

Seasonal, annual and decadal change in tadpole populations in tropical Australian streams

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Abstract. Declines due to fungal disease (chytridiomycosis) have affected many stream-dwelling frog species, especially in the tropics, leading to reduced abundance and diversity of their tadpoles. Studies in the Australian Wet Tropics have demonstrated that some frog species have declined or disappeared, while others have persisted. To assess the occurrence of stream-breeding frogs, we monitored tadpole populations of five frog species in Wet Tropics streams in the early 1990s (uplands, before chytridiomycosis emergence), and in 2011–2013 (uplands and lowlands, after chytridiomycosis emergence), and investigated environmental factors that might influence tadpole abundance. Riffle-dwelling tadpoles of two frog species disappeared from the upland stream site during the 1990s, reflecting reported losses of adult populations. Tadpoles of one upland pool species initially declined but had recovered by 2011–2013. Samples from the lowlands in 2011 to 2013 indicated no similar loss. Chytridiomycosis was the likely cause of changes in tadpole abundances between the two survey periods, given its known occurrence and documented effects on adult frogs in these systems; however, we did not measure its prevalence in this study. Tadpole populations fluctuated seasonally, with abundances highest in spring and summer, reflecting the timing of frog reproduction. The most important biophysical influence on the assemblages that we measured was current velocity. Tadpole peak abundances suggest that they make a substantial contribution at the consumer level of food webs, and that their loss has altered food webs substantially in upland streams.

Keywords: amphibian decline, chytridiomycosis, *Litoria*, *Mixophyes*, recovery, seasonal abundance, wet tropics.

