Residual impacts on water quality and sockeye salmon fry habitat : Twenty years after the end of log storage in Morrison Arm of Babine Lake

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Table of Contents

Table of Tables

Table of Figures

Abstract

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In 1984, an aquatic log transportation system was developed on Babine Lake, as part of a ten (10) year logging plan for the Morrison Arm Watershed. Logs cut during the winter were stored at the North end of Morrison Arm until late spring. Two studies by Levy *et al.* (1990) and Power and Northcote (1991) showed that hypoxic conditions developed in the log storage area following the spring thaw in 1985. A decrease in the number of juvenile sockeye in the log storage area was also observed, and appeared to be a response to the hypoxic conditions. The objective of the study reported here is to replicate the protocol used in the Levy *et al.* (1990) study during the spring of 2012 to establish if the log storage negative impacts observed by Levy *et al.* (1990) and Power and Northcote (1991) are still affecting the Morrison River juvenile sockeye migrating into Morrison Arm.

The results from the present study show that in the spring of 2012, approximately 20 years after the end of log storage at the North end Morrison Arm, dissolved oxygen concentration and juvenile sockeye numbers observed in the log storage area were not different than at the reference sites.

Twenty years after the end of log storage at the north end of Morrison Arm of Babine Lake, the deleterious effect of log storage on dissolved oxygen concentration and on juvenile sockeye salmon habitat observed by Levy *et al.* (1990) and Power and Northcote (1991) in 1985 have dissipated.

Considering that no sign of impact from log storage could be observed in the spring of 2012, no habitat remediation work is necessary at the North end of Morrison Arm.

Introduction

The Morrison River enters Babine Lake from the northwest. Morrison and Tahlo Lakes are important sockeye (*Oncorhynchus nerka*) nursery lakes that collectively host the second largest wild sockeye population in the Skeena. Downstream migration of juvenile sockeye salmon from Morrison River into Morrison Arm occurs during May, shortly after the spring ice thaw. Immediately following their entry into Morrison Arm, juvenile sockeye salmon utilize the shallow water (<1m) in the littoral zone, where they feed, for approximately one month before moving offshore for the remainder of their lake occupancy (Levy, 1990; McDonald, 1969).

In 1983, Houston Forest Products proposed a ten (l0) year logging plan for the Morrison Arm Watershed of Babine Lake, British Columbia (Figure 1). The proposal included an aquatic log transportation system involving log dumping, storage, towing and dewatering. Because of concerns about potential deleterious impacts of transportation and storage of logs on aquatic environments, the proposed plan to harvest timber in the Morrison Arm Watershed was given approval under the condition that a study be undertaken to evaluate the impacts of log storage on the aquatic resources, and particularly on juvenile sockeye salmon rearing in Morrison Arm (Power and Northcote, 1991; Levy *et al.* 1990). More specifically, Levy *et al.* (1990) monitored the limnological conditions and habitat use by juvenile sockeye salmon migrating out of Morrison River both prior (1983) and subsequent to the development of the log dump and storage (1984 and 1985).

The Levy *et al.* (1990) study showed that hypoxic conditions developed in the epilimnion as water temperature increased following the spring ice thaw in 1985. Levy *et al.* (1990) attributed the de-oxygenation in the log storage area to increased bacterial growth and respiration stimulated by organic carbon leachates from the floating logs. The bacteria grew on the underside of submerged logs, forming a gelatinous slime layer and strands. Slime material was also observed coating the bottom sediments within the log dump site. No slime material had been observed on bottom sediments in 1983, prior to the log storage area development (Levy *et al.* 1990). The increase in bacterial respiration phenomenon was compounded by the limited horizontal and vertical water circulation in the log storage area when logs were present, as evidenced by a fluorescent dye tracer study conducted in 1985 (Power and Northcote, 1991).

In 1985 the Morrison River juvenile sockeye entry into Morrison Arm coincided with oxygen depletion in the log-handling area. Concurrently, Levy *et al.* (1990) observed a decrease in the number of juvenile sockeye salmon utilizing the littoral habitat in the affected areas of the log storage area. Levy *et al.* (1990) explained this decrease as a behavioral response to the epilimnetic hypoxia. The juvenile sockeye avoided the oxygen-depleted water, as was reported by Davis (1975) for juvenile coho and Chinook salmon. Power and Northcote (1991) report a decrease in zooplankton density and a decline in feeding by cage-held sockeye fry. Even though Levy *et al.* (1990) and Power and Northcote (1991) did not observe any mortalities of juvenile sockeye in the log storage area, the avoidance behavior observed may have increased mortality rates of juvenile sockeye in the vicinity of the log storage area by increasing predation and energy expenditure, and by negatively affecting feeding behavior (Davis, 1975). Power and Northcote (1991) reported that schools of juvenile sockeye salmon showed disoriented behavior within the storage area during early June 1985. Clearly, substantial juvenile sockeye habitat was lost due to log storage at the North end of Morrison Arm.

