Technical Memorandum for Square Lake Monitoring Research (2012)

Prepared by Leif K. Hembre, Ph.D. (Hamline University)

Consultant: Emmons & Olivier Resources, Inc. (EOR)

Client: Carnelian-Marine St. Croix Watershed District

Subconsultant: Hamline University

Background

The monitoring research reported on in this memorandum was done as a follow-up to the 2010 'Square Lake Implementation Plan Refinement' Clean Water Partnership (CWP) study. These data and those from the 2010 CWP study will be compared with data to be collected in 2013-2015 during which a moratorium on the stocking of rainbow trout by the Minnesota Department of Natural Resources is in place.

Methods

Square Lake was sampled once each month from February to September during 2012. On the February and March sampling dates when there was ice cover, whole water column zooplankton net tows were taken from 3 locations (Fig. 1). For the April-September dates, in addition to the whole water column net tows at the 3 sites, incremental samples were taken from four different depths in the water column at the location in the deepest part of the lake (site C in Fig. 1). The purpose of taking incremental samples was to investigate whether the taxonomic composition and abundance of zooplankton differed at different depths. Duplicate samples were collected and analyzed in all cases.

Temperature and dissolved oxygen profiles were also performed at the deepest sampling location on all dates, and secchi depth measurements were made for dates during the open-water season (April-September). Temperature/oxygen data provide information about the stratification pattern in the lake and the size of the *Daphnia pulicaria* habitat/refuge zone at different times of year.

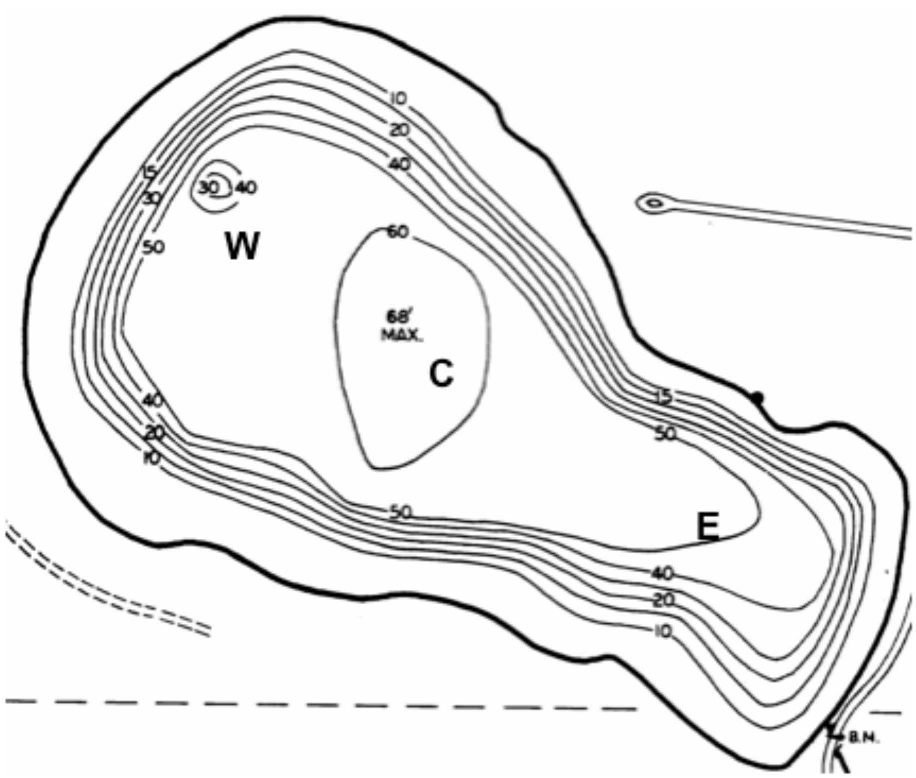


Figure 1. Bathymetric map of Square Lake showing the three sampling locations (W, C, and E).

Results

Environmental conditions

The early spring in 2012 (ice-out in late March) resulted in Square Lake becoming strongly stratified (Fig.2) by mid-May (surface waters ~ 19 ^oC). By early June, there was substantial hypoxia in the deep water (O_2 < 1 mg/L below 12 m). Through the remainder of the summer this region of hypoxia expanded and by the last sampling date (9/6) oxygen levels were less than 1 mg/L at depths beneath 9 m.

On the dates that we sampled Square Lake in 2012, there was relatively little variation in secchi depth. Water clarity was the lowest (3.5 m) on the May 17 sampling date and highest (5.25 m) on September 6 (Fig. 3, top panel). The summer (May-September) average (+/- SD) from our sampling dates was 4.28 +/- 0.67 m. Incorporation of supplemental secchi depth data from the Minnesota Pollution Control Agency (MPCA) database indicates that the changes in water clarity were more dynamic (Fig. 3, bottom panel) than we were able to discern from the monthly sampling events. Notably, there were two peaks in water clarity, one in mid-June and another in late September, when secchi depths greater than 6 m were observed. The summer (May-September) secchi depth average (+/- SD) using all available data was 4.98 +/- 0.69 m.