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Supplementary material

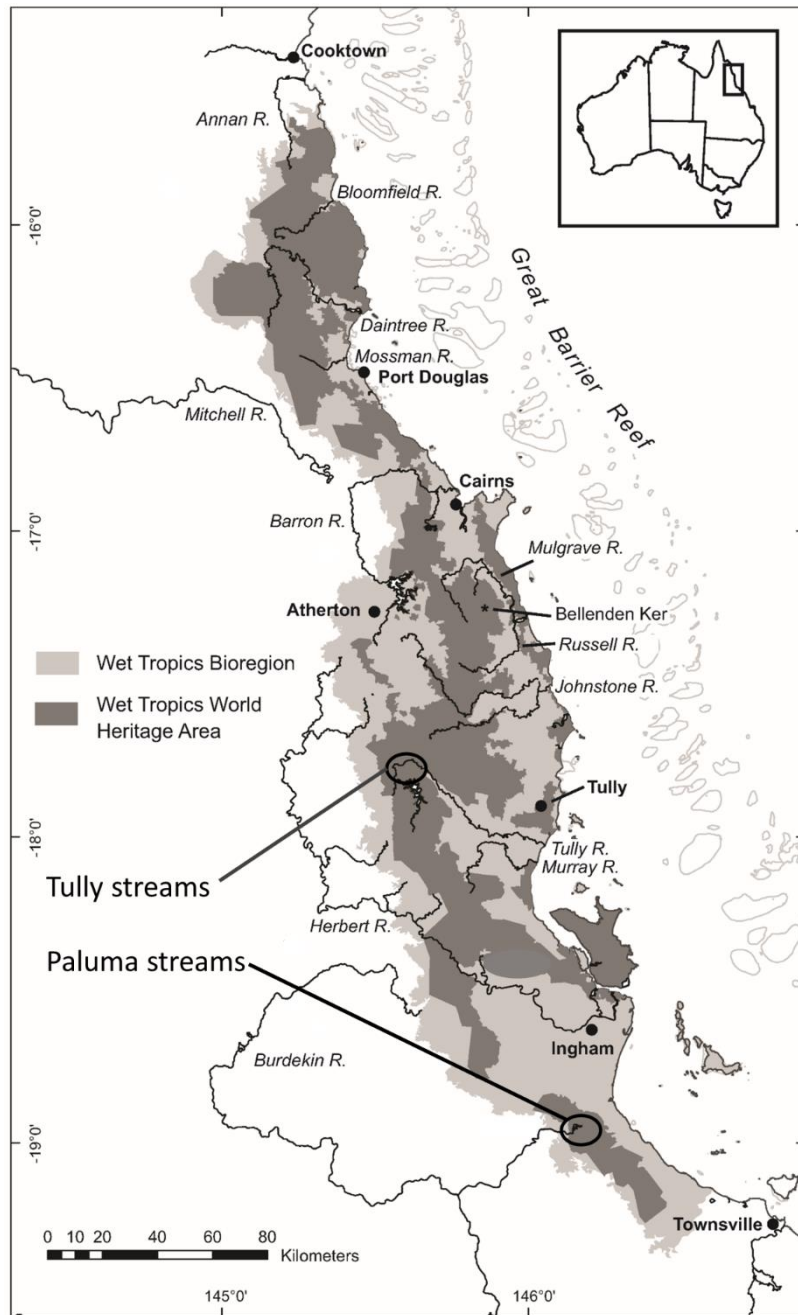


Figure S1. Location of study streams in the Queensland Wet Tropics.