The objective of the study being reported on here was to replicate the experimental protocols used by the Levy *et al.* (1990) study during the spring of 2012, to establish if the deleterious impacts caused by aquatic log storage observed by Levy *et al.* (1990) and Power and Northcote (1991) are still affecting the Morrison River juvenile sockeye migrating into Morrison Arm.

Figure 1. Map showing the general location of the study area.

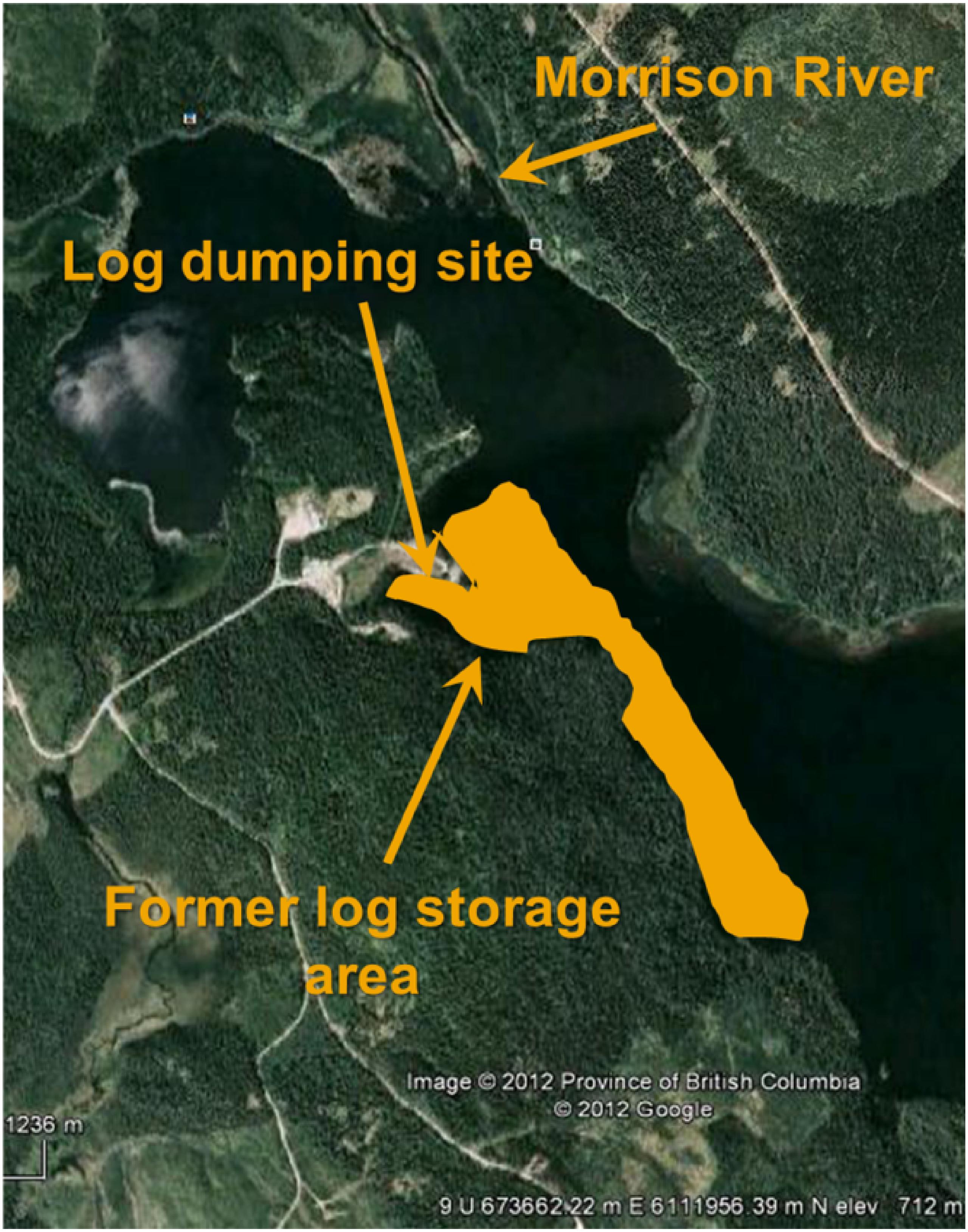

Figure 2. Satellite image showing the North end of Morrison Arm of Babine Lake.

Methods

2.1 Study Area

Babine Lake is the largest natural lake in British Columbia, and is utilized by a variety of salmon species, including Chinook (*Oncorhynchus tsawytscha*), coho (*Oncorhynchus kisutch*), pink (*Oncorhynchus gorbusha*) and sockeye, as well as steelhead and rainbow trout (*Oncorhynchus mykiss*), cutthroat trout (*Oncorhynchus clarki*), Dolly Varden (*Salvelinus malma*), bull trout (*Salvelinus confluentus*), and lake char (*Salvelinus namaycush*). Over the last few decades, the Babine River watershed has contributed 90% or more of the total Skeena River sockeye escapement (McKinnell and Rutherford 1994). The Morrison River is one of the major wild sockeye salmon producers of the Lake Babine area. This study was undertaken at the north end of the Morrison Arm of Babine Lake, in the same area where Levy *et al.* (1990) completed their study in the mid-1980's (Figures 1 and 2).