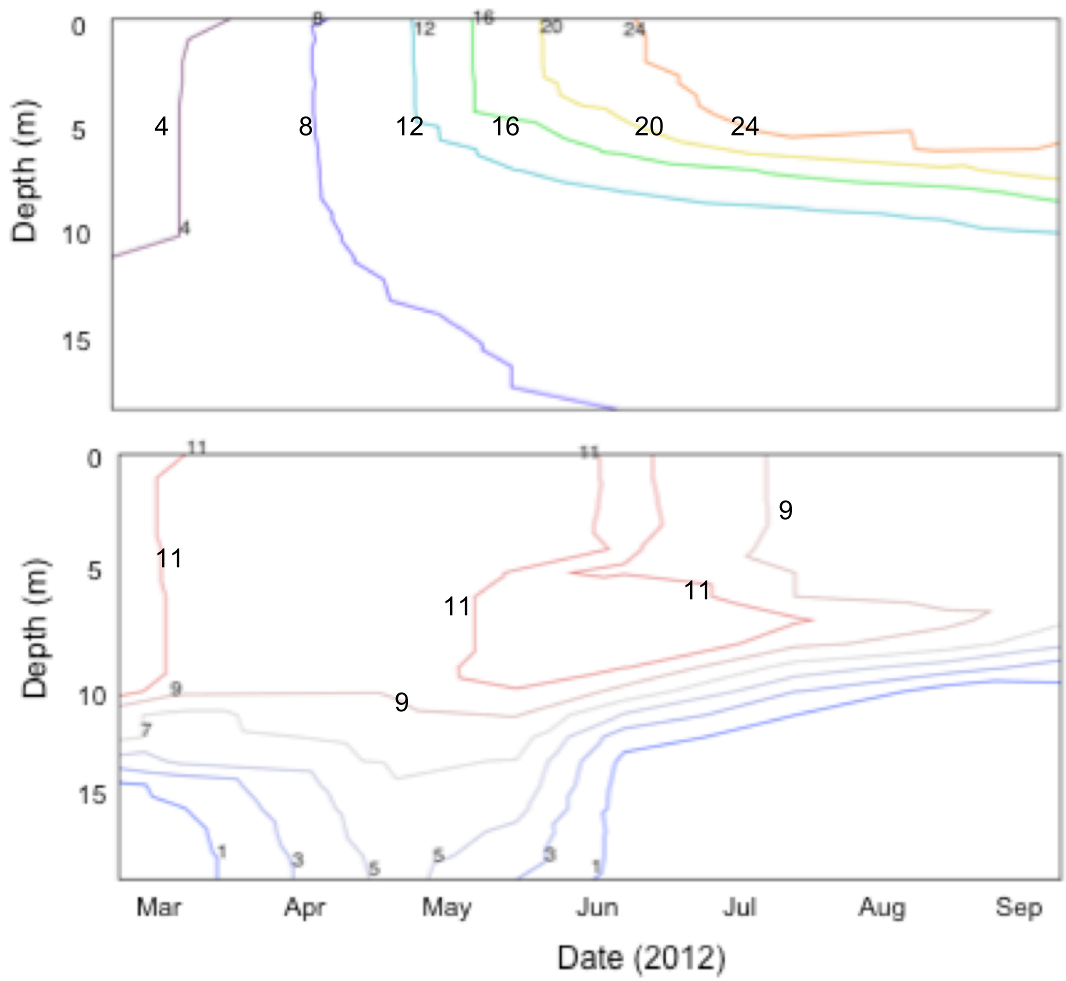


Figure 2. Contour plots of water temperature (top panel) and dissolved oxygen concentration (bottom panel) at different depths from 25 February through 6 September 2012. Contour lines are labeled in °C for temperature and mg/L for dissolved oxygen. See Appendixes II and III for data used to generate these plots.

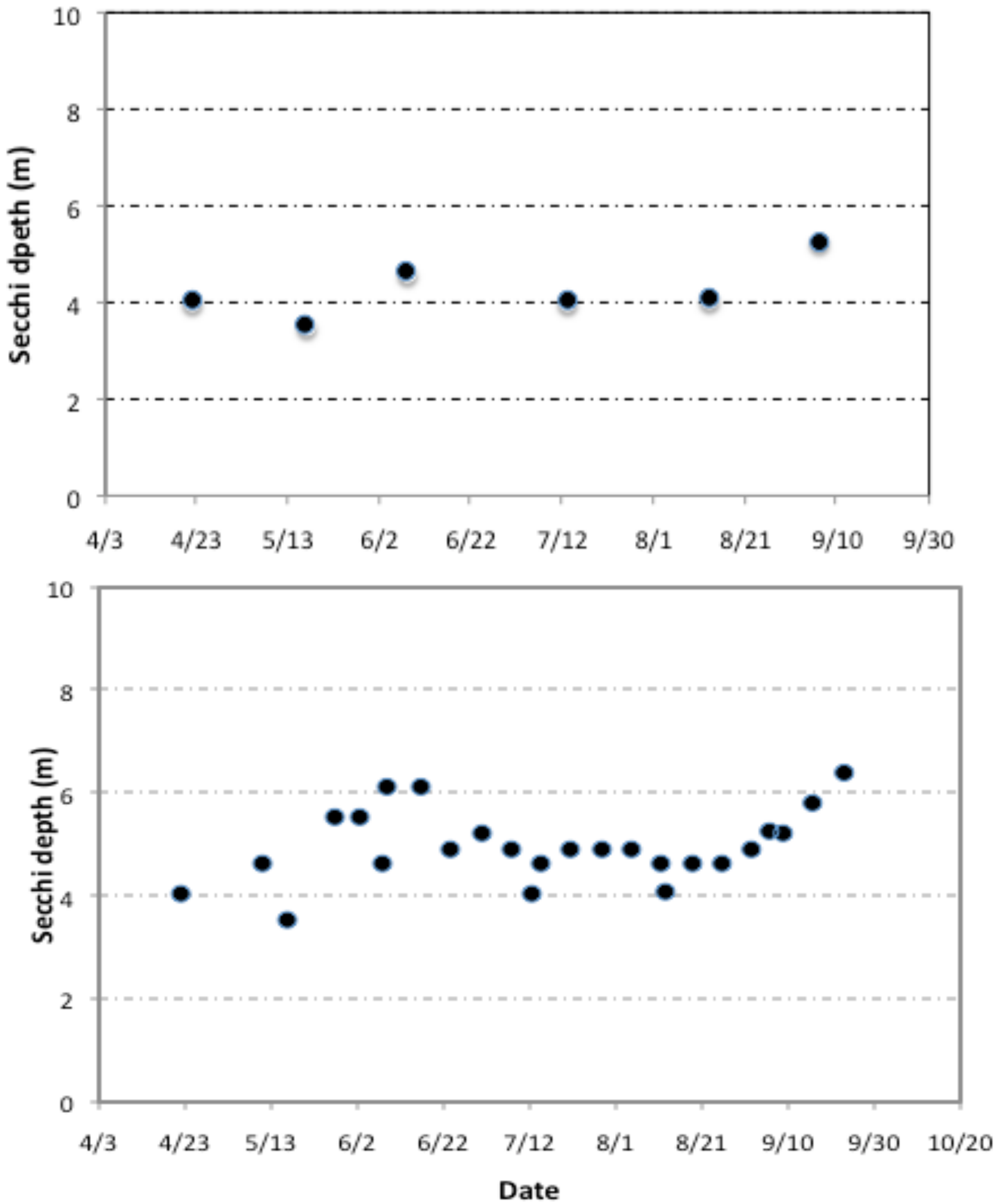


Figure 3. Secchi depth measurements from open-water dates (April-September) in 2012. The top panel of this figure shows the secchi data from the six dates that we sampled the lake, and the bottom panel includes additional data from the MPCA water quality database.

