus	Hair	Female	Juvenile	Summer	UP Experimental Farm	8.906211167	-13.33150122
20	R. rattus	Hair	Male	Juvenile	Autumn	UP Experimental Farm	7.971246363	-12.89017486
21	R. rattus	Hair	Male	Juvenile	Autumn	UP Experimental Farm	8.408476007	-13.49740637
23	R. rattus	Hair	Male	Adult	Summer	UP Experimental Farm	7.299455615	-14.24779921
24	R. rattus	Hair	Female	Adult	Summer	UP Experimental Farm	9.131426454	-11.61526971
25	R. rattus	Hair	Female	Adult	Summer	UP Experimental Farm	7.618712694	-13.2040382
26	R. rattus	Hair	Male	Adult	Autumn	UP Experimental Farm	7.358407354	-13.36936456

Rat ID	Species	Tissue	Sex	Age	Season	Location	N	C
61	R. rattus	Hair	Male	Subadult	Summer	UP Experimental Farm	7.890026189	-20.76329062
63	R. rattus	Hair	Male	Subadult	Summer	UP Experimental Farm	8.163411295	-13.05427279
64	R. rattus	Hair	Male	Subadult	Summer	UP Experimental Farm	8.450732025	-12.02394335
65	R. rattus	Hair	Male	Subadult	Autumn	UP Experimental Farm	7.878664556	-14.22573274
66	R. rattus	Hair	Male	Subadult	Autumn	UP Experimental Farm	8.082914083	-12.77180668
67	R. rattus	Hair	Female	Adult	Summer	UP Experimental Farm	8.168799682	-13.26539021
68	R. rattus	Hair	Male	Adult	Spring	UP Experimental Farm	8.906680228	-11.8718485
69	R. rattus	Hair	Female	Adult	Summer	UP Experimental Farm	8.318278354	-12.85159608
70	R. rattus	Hair	Male	Subadult	Summer	UP Experimental Farm	8.967661804	-12.0890591
86	R. rattus	Hair	Female	Subadult	Summer	UP Experimental Farm	9.181586317	-13.13993289
81	R. tanezumi	Hair	Male	Juvenile	Autumn	Hammanskraal	7.81	-16.69
4	R. tanezumi	Hair	Female	Adult	Spring	Hammanskraal	7.52	-20.77
3	R. tanezumi	Hair	Male	Adult	Spring	Hammanskraal	5.78	-15.74
57	R. tanezumi	Hair	Female	Adult	Summer	Hammanskraal	7.29	-21.73
58	R. tanezumi	Hair	Female	Adult	Summer	Hammanskraal	6.98	-21.74
35	R. tanezumi	Hair	Female	Juvenile	Summer	Hammanskraal	10.98	-15.87
56	R. tanezumi	Hair	Female	Sub-adult	Summer	Hammanskraal	5.96	-15.62
18	R. tanezumi	Hair	Male	Juvenile	Summer	Hammanskraal	7.23	-20.92
1	R. tanezumi	Hair	Male	Adult	Winter	Hammanskraal	6.67	-16.32
2	R. tanezumi	Hair	Male	Sub-adult	Winter	Hammanskraal	6.52	-12.09
82	R. tanezumi	Hair	Male	Sub-adult	Winter	Hammanskraal	4.69	-17.6