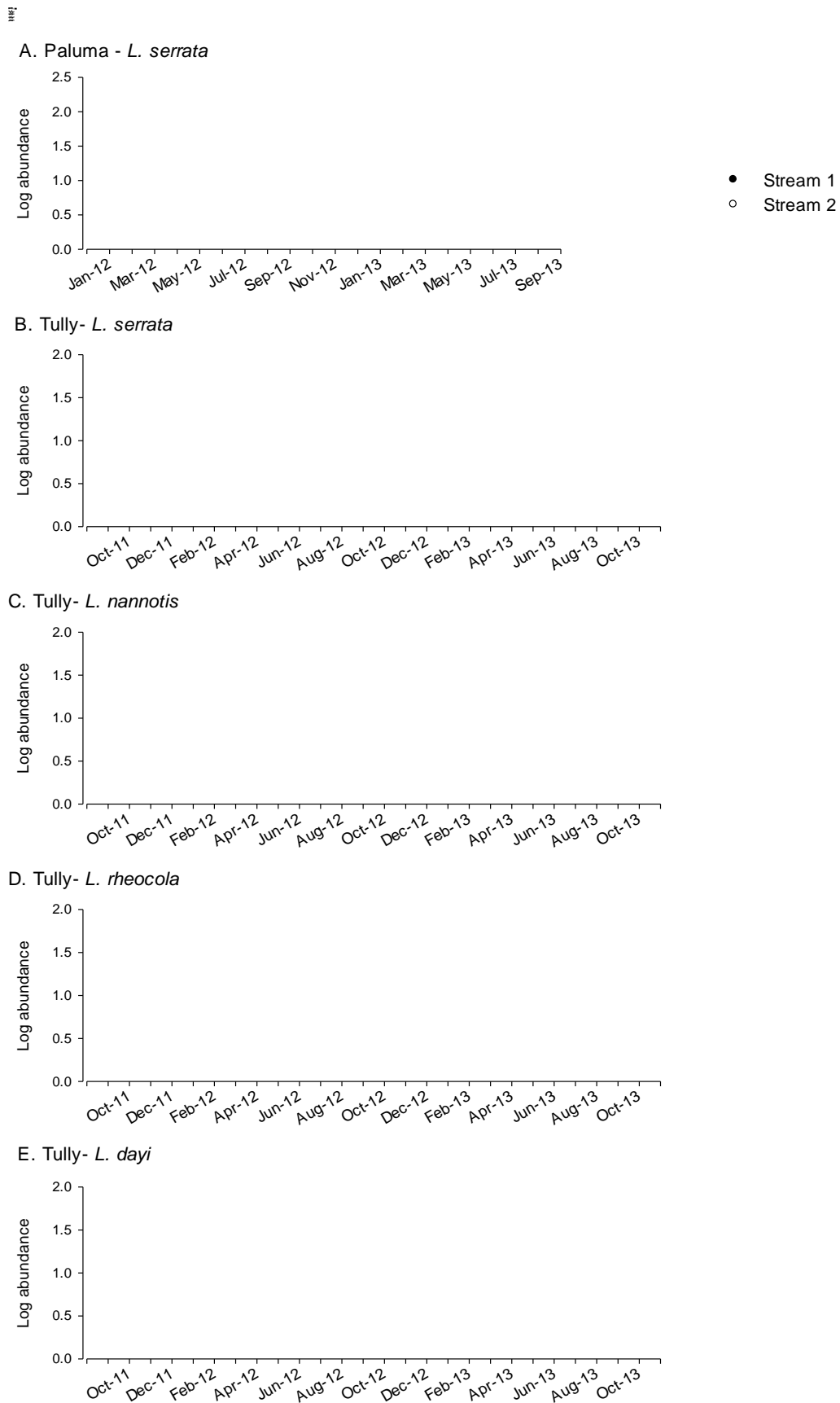


Figure S2. Tadpole abundances in Birthday Creek (Stream 1) and Camp Creek (Stream 2) at Paluma for (A) *Litoria serrata*, and Streams 1 and 2 at Tully for (B) *L. serrata*, (C) *L. nannotis*, (D) *L. rheocola* and (E) *L. dayi*.

Table S1. Characteristics of tadpoles of five frog species recorded in this study (based on Anstis, 2013*). Total length and body length are maxima, recorded at the Gosner developmental stage indicated. ✓ indicates feature recorded by Anstis (2013).

Species	Common name	Length (mm)		Gosner stage	Dorsal view depressed?	Lateral view	Oral disc suctorial?	Tooth row formula	Behaviour	Habitat	Food
		Total	Body								
<i>Litoria dayi</i>	Australian lace-lid	36	15	35	✓	Stream-lined	✓	2/3	Powerful swimmers, benthic	Rapids	Algae, sediments
<i>L. nannotis</i>	Waterfall frog	62	24	38	✓	Stream-lined	✓	2/3	Powerful swimmers, benthic	Rapids, runs	Algae
<i>L. rheocola</i>	Common mist frog	50	18	35–41	✓	Stream-lined	✓	2/3	Powerful swimmers, benthic	Rapids, pools	Algae
<i>L. serrata</i>	Green-eyed tree frog	41	15	37		Rounded snout		2(2)/3(1)	Benthic	Pools	Algae, sediments
<i>Myxophyes coggeri</i>	Mottled barred frog	92	33	40		Rounded snout; stream-lined	✓	5–7(2–6)/3)1)	Strong swimmers, benthic	Pools, riffles	Algae, detritus

*Anstis, M. (2013): Tadpoles and Frogs of Australia. New Holland Publishers, Australia. 832 pp.

Table S2. First 20 models in the model sets for tadpoles of each species at each site.