Daphnia pulicaria population dynamics

The population densities of the large-bodied *Daphnia* species (*D. pulicaria*) were near 1 per liter on the winter and spring sampling dates (February-May), and were highest (1.61 +/- 0.26 L^{-1}) on the June 8 sampling date (Fig. 4). By July 13, *D. pulicaria* densities in the water column were quite low (< 0.53 L^{-1}), and bottomed out in August and early September at densities less than 0.15 L^{-1}.

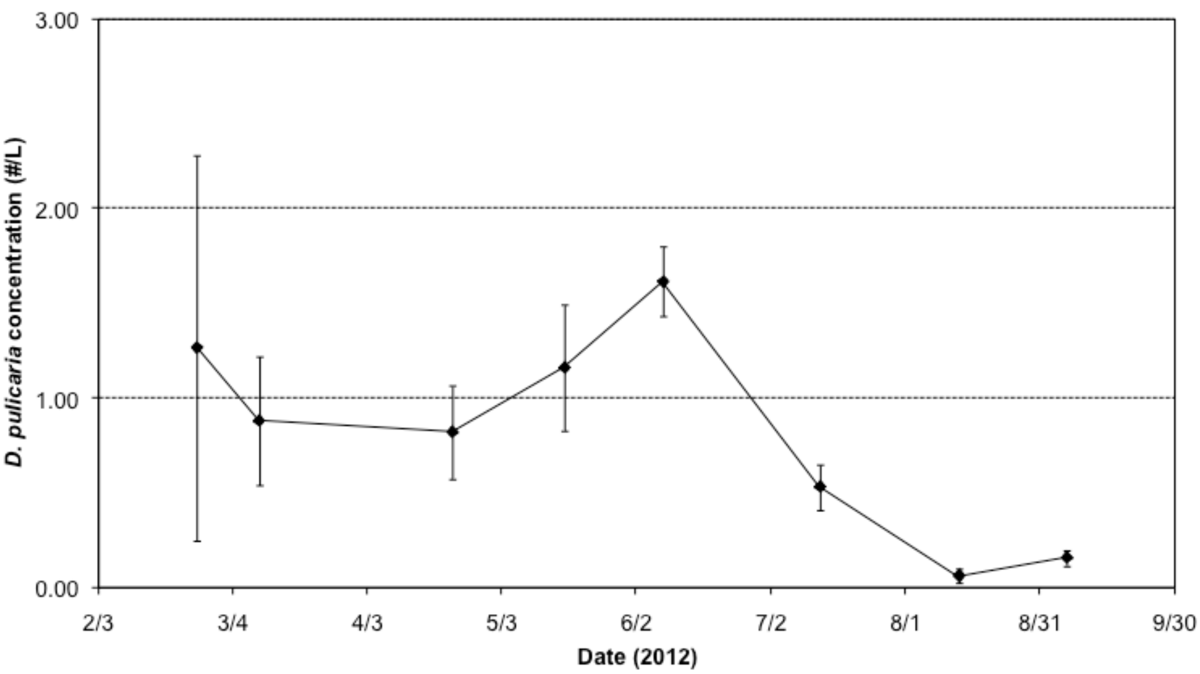


Figure 4. Population dynamics for *Daphnia pulicaria* in 2012. Values are means (+/- SD) calculated from water column net tows from the three sampling locations.