Logging in the Morrison Watershed began in the winter of 1984. Trees were cut primarily in the winter and trucks transported bundles of logs to a dump site where they were deposited onto a slide and into a sheltered bay at the northern end of Morrison Arm of Babine Lake (Figure 2). A compressed air bubbler system kept the dump site ice-free throughout the winter. The logs were stored in the storage area (Figures 1 and 2) until approximately 1 to 2 months after the spring thaw in early May. The logs bundles were gathered to form booms and were towed 42 km to a dewatering site in the main basin of Babine lake (Figure 1).

2.2 Study Design

For this study, the sampling design used by Levy *et al.* (1990) was replicated. From May 12th, to June 4th 2012, the same four reference sites (West reference, North reference, East reference, and South reference) and one affected (log storage 1) site that Levy *et al.* (1990) sampled were sampled again (Figure 3). An additional affected sampling site (log storage 2) was sampled in 2012 (Figure 3).

Table 1 shows the sampling schedule for each site. Each time a sampling site was visited, sub-surface (1m depth) water temperature and dissolved oxygen were measured approximately 10m out from the shoreline, and visual counts of juvenile sockeye were conducted to obtain an index of relative density of juvenile sockeye salmon at both reference and affected sites.

In the spring of 1985, Levy *et al.* (1990) also made water temperature and dissolved oxygen measurement profiles with 1m intervals, from surface to bottom. These temperature and dissolved oxygen profiles were done at 14 sites, along 3 transects within the log storage area (Figure 4). In the spring of 2012, temperature and dissolved oxygen measurement profiles at 1 m intervals were also conducted at the same 14 sampling sites used by Levy *et al.* (1990).

2.2.1 Water temperature and dissolved oxygen measurements

Temperature and dissolved oxygen were measured with a YSI Model 85 dissolved oxygen meter that was regularly calibrated.

Figure 3. Satellite image showing the affected and reference sampling sites

Figure 4. Satellite image showing Transects 1, 2, and 3

Table 1. Sampling schedule at the six sampling sites.

Date	West Ref.	North Ref.	East Ref.	South Ref.	Log Storage 1	Log storage 2
12-May	--	Sampled	Sampled	--	Sampled	--
13-May	Sampled	--	--	Sampled	--	Sampled
14-May	--	Sampled	Sampled	--	Sampled	--
15-May	Sampled	--	--	Sampled	--	Sampled
16-May	--	Sampled	Sampled	--	Sampled	--
17-May	Sampled	--	--	Sampled	--	Sampled
18-May	--	Sampled	Sampled	--	Sampled	--
19-May	Sampled	--	--	Sampled	--	Sampled
20-May	--	Sampled	Sampled	--	Sampled	--
21-May	Sampled	--	--	Sampled	--	Sampled
22-May	--	--	--	--	--	--
23-May	--	Sampled	Sampled	--	Sampled	--
24-May	Sampled	--	--	Sampled	--	Sampled
25-May	--	Sampled	Sampled	--	Sampled	--
26-May	--	--	--	--	--	--
27-May	Sampled	--	--	Sampled	Sampled	--
28-May	--	Sampled	Sampled	--	--	Sampled
29-May	Sampled	--	--	Sampled	Sampled	--
30-May	--	Sampled	Sampled	--	--	Sampled
31-May	Sampled	--	--	Sampled	Sampled	--
01-Jun	--	Sampled	Sampled	--	--	Sampled
02-Jun	Sampled	--	--	Sampled	Sampled	--
03-Jun	--	Sampled	Sampled	--	--	Sampled
04-Jun	Sampled	--	--	Sampled	Sampled	--

2.2.2 Visual counts of juvenile sockeye salmon

The juvenile sockeye visual enumeration technique developed by Levy *et al.* (1990) was replicated in 2012. At each sampling site, three 1m x 1m counting grids were placed at a distance of approximately 1 to 2m from the shoreline, in water depths between 0.3-0.5m. The grids were constructed with wood stakes and string, and were spaced approximately 10m apart (Figure 5). Observers seating on adjacent 1.5 m high scaffolds counted the number of juvenile sockeye which swam through the grids during 3 consecutive 15 minutes observations periods. All sockeye fry transiting through the counting grids were counted, including an unknown but likely small number of fish that backtracked. Juvenile sockeye were easily differentiated from co-occurring cyprinids because of their swimming pattern, and behavior.

All of the grids had to be moved closer to shore during the study because the water level in Babine Lake rose by more than 0.5m between May 12th and June4th, 2012, due to snow melt contributions.