Intercept	algal cover	canopy cover	log(flow rate)	litter cover	log(14 day rainfall)	log(1 day rainfall)	log(3 day rainfall)	log(7 day rainfall)	Water temperature	d.f.	Log likelihood	AICc	delta	weight
Paluma <i>L. serrata</i>, top 14 models averaged														
0.505	–	–0.006	–17.300	–	–	–	–	–	0.156	5	–310.183	631.135	0	0.113
–0.166	–	–	–15.966	–	–	–	–	–	0.170	4	–311.572	631.650	0.514	0.087
0.505	–	–0.006	–16.021	0.004	–	–	–	–	0.142	6	–309.524	632.138	1.003	0.068
0.616	–	–0.006	–17.272	–	–	0.191	–	–	0.146	6	–309.960	633.011	1.875	0.044
0.397	–	–0.006	–17.201	–	–0.090	–	–	–	0.169	6	–310.006	633.102	1.967	0.042
–0.239	–	–	–14.849	0.003	–	–	–	–	0.161	5	–311.208	633.186	2.051	0.041
0.331	–	–0.006	–17.294	–	–	–	–	–0.055	0.168	6	–310.116	633.323	2.187	0.038
0.458	–	–0.006	–17.326	–	–	–	–0.028	–	0.160	6	–310.168	633.427	2.292	0.036
0.504	0.002	–0.006	–17.411	–	–	–	–	–	0.156	6	–310.179	633.449	2.314	0.036
–0.048	–	–	–15.948	–	–	0.189	–	–	0.160	5	–311.357	633.483	2.348	0.035
–0.276	–	–	–15.842	–	–0.091	–	–	–	0.183	5	–311.393	633.555	2.419	0.034
–0.349	–	–	–15.950	–	–	–	–	–0.059	0.183	5	–311.495	633.759	2.623	0.030
–0.147	0.008	–	–16.461	–	–	–	–	–	0.169	5	–311.509	633.787	2.652	0.030
–0.159	–	–	–15.966	–	–	–	0.003	–	0.169	5	–311.571	633.912	2.777	0.028
–0.151	–	–	–15.665	–	–0.195	0.384	–	–	0.177	6	–310.747	634.585	3.449	0.020
–0.481	–	–	–15.868	–	–	0.397	–	–0.181	0.190	6	–310.878	634.847	3.711	0.018
–0.132	–	–	–14.887	0.003	–	0.174	–	–	0.153	6	–311.024	635.140	4.004	0.015
–0.338	–	–	–14.756	0.003	–0.086	–	–	–	0.173	6	–311.048	635.187	4.052	0.015
–0.434	–	–	–14.798	0.003	–	–	–	–0.064	0.175	6	–311.115	635.321	4.186	0.014
Tully <i>L. serrata</i>, top 13 models averaged														
1.462	0.020	–	–14.700	–	–	–	–1.044	–	–	5	–123.167	256.775	0	0.133

1.391	0.019	-	-14.911	-	-	-1.296	-	-	-	5	-123.544	257.530	0.754	0.091
0.659	0.021	-	-14.191	0.031	-	-	-1.177	-	-	6	-122.724	258.070	1.295	0.069
1.262	0.022	-	-14.620	-	-	-	-1.272	0.287	-	6	-123.069	258.761	1.985	0.049
1.590	0.020	-	-14.676	-	-0.126	-	-0.959	-	-	6	-123.128	258.879	2.103	0.046
1.468	0.020	-	-14.764	-	-	-0.276	-0.848	-	-	6	-123.141	258.904	2.129	0.046
1.164	0.020	-	-14.732	-	-	-	-1.054	-	0.014	6	-123.157	258.937	2.161	0.045
1.504	0.020	-0.001	-14.719	-	-	-	-1.038	-	-	6	-123.164	258.950	2.174	0.045
0.818	0.019	-	-14.554	0.021	-	-1.379	-	-	-	6	-123.334	259.291	2.515	0.038
1.622	0.018	-	-14.839	-	-0.218	-1.110	-	-	-	6	-123.416	259.454	2.679	0.035
1.526	0.018	-0.003	-14.984	-	-	-1.280	-	-	-	6	-123.512	259.647	2.871	0.032
1.499	0.018	-	-14.939	-	-	-1.179	-	-0.133	-	6	-123.513	259.648	2.872	0.032
1.276	0.019	-	-14.924	-	-	-1.302	-	-	0.006	6	-123.543	259.708	2.933	0.031
1.721	0.018	-	-14.733	-	-	-	-	-0.788	-	5	-125.105	260.651	3.876	0.019
1.730	0.017	-	-14.342	-	-0.671	-	-	-	-	5	-125.253	260.948	4.172	0.016
2.207	-	-	-18.422	-	-	-1.492	-	-	-	4	-126.335	260.963	4.187	0.016
2.410	-	-	-18.740	-	-	-	-1.199	-	-	4	-126.640	261.572	4.797	0.012
2.612	-	-	-17.793	-	-0.482	-1.072	-	-	-	5	-125.796	262.033	5.257	0.010
0.694	0.024	-	-14.030	-	-	-	-	-	-	4	-127.036	262.364	5.588	0.008
0.656	0.017	-	-14.948	-	-	-	-	-0.881	0.056	6	-124.990	262.603	5.828	0.007