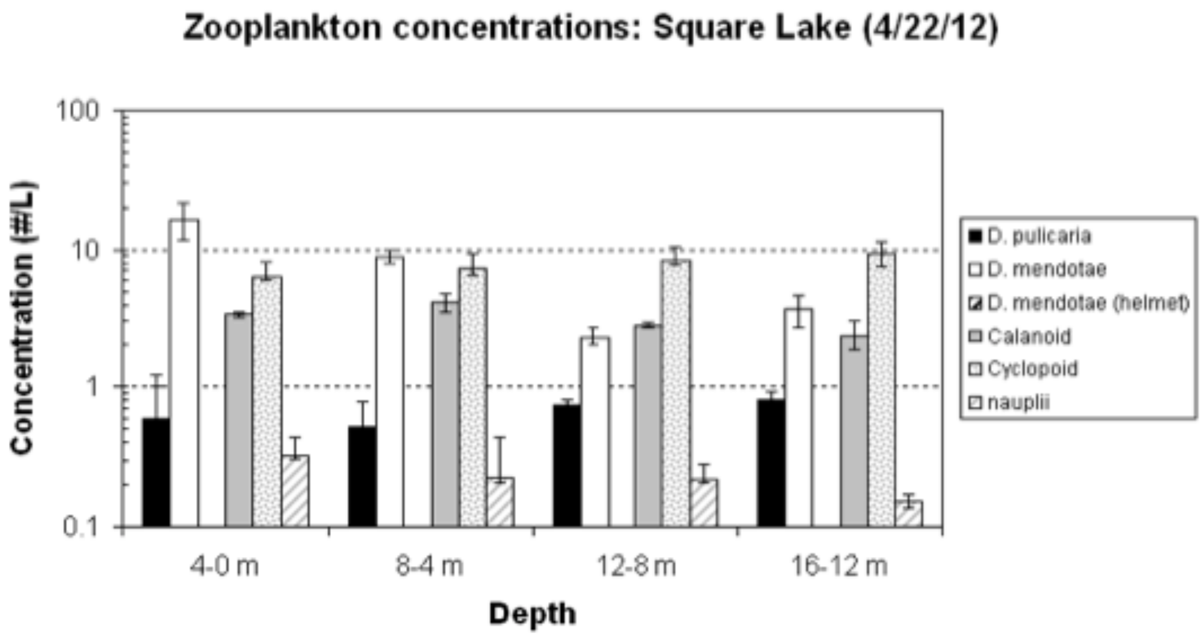
Zooplankton Community Structure

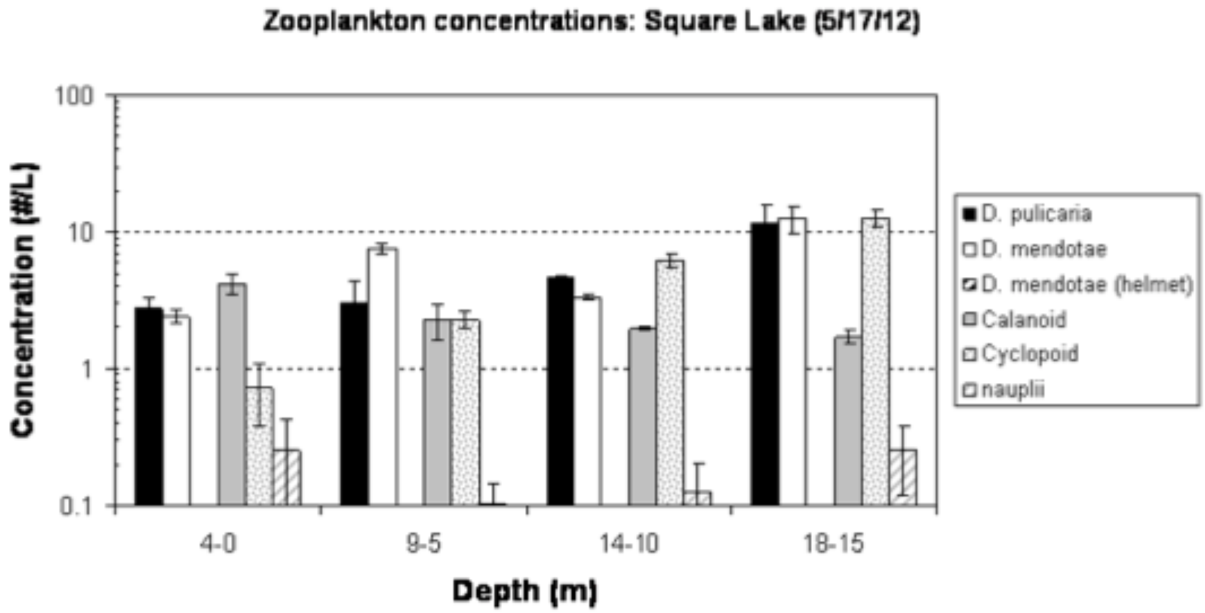
The zooplankton community of Square Lake is dominated by two species of *Daphnia* (*D. pulicaria* and *D. mendotae*), and calanoid and cyclopoid copepods. Densities of these most common taxa in samples from incremental depths during the open-water season (April-September) are shown in a multi-panel figure (Fig. 5). All data for these taxa, and rarer types can be found in Appendix I.

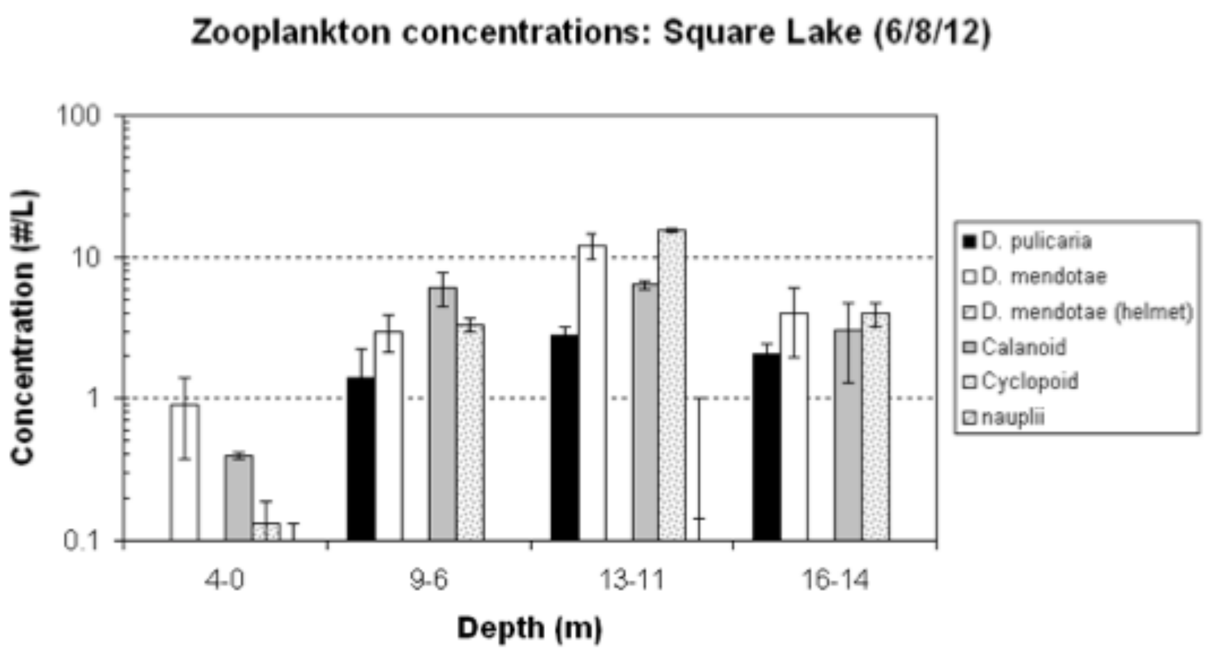
On the April 22 sampling date there was little differentiation of the zooplankton community with respect to depth. The taxonomic composition of samples collected from the shallowest three depths on May 17 also did not vary considerably, but in the samples from deep water (18-15 m) *D. pulicaria* was significantly more abundant (11.6 L^{-1}) than it was in samples from shallower water.

As stratification intensified in June and beyond (Fig. 2), there was more heterogeneity among samples collected from different depths. Specifically, the large-bodied *D. pulicaria* is found only at trace levels in samples from the epilimnion and is most abundant in samples collected from metalimnetic depths (Fig. 5). In addition, densities of all of the most common types of zooplankton are lower in the samples from the deepest water (hypolimnion) compared to the metalimnetic depths.