Results and Discussions

3.1 Water Temperature and Dissolved Oxygen

In 1984, following the initiation of log dumping into the Morrison Arm of Babine Lake, Levy *et al.* (1990) observed minor dissolved oxygen depressions at the log storage sampling site compared to values obtained from the reference sites (Figure 6). In the spring of 1985, the surface dissolved oxygen at the log dump site was significantly reduced compared to the reference sites on all seven sampling dates (Figure 6). Dissolved oxygen concentrations ranged from approximately 55% to 90% saturation at the affected site, and from approximately 85% to 105% at the reference sites (Figure 6).

Furthermore, surface dissolved oxygen concentrations of less than 5 mg/l were measured on May 30th and June 3rd, 1985 within the log storage area (Figure 7). On those two sampling dates Levy *et al.* (1990) frequently measured surface dissolved oxygen concentrations below 2 mg/l and occasionally below 1 mg/l in the log storage area.

According to Levy *et al.* (1990), the low oxygen concentrations measured in the log storage area was related to water temperature, and water circulation, but mostly caused by respiration of bacteria, which formed a gelatinous slime layer on the underside of submerged logs, as well as covering the bottom sediments.. Water along transect 1 was more hypoxic on all five sampling days (Figures 4 and 6) probably because of bacterial respiration combined with restricted water circulation in the small sheltered bay covered by log booms. Power (1987) reports on a rhodamine-B surface dye tracer study to examine water movement in the vicinity of transect 1 on June 3 1985. The results suggested that water in the small sheltered bay covered with log booms was virtually stagnant. The dye cloud did not expand more than 10 m in any direction for an entire day. In comparison, dye released in open water moved at rates between 15-30 m/h.

Moreover, increases in dissolved oxygen concentration and decreases in water temperature were noted on June 18th and June 21st, 1985 along all three transects (Figure 6). These changes occurred immediately after log bundles were removed from the areas around transects 2 and 3 (Levy *et al.* 1990). It appears that the removal of the log booms improved water movement, and thus oxygenation, within the log storage area and within the small sheltered bay.

Figure 8 shows the data from surface temperature and dissolved oxygen measurements at the reference and affected (log storage 1 and log storage 2) sampling sites between May 12th and June 4th, 2012. No significant differences are noted between the results obtained at the reference sites compared to the affected sites. Percent saturation of dissolved oxygen varied from 80% at the South reference site to 109% at the Log storage 2 affected site. No hypoxic conditions were noted along the three transects where water temperature and dissolved oxygen measurements profiles were completed in the spring of 2012 (Appendix 1).

These results confirm the conclusions put forward by Levy *et al.* (1990). The significantly lower dissolved oxygen concentration and higher surface water temperature observed in the log storage area compared to the reference sites were most likely due to bacterial respiration combined with the lack of water circulation within the log storage area caused by the presence of the log booms. When log booms were not present in the spring of 2012, dissolved oxygen concentration and surface water temperature observed in the log storage area were not different from dissolved oxygen concentration and surface water temperature observed at reference sites.

Figure 5. Photo showing the juvenile sockeye observing platforms and grids. May 13th, 2012.