Tully *L. dayi*, top 16 models averaged

-1.248	-0.029	-0.011	8.100	-	-	-	-	-0.400	-	6	-121.200	255.023	0	0.109
-1.527	-	-0.011	8.926	-	-	-	-	-0.395	-	5	-122.507	255.454	0.432	0.088
-1.523	-0.027	-0.011	8.262	-	-	-	-0.351	-	-	6	-122.112	256.845	1.823	0.044
29.357	-	-0.011	8.790	-1.234	-	-	-	-0.391	-	6	-122.148	256.918	1.895	0.042
-1.779	-	-0.010	9.036	-	-	-	-0.355	-	-	5	-123.283	257.006	1.984	0.040
-2.204	-	-0.011	9.055	-	-	-	-	-0.429	0.032	6	-122.328	257.278	2.255	0.035
-1.543	-	-0.011	8.964	-	-	-0.064	-	-0.364	-	6	-122.486	257.594	2.571	0.030

-1.569	-	-0.011	8.887	-	0.066	-	-	-0.432	-	6	-122.490	257.602	2.579	0.030
-1.262	-0.026	-0.010	8.283	-	-0.364	-	-	-	-	6	-122.505	257.633	2.610	0.030
-1.526	-	-0.011	8.925	-	-	-	0.004	-0.398	-	6	-122.507	257.635	2.613	0.029
-1.621	-0.027	-0.011	8.316	-	-	-0.364	-	-	-	6	-122.532	257.687	2.664	0.029
-1.511	-	-0.010	9.092	-	-0.374	-	-	-	-	5	-123.642	257.725	2.702	0.028
-1.870	-	-0.010	9.076	-	-	-0.373	-	-	-	5	-123.654	257.750	2.727	0.028
-1.751	-0.026	-0.011	8.094	-	-	-	-	-	-	5	-123.691	257.824	2.801	0.027
-1.998	-	-0.010	8.829	-	-	-	-	-	-	4	-124.836	257.965	2.942	0.025
29.028	-	-0.010	8.901	-1.231	-	-	-0.349	-	-	6	-122.937	258.496	3.473	0.019
-1.616	-	-0.010	9.103	-	-0.167	-	-0.267	-	-	6	-123.133	258.889	3.866	0.016
-2.195	-	-0.011	9.113	-	-	-	-0.373	-	0.019	6	-123.217	259.055	4.033	0.014
-1.595	-	-0.010	9.177	-	-0.246	-0.251	-	-	-	6	-123.255	259.132	4.109	0.014
29.278	-	-0.010	8.940	-1.230	-0.370	-	-	-	-	6	-123.261	259.143	4.121	0.014

Tully *L. nannotis*, model 1 used without averaging

3.817	-0.019	-	3.171	-0.088	-0.526	-	-	-	-	6	-324.470	661.563	0	0.463
3.563	-0.021	-	2.976	-0.088	-	-	-	-0.394	-	6	-325.960	664.542	2.979	0.104
1.825	-0.020	-0.006	3.647	-	-0.538	-	-	-	-	6	-326.198	665.019	3.456	0.082
1.736	-0.022	-0.008	3.499	-	-	-	-	-0.476	-	6	-326.387	665.396	3.833	0.068
-0.013	-0.019	-	3.838	-	-0.615	-	-	-	0.075	6	-326.631	665.885	4.321	0.053
1.518	-0.019	-	3.649	-	-0.541	-	-	-	-	5	-328.188	666.817	5.254	0.033
3.288	-0.020	-0.006	2.863	-0.084	-	-	-	-	-	6	-327.798	668.219	6.656	0.017
1.523	-0.019	-	3.629	-	-0.442	-	-	-0.121	-	6	-328.030	668.683	7.120	0.013
1.529	-0.018	-	3.703	-	-0.607	-	0.096	-	-	6	-328.043	668.709	7.146	0.013
3.240	-0.020	-	2.858	-0.088	-	-0.262	-	-	-	6	-328.116	668.853	7.290	0.012
1.517	-0.019	-	3.646	-	-0.537	-0.007	-	-	-	6	-328.188	668.997	7.434	0.011
3.186	-0.019	-	2.830	-0.091	-	-	-	-	-	5	-329.288	669.018	7.455	0.011
-0.172	-0.020	-	3.617	-	-	-	-	-0.474	0.069	6	-328.291	669.204	7.641	0.010