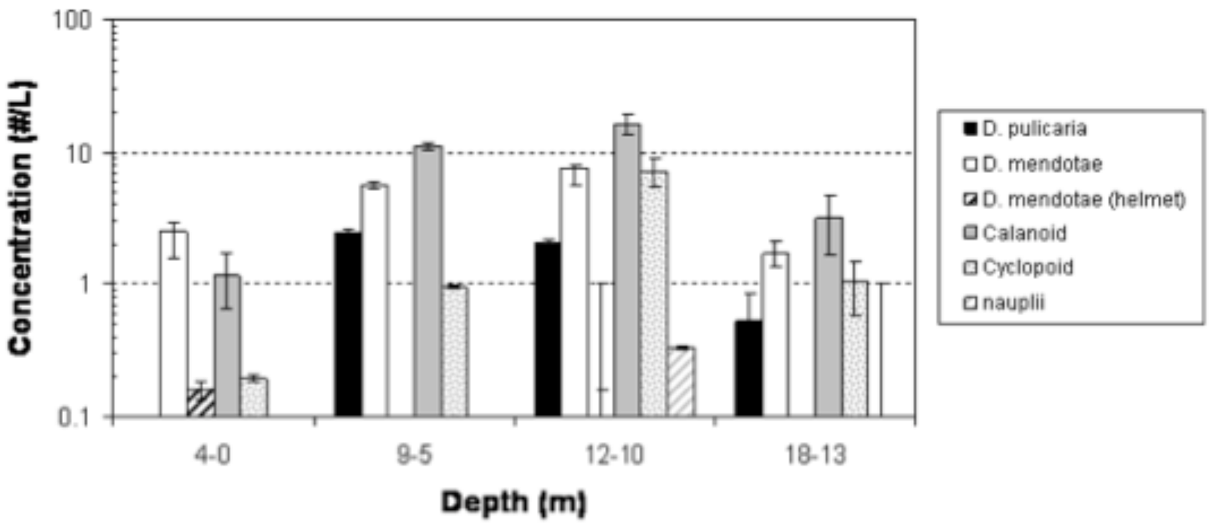
Lastly, the smaller-bodied *D. mendotae* was more abundant that *D. pulicaria* on all dates. This disparity was especially pronounced in samples from August and September (Fig. 5).



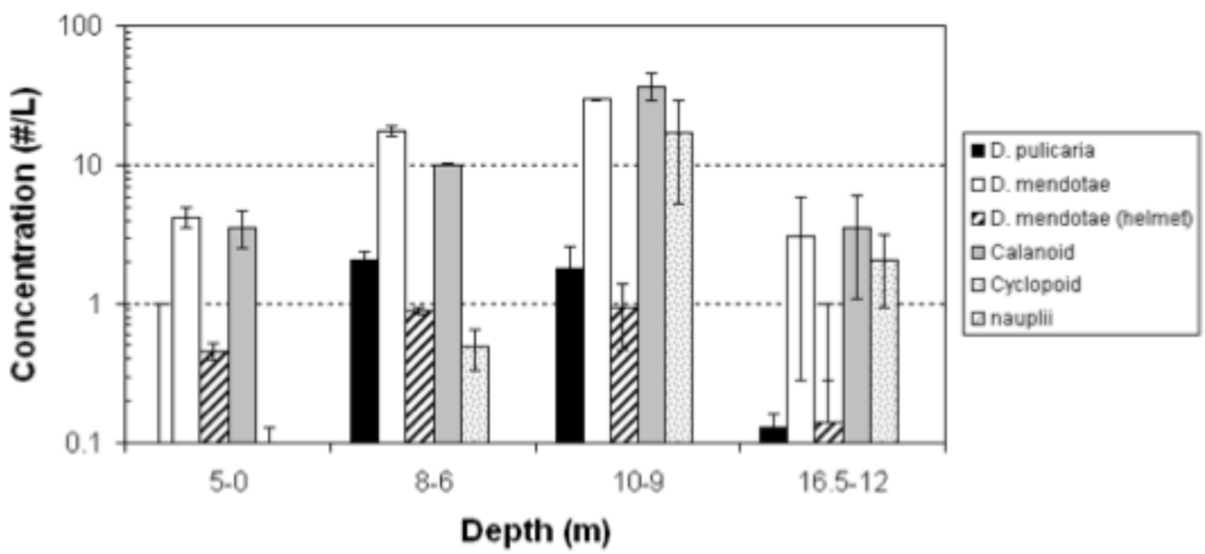

Zooplankton concentrations: Square Lake (5/17/12)
Concentration (#/L)
100
10
1
0.1
4-0
9-5
14-10
18-15
Depth (m)
D. pulicaria
D. mendotae
D. mendotae (helmet)
Calanoid
Cyclopoid
nauplii


Zooplankton concentrations: Square Lake (6/8/12)
Concentration (#/L)
100
10
1
0.1
4-0
9-6
13-11
16-14
Depth (m)
D. pulicaria
D. mendotae
D. mendotae (helmet)
Calanoid
Cyclopoid
nauplii

Zooplankton concentrations: Square Lake (7/13/12)



Zooplankton concentrations: Square Lake (8/13/12)



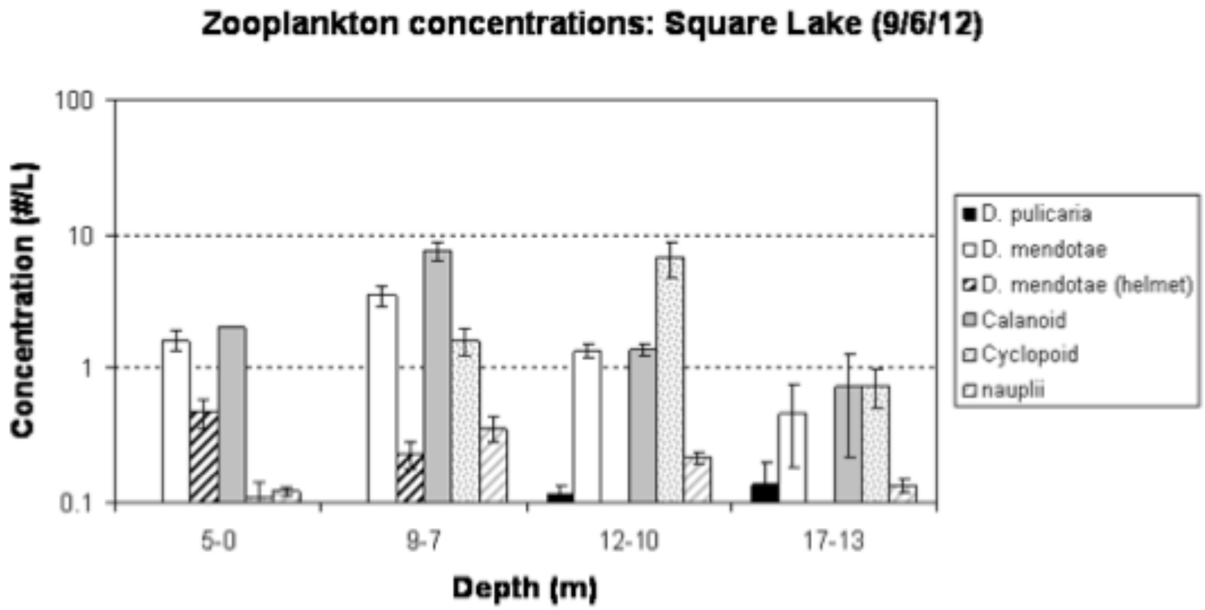


Figure 5. Mean concentrations (+/- SD) of the most common types of zooplankton from net samples of incremental depths from the central sampling location (see Fig. 1) during the 2012 open water season (April-September). See Appendix I for data for all taxa from individual samples.