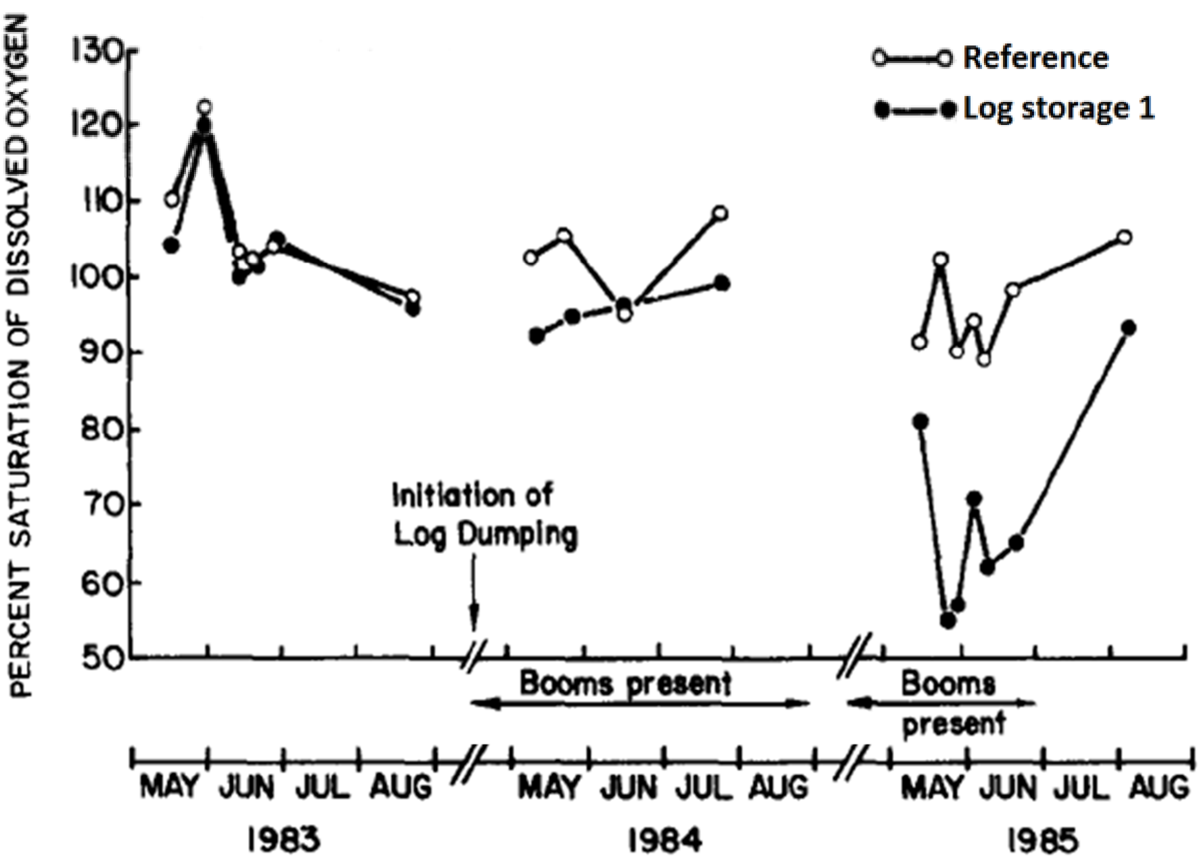

Figure 6. Graph showing the percent saturation of dissolved oxygen in 1 m depth waters at the log storage 1 and reference sites between 1983 and 1985 (from Levy *et al.* 1990).

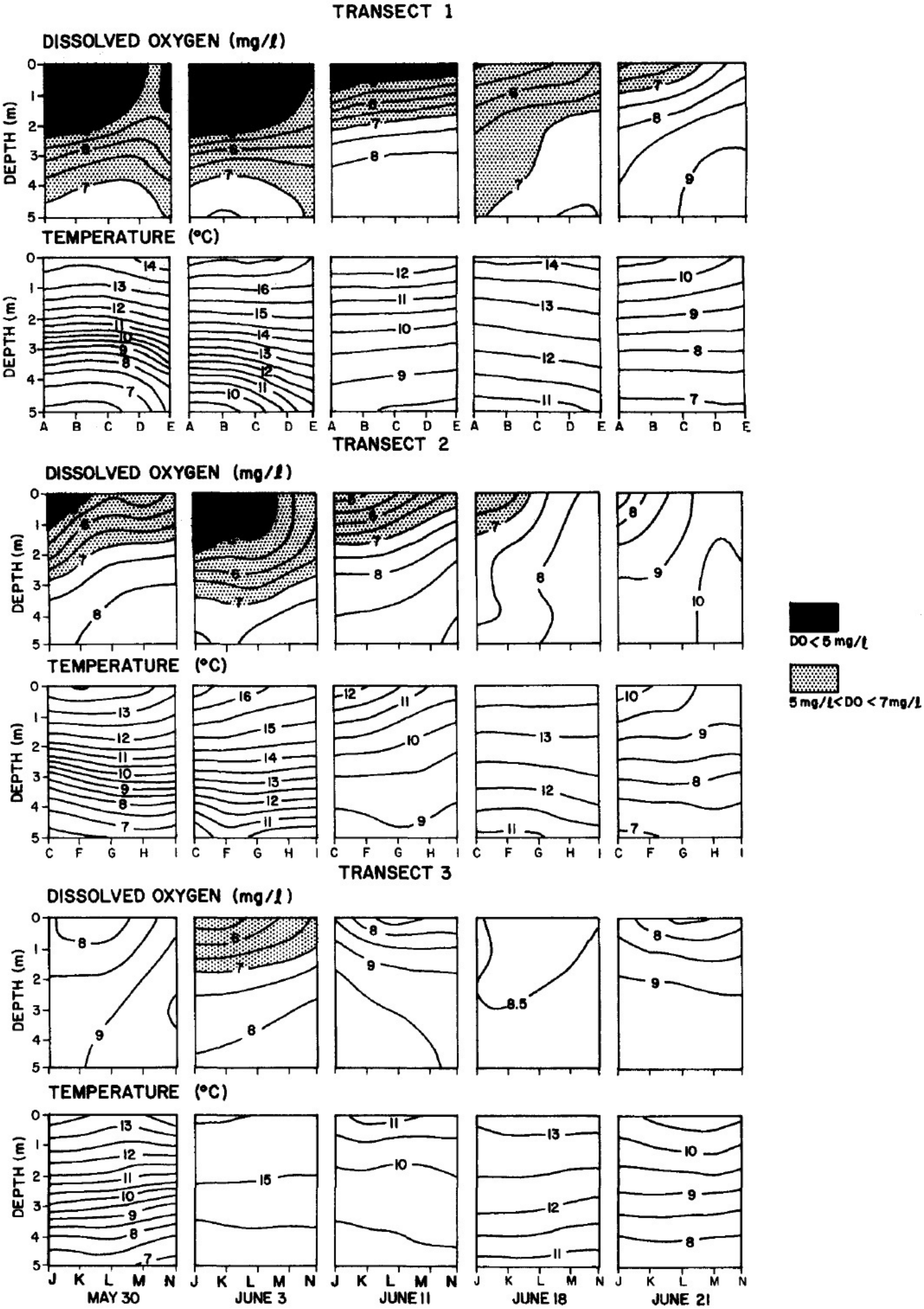

Figure 7. Isopleths graph showing the dissolved oxygen measured at 14 sampling sites along three transects in the log storage area (from Levy *et al.* 1990).