3.298	-0.020	-	2.821	-0.089	-	-	-0.196	-	-	6	-328.406	669.434	7.871	0.009
1.264	-0.020	-	3.450	-	-	-	-	-0.413	-	5	-329.575	669.592	8.029	0.008
1.332	-0.020	-	3.614	-	-	-	0.368	-0.736	-	6	-328.601	669.824	8.261	0.007
2.327	-0.020	-	2.929	-0.092	-	-	-	-	0.041	6	-328.835	670.292	8.729	0.006
1.946	-	-	4.588	-0.084	-0.595	-	-	-	0.070	6	-328.835	670.293	8.730	0.006
4.798	-0.030	-0.007	-	-0.099	-	-	-	-0.402	-	6	-329.076	670.773	9.210	0.005
3.370	-	-	4.394	-0.083	-0.528	-	-	-	-	5	-330.172	670.786	9.223	0.005

Tully *L. rheocola*, top 9 models averaged

1.118	-	-	-2.327	-	-0.783	-1.999	1.911	-	-	6	-196.577	405.776	0	0.104
0.712	-0.014	-	-3.949	-	-	-1.961	1.420	-	-	6	-196.765	406.152	0.376	0.086
1.148	-0.010	-	-	-	-1.087	-1.931	2.043	-	-	6	-197.216	407.053	1.277	0.055
0.980	-	-	-	-	-0.971	-1.883	1.916	-	-	5	-198.437	407.315	1.539	0.048
1.276	-	-0.006	-	-	-0.974	-1.828	1.890	-	-	6	-197.694	408.011	2.234	0.034
1.454	-0.014	-	-3.144	-	-1.337	-	-	0.978	-	6	-197.737	408.096	2.320	0.033
0.498	-	-	-3.029	-	-	-1.886	1.331	-	-	5	-198.833	408.107	2.330	0.032
0.839	-	-0.007	-3.101	-	-	-1.826	1.300	-	-	6	-197.933	408.489	2.713	0.027
1.086	-	-	-2.631	-	-1.199	-0.728	-	1.265	-	6	-198.015	408.652	2.875	0.025
1.529	-0.015	-0.010	-3.841	-	-	-0.453	-	-	-	6	-198.219	409.060	3.284	0.020
-0.690	-0.017	-0.012	-4.124	-	-	-	-	-	0.098	6	-198.221	409.064	3.288	0.020
1.856	-0.016	-0.010	-3.459	-	-0.411	-	-	-	-	6	-198.302	409.226	3.450	0.018
0.711	-	-	-	0.010	-0.947	-1.884	1.886	-	-	6	-198.320	409.262	3.485	0.018
0.979	-	-	-	-	-1.120	-1.752	1.672	0.280	-	6	-198.344	409.310	3.533	0.018
0.688	-	-	-2.717	-	-	-2.144	1.932	-0.478	-	6	-198.358	409.339	3.562	0.017
0.903	-	-	-	-	-0.971	-1.868	1.904	-	0.004	6	-198.435	409.493	3.716	0.016
1.344	-0.016	-0.011	-3.892	-	-	-	-	-	-	5	-199.568	409.577	3.801	0.016
0.363	-	-	-2.961	0.005	-	-1.883	1.320	-	-	6	-198.804	410.231	4.454	0.011
1.005	-0.012	-	-3.516	-	-	-0.485	-	-	-	5	-199.903	410.246	4.470	0.011

-0.641 -0.015 - -3.326 - -0.470 - - - 0.095 6 -198.823 410.268 4.491 0.011