Discussion

Overall, the water quality and zooplankton data collected in 2012 are consistent with other data from past decade (e.g., the 2010 Clean Water Partnership (CWP) study and 2004-2005 LCMR study). The average summer secchi depth was less than 5 m (Fig. 3), and the hypolimnion became strongly hypoxic (O_2 < 1 mg/L) by early June.

In addition, *D. pulicaria* densities were very low (< 0.2 L^{-1}) in late summer (August-September). Interestingly, the peak densities of the phytoplankton-grazing *D. pulicaria* observed in early June just preceded the maximum secchi depth (6.1 m on June 17, MPCA database), supporting the connection between high population densities of the *D. pulicaria* and clearer water in Square Lake. Lastly, *D. pulicaria* densities were highest in samples collected from deep water with sufficient oxygen (> 1 mg/L). This ‘refuge’ phenomenon has been seen in other recent studies of Square Lake.

Appendix I. Zooplankton densities (#/L) from samples collected at the three sampling locations during 2012. See information for abbreviations below the table.

Date	Lc	Z (m)	Rep	DP	DM	DMh	Cal	Cyc	Nau	Chy	Bos	Lp	Hy	Chb	Rot	Dia	Glo
2/25	W	11-0	a	3.74	3.41	0	7.81	34.6	6.73	0.17	0	0	0	0	0.75	0	0
2/25	W	11-0	b	2.08	3.40	0.08	8.98	43.8	15.2	0.17	0	0	0	0	0.83	0	0
2/25	C	16-0	a	0.55	2.32	0	3.87	47.2	8.35	0	0	0	0	0	0.50	0	0
2/25	C	16-0	b	0.66	2.43	0	2.99	43.9	4.59	0	0	0	0	0	0.44	0	0
2/25	E	13-0	a	0.37	2.7	0	2.6	46.8	8.09	0	0	0	0	0	0.74	0	0
2/25	E	13-0	b	0.16	2.32	0.03	3.81	43.8	6.39	0	0	0	0	0	0.67	0	0
3/10	W	12-0	a	0.52	4.28	0	5.01	34.6	5.46	0.15	0	0	0	0	0.44	0	0
3/10	W	12-0	b	0.44	3.69	0	4.79	28.6	5.6	0.07	0	0	0	0	0.59	0	0
3/10	C	17-0	a	0.68	6.14	0	3.28	38.8	5.31	0.05	0	0	0	0	0.99	0	0
3/10	C	17-0	b	0.81	5.13	0	3.22	41.5	6.34	0.05	0	0	0	0	0.66	0	0
3/10	E	13-0	a	1.25	4.01	0	3.82	51.2	6.65	0	0	0	0	0	1.19	0	0
3/10	E	13-0	b	1.57	4.63	0	3.27	61.8	6.6	0.07	0	0	0	0	0.68	0	0
4/22	W	13.5-0	a	0.31	8.53	0.02	4.34	6.35	0.02	0.36	0	0	0	0	0.04	0	0
4/22	W	13.5-0	b	0.56	10.2	0	3.56	6.31	0.02	0.18	0.06	0	0	0	0.04	0	0
4/22	E	11-0	a	1.29	11	0	1.94	4.15	0.02	0.09	0	0	0	0	0.02	0.02	0
4/22	E	11-0	b	0.50	9.7	0	1.01	4.34	0.14	0.09	0	0	0.02	0	0	0	0
4/22	C	16-0	a	1.79	7.15	0	4.2	7.15	0.09	0.09	0	0	0	0	0	0	0
4/22	C	16-0	b	0.45	8.79	0	4.02	8.26	0	0.11	0	0	0	0	0	0	0

Date	Lc	Z (m)	Rep	DP	DM	DMh	Cal	Cyc	Nau	Chy	Bos	Lp	Hy	Chb	Rot	Dia	Glo
4/22	C	4-0	a	0.15	13.0	0.04	3.33	6.61	0.40	0.07	0	0	0	0	0.22	0	0
4/22	C	4-0	b	1.03	19.9	0	3.54	6.08	0.25	0.11	0	0	0	0	0.04	0	0
4/22	C	8-4	a	0.71	9.72	0	3.75	6.75	0.07	0.28	0	0	0	0	0	0	0
4/22	C	8-4	b	0.33	8.20	0	4.67	7.97	0.38	0.14	0	0	0	0	0.05	0	0
4/22	C	12-8	a	0.71	2.58	0	2.72	9.01	0.18	0.18	0	0	0	0	0.04	0	0
4/22	C	12-8	b	0.80	2.12	0	2.86	7.96	0.27	0.27	0	0	0	0	0	0.05	0
4/22	C	16-12	a	0.90	4.43	0	2.83	10.8	0.14	0.09	0	0	0	0	0.09	0	0
4/22	C	16-12	b	0.70	2.97	0	2.02	8.09	0.17	0	0	0	0	0	0.08	0	0
5/17	W	14-0	a	0.44	5.3	0	1.6	2.04	0	0.53	0	0	0	0	0	0	0
5/17	W	14-0	b	1.05	7.23	0	1.76	2.71	0	0.52	0	0	0	0	0.05	0	0
5/17	E	15-0	a	1.97	4.90	0	1.1	4.63	0.09	0.23	0	0	0.05	0	0.05	0	0
5/17	E	15-0	b	1.37	5.68	0	1.51	3.71	0.05	0.37	0	0	0	0	0.05	0	0
5/17	C	18-0	a	1.05	5.30	0	1.48	6.90	0.04	0.23	0	0	0.04	0	0.04	0	0
5/17	C	18-0	b	1.07	11.2	0	1.63	8.11	0	0.44	0	0	0	0	0	0	0
5/17	C	4-0	a	2.23	2.65	0	4.92	1.09	0.42	0.21	0	0	0	0	0.08	0	0
5/17	C	4-0	b	3.27	2.15	0	3.46	0.37	0.09	0.19	0	0	0	0	0	0	0
5/17	C	9-5	a	1.67	7.07	0	1.61	1.93	0.06	0.32	0	0	0	0	0	0	0
5/17	C	9-5	b	4.38	8.27	0	2.88	2.59	0.14	0.14	0	0	0	0	0.14	0	0
5/17	C	14-10	a	4.5	3.44	0	1.92	5.65	0.21	0.49	0	0	0	0	0.16	0	0
5/17	C	14-10	b	4.8	3.15	0	2.00	6.97	0.04	0.58	0	0	0	0	0.58	0	0