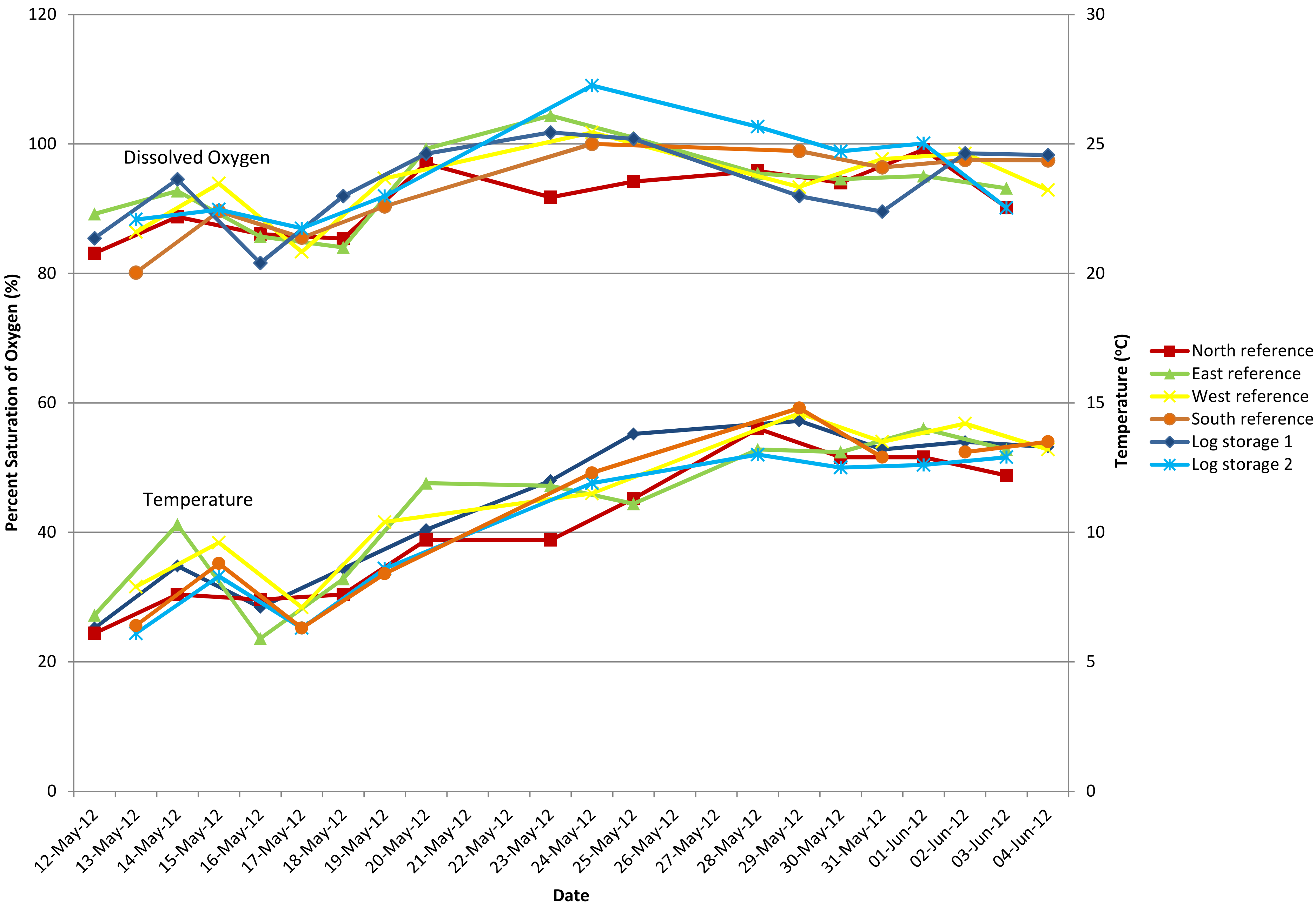

Figure 8. Graph showing surface water temperature and percent saturation of oxygen from May 12th to June 4, 2012.