Date	Lc	Z (m)	Rep	DP	DM	DMh	Cal	Cyc	Nau	Chy	Bos	Lp	Hy	Chb	Rot	Dia	Glo
5/17	C	18-15	a	15.7	15.5	0	1.91	14.4	0.12	0.36	0	0	0	0	0	0	0
5/17	C	18-15	b	7.57	9.68	0	1.53	11.1	0.38	0.48	0	0	0	0	0	0	0
6/8	W	13-0	a	2.05	14.8	0	4.64	2.48	0.05	0.16	0	0	0	0	0	0	0
6/8	W	13-0	b	1.35	11.5	0	3.88	3.40	0	0	0	0.11	0	0	0	0	0
6/8	E	13-0	a	0.86	2.05	0	3.40	2.16	0	0	0	0	0	0	0	0	0
6/8	E	13-0	b	1.78	4.32	0	5.07	3.18	0.05	0.05	0	0	0	0	0	0	0.11
6/8	C	16-0	a	1.84	4.38	0	3.86	4.08	0.09	0.04	0	0	0	0	0	0	0
6/8	C	16-0	b	1.80	8.50	0	8.28	6.92	0	0	0	0	0.04	0.03	0	0	0
6/8	C	4-0	a	0.04	1.4	0	0.41	0.19	0.13	0.02	0	0	0	0	0.06	0	0.04
6/8	C	4-0	b	0	0.38	0	0.38	0.08	0.04	0.02	0	0	0	0	0.02	0.02	0.08
6/8	C	9-6	a	2.19	3.92	0	4.51	3.01	0	0	0	0	0	0	0	0	0.05
6/8	C	9-6	b	0.56	2.12	0	7.73	3.74	0.06	0.06	0	0	0	0	0	0	0
6/8	C	13-11	a	3.25	14.8	0	6.86	14.9	0	0.14	0	0	0	0	0.14	0	0
6/8	C	13-11	b	2.4	9.76	0	6.01	16.1	0.14	0	0	0	0	0	0	0	0
6/8	C	16-14	a	1.77	1.91	0	1.27	4.74	0.07	0	0	0	0	0	0.07	0	0
6/8	C	16-14	b	2.4	6.09	0	4.81	3.29	0.08	0	0	0	0	0	0.08	0	0
7/13	W	13-0	a	0.58	4.18	0	9.55	3.62	0	0	0	0	0	*	0	0	0.26
7/13	W	13-0	b	0.23	4.06	0.03	8.97	2.85	0.10	0.03	0	0	0	0	0	0	0.91
7/13	E	15-0	a	0.39	4.96	0.03	8.39	1.01	0	0	0	0.03	*	0	0	0	0
7/13	E	15-0	b	0.51	4.21	0	8.51	1.68	0	0	0	0.05	0	0	0	0.05	0.56

Date	Lc	Z (m)	Rep	DP	DM	DMh	Cal	Cyc	Nau	Chy	Bos	Lp	Hy	Chb	Rot	Dia	Glo
7/13	C	18-0	a	0.58	5.18	0	7.13	1.75	0	0	0	0.04	0	*	0	0	0.23
7/13	C	18-0	b	0.86	4.48	0	8.84	2.57	0.08	0	0	0	0	*	0	0	0.31
7/13	C	4-0	a	0	3.51	0.13	1.69	0.21	0.03	0	0	0	0	0	0	0.02	0.84
7/13	C	4-0	b	0	1.55	0.19	0.66	0.19	0	0.02	0	0.02	0	0	0	0	2.29
7/13	C	9-5	a	2.25	5.99	0	11.8	0.99	0	0	0	0.06	0	0	0	0	0.16
7/13	C	9-5	b	2.57	5.38	0	10.5	0.94	0	0	0	0.12	0	0	0	0	0.35
7/13	C	12-10	a	1.94	5.72	0	13.7	5.47	0.34	0.08	0	0	0	0	0	0	0.17
7/13	C	12-10	b	2.15	9.62	0.16	19.2	9.06	0.32	0	0	0	0	0	0	0	0.32
7/13	C	18-13	a	0.86	2.1	0	4.73	1.49	0.06	0	0	0	0	0	0	0	0.32
7/13	C	18-13	b	0.19	1.36	0	1.68	0.58	0	0	0	0.04	0	*	0	0	0.46
8/13	E	13-0	a	0.14	0.72	0.08	7.73	4.37	0	0	0	0.03	0	*	0	0	0.20
8/13	E	13-0	b	0.07	1.1	0.07	9.03	5.7	0	0	0	0	0	0	0	0	0.62
8/13	W	12.5-0	a	0.10	1.88	0.17	4.44	3.53	0	0	0	0.10	0	0	0	0	0.57
8/13	W	12.5-0	b	0.05	1.94	0.11	5.36	4.33	0.05	0	0	0.03	0	0	0	0	1.39
8/13	C	16.5-0	a	0	1.45	0.06	5.75	3.54	0.06	0	0	0	0	*	0	0	0.26
8/13	C	16.5-0	b	0	3.75	0	7.38	4.08	0	0.04	0	0	0	*	0	0	0.33
8/13	C	5-0	a	0.10	5.01	0.39	4.75	0.03	0	0	0	0.03	0	0	0	0	1.15
8/13	C	5-0	b	0	3.58	0.52	2.52	0.13	0.03	0	0	0.03	0	0	0	0	0.29
8/13	C	8-6	a	2.36	19.4	0.84	10	0.34	0.08	0	0	0.17	0	0	0	0	1.68
8/13	C	8-6	b	1.78	16.1	0.94	10.3	0.65	0	0	0	0	0	0	0	0	0.65

Date	Lc	Z (m)	Rep	DP	DM	DMh	Cal	Cyc	Nau	Chy	Bos	Lp	Hy	Chb	Rot	Dia	Glo
8/13	C	10-9	a	0.93	29.9	1.39	28.9	5.32	0	0	0	0.93	0	0	0	0	1.39
8/13	C	10-9	b	2.59	29.4	0.46	45.1	29.4	0	0	0	0	0	0	0	0	0.69
8/13	C	16.5-12	a	0.09	5.94	0.28	6.13	3.24	0.03	0	0	0.13	0	0	0	0	0
8/13	C	16.5-12	b	0.16	0.28	0	1.09	0.93	0	0	0	0	0	0	0	0	0
9/6	E	13-0	a	0.26	2.69	0.19	5.34	5.83	0.03	0	0	0.07	0	0	0	0	0.13
9/6	E	13-0	b	0.16	2.29	0.13	6.17	6.75	0.16	0	0	0.16	0	0	0	0	0.10
9/6	W	14-0	a	0.18	2.69	0.12	4.55	3.27	0.03	0	0	0	0	0	0	0	0.06
9/6	W	14-0	b	0	2.15	0	4.34	4.55	0	0	0	0	0	0	0	0	0
9/6	C	17-0	a	0.02	1.63	0.07	3.3	3.16	0.02	0	0	0	0	*	0	0	0.02
9/6	C	17-0	b	0.29	2.14	0.04	2.99	3.23	0.01	0.01	0	0	0	*	0	0	0.04
9/6	C	5-0	a	0	1.88	0.59	2.02	0.14	0.11	0	0	0	0	0	0	0	0.11
9/6	C	5-0	b	0	1.34	0.35	2.03	0.08	0.13	0	0	0	0	0	*	0	0.07
9/6	C	9-7	a	0	2.89	0.18	6.33	1.24	0.44	0.06	0	0.09	0	0	0	0	0.03
9/6	C	9-7	b	0	4.14	0.28	8.77	1.96	0.28	0	0	0	0	0	0	0	0
9/6	C	12-10	a	0.14	1.51	0.03	1.25	8.79	0.24	0	0	0	0	0	0	0	0
9/6	C	12-10	b	0.10	1.21	0.07	1.51	4.84	0.20	0	0	0.03	0	0	0	0	0.03
9/6	C	17-13	a	0.08	0.75	0.08	1.27	0.97	0.15	0	0	0	0	*	0	0	0.08
9/6	C	17-13	b	0.2	0.19	0.03	0.22	0.51	0.12	0	0	0	0	0	0	0	0

Codes: Lc = sampling location (see Fig. 1); Z = depth (m); Rep = replicate; DP = *Daphnia pulicaria*; *Daphnia mendotae*; DMh = *Daphnia mendotae* (helmeted morph); Cal = calanoid copepod; Cyc = cyclopoid copepod; Nau = copepod nauplii; Chy = *Chydorus*; Bos = *Bosmina*; Lp = *Leptodora*; Hy = *Hydracarina;* Chb= *Chaoborus*; Rot = total rotifers (including *Keratella*, *Kelicottia*, and *Asplanchna*); Dia = *Diaphanosoma*; Glo = *Gloeotrichia* (colonial cyanobacterium that forms large clumps). Asterisks (*) in cells denote densities < 0.01/L.

Appendix 2. Depth profiles for temperature (^oC) at the central sampling location for the 2012 sampling dates.

Depth (m)	2/25	3/10	4/22	5/17	6/8	7/13	8/13	9/6
0	0.6	1.9	10.5	18.7	23.6	28	24.8	24.5
1	3.5	3.7	10.4	18.7	23.3	28	24.7	24.5
2	3.8	3.9	10.4	18.7	23.3	28	24.6	24.5
3	3.9	3.9	10.3	18.6	21.9	28	24.6	24.4
4	3.9	4	10.3	18.5	20.8	27.8	24.5	24.3
5	3.9	4	10.2	14.7	19.3	25.8	24.5	24.3
6	3.9	4	10.1	12.8	16.8	22.1	24.4	23.9
7	3.9	4	10	11.9	13.4	16.7	19.1	21.9
8	3.9	4	9.9	10.7	11.9	13.6	14.7	17.2
9	3.9	4	9.5	9.9	10.4	11.4	12.4	14.3
10	3.9	4	9.2	9.4	9.6	10.2	10.8	11.7
11	4	4	8.8	8.8	8.9	9.7	9.9	10.4
12	4	4	8.1	8.4	8.4	9.1	9.2	9.5
13	4	4	8	8.3	8.3	8.8	8.8	8.8
14	4	4	7.8	8.2	8.2	8.5	8.5	8.6
15	4	4	7.7	8.1	8.1	8.3	8.4	8.4
16	4	4	7.7	8	8	8.2	8.2	8.3
17	4	4	7.6	8	8	8.1	8.1	8.3
18	4	4	7.5	7.9	8	8.1	8.1	8.2

Appendix 3. Depth profiles for dissolved oxygen (mg/L) at the central sampling location for the 2012 sampling dates.

Depth (m)	2/25	3/10	4/22	5/17	6/8	7/13	8/13	9/6
0	12.7	11	9.4	9.5	11.5	8.5	8.2	8.7
1	11.9	10.3	9.4	9.3	11.5	8.5	8.25	8.65
2	11.9	10.3	9.4	9.2	11.6	8.5	8.25	8.7
3	11.9	10.3	9.4	9.2	11.7	8.5	8.25	8.8
4	11.9	10.5	9.2	9.3	11.3	8.3	8.3	8.75
5	11.9	10.5	9.2	11.2	10.8	9	8.3	8.25
6	11.9	10.6	9.3	11.9	13.1	9	8.3	8.2
7	11.9	10.6	9.3	11.9	14.9	11.2	9.5	7.4
8	11.9	10.6	9.3	11.9	14.1	9.5	8.1	5.5
9	11.9	10.6	9.3	12.6	11.1	6.2	4	2.1
10	11.9	9.5	9.2	10.8	8.5	3.1	0.2	0.4
11	7.3	6.5	8.6	9.1	4.8	1	0.25	0.3
12	7.3	6.4	7.5	7.9	1.8	0.1	0.05	0.05
13	4.1	5.4	7.3	6.9	0.5	0.1	0.05	0.04
14	0.6	1.6	6.9	6.4	0.2	0	0.03	0.04
15	0.4	1	6.6	5.6	0.1	0	0.03	0.04
16	0.3	0.4	6.4	4.5	0.3	0	0.02	0.04
17	0.2	0.2	5.9	4	0.3	0	0.02	0.04
18	0.2	0.2	5.7	3	0.2	0	0.02	0.03