3.2 Visual Counts of Juvenile Sockeye Salmon

Levy *et al.* (1990) conducted counting grid observations in the spring of 1983, before log storage, and in the spring of 1985, following two winters of log storage. Results from these observations show inherent variability in the mean number of juvenile sockeye observed in the counting grids at the different sites. Despite this spatial variability, it appears that in 1983, and on May 21st 1985, the mean number of juvenile sockeye observed at the affected site (log storage 1) was equivalent, or higher than the number of juvenile sockeye observed at the reference sites (Figure 9). On May 28th 1985, a significant change was observed. The mean number of juvenile sockeye observed in the grids at the log storage 1 site was significantly lower (2 m^{-2} 15 min^{-1}) than at the reference sites (199 m^{-2} 15 min^{-1}) (Figure 9). According to Levy *et al.* (1990), juvenile sockeye may have actively avoided the log storage area because of the lack of oxygen that was observed in the spring of 1985.

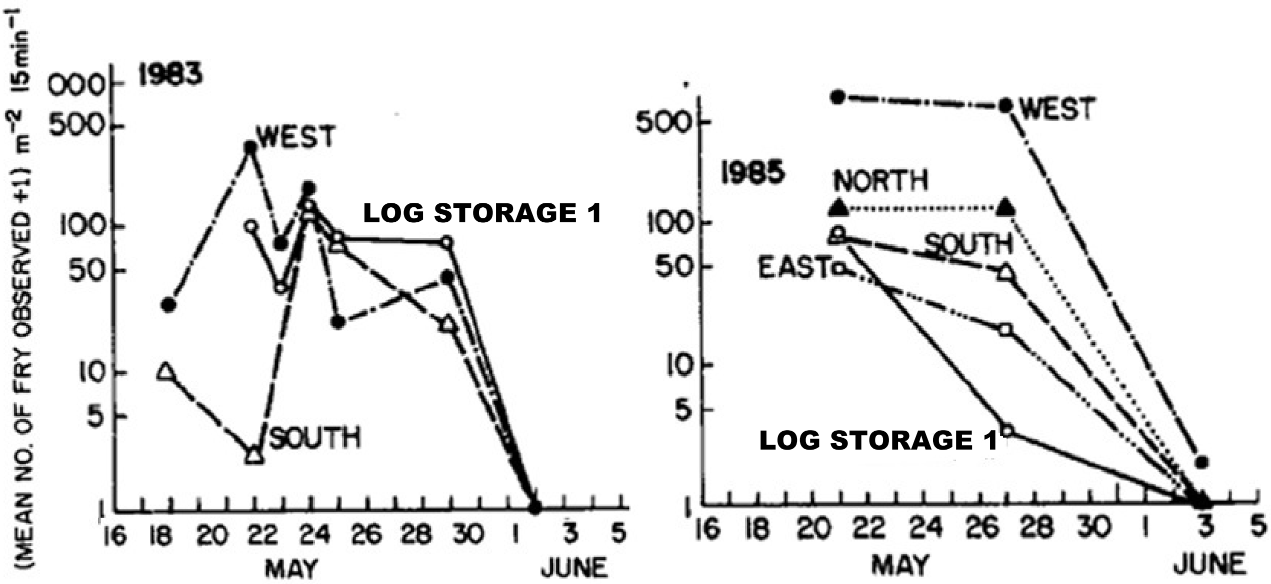

Figure 9. Log based graphs showing the mean number of juvenile sockeye observed swimming through the counting grids at the reference (West, South, East, and North) and affected (Log storage 1) sites in the spring of 1983 and 1985 (from Levy *et al.* 1990).

In the spring of 2012, juvenile sockeye migrating from the Morrison River were observed at the North end of Morrison Arm throughout the entire sampling period, extending from May 12th until June 4th. Figure 10 shows the data obtained during the visual counts of juvenile sockeye conducted in 2012 at four reference sites and 2 affected sites. Similar to the observations made in 1983 by Levy *et al.* (1990), the mean number of juvenile sockeye observed during the spring of 2012 varied significantly between sampling sites, and temporally (Figure 10). Globally, the data range observed in 2012 is similar to the data range observed in 1983. The mean number of juvenile sockeye observed in 2012 varied from 0 m^{-2} 15 min^{-1} on May 30th, at the East reference site, to 474 m^{-2} 15 min^{-1} on May 27th, at the South reference site. Overall, the mean number of juvenile sockeye observed at the affected sites was slightly higher (43 m^{-2} 15 min^{-1}), but not significantly different than the mean number of juvenile sockeye observed at the reference sites (39 m^{-2} 15 min^{-1}) (Table 2).

The 2012 visual counts of juvenile sockeye results show that in the spring of 2012, juvenile sockeye migrating from the Morrison River did not avoid the log storage area as Levy *et al.* (1990) observed in 1985. In 2012, the juvenile sockeye utilized the littoral habitat in the log storage area as much as the littoral habitat at the reference sites. These results support Levy's conclusions that juvenile sockeye avoided the log storage area because of the hypoxic conditions caused by the presence of log booms.

Table 2. Comparison of the mean number of juvenile sockeye observed at the reference and affected sites.

	Mean Number of juvenile Sockeye Observed1 per m² per 15min	**Student's *t*- Test Result**
Log storage sites	43	P= 0.66 - Not significantly different
Reference sites	39	

3.3 Video Survey of Northern Morrison arm sediments.

On June 3rd 2012 we performed exploratory transects on the former Morrison Arm log storage areas with a suspended underwater video camera close to the lake bed surface. The resulting images showed no significant amount of bark or other organic material except for a few submerged logs, and no bacterial slime material coating the bottom sediments.

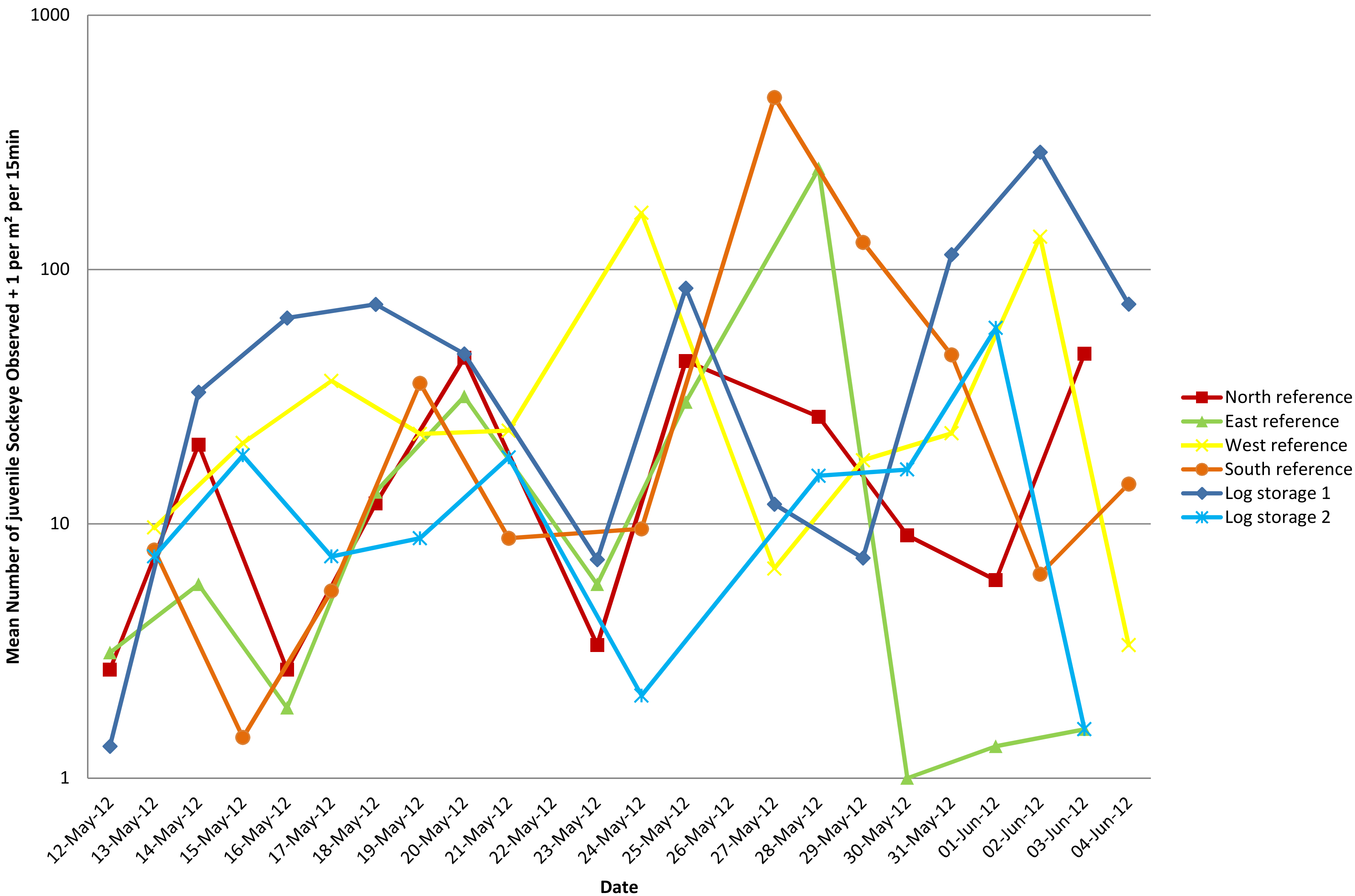

Figure 10. Log based graph showing the mean number of juvenile sockeye observed swimming through the counting grids at the reference (West, South, East, and North) and affected (Log storage 1, and Log storage 2) sites in the spring of 2012.

Conclusions

The results from this study show that twenty (20) years after the end of log storage at the North end of Morrison Arm of Babine Lake, the deleterious effects of log storage on dissolved oxygen concentration and on juvenile sockeye salmon habitat observed by Levy *et al.* (1990) in 1985 have dissipated. The results obtained in the spring of 2012 show that dissolved oxygen concentrations and juvenile sockeye presence are back to reference levels in the area used for log storage in the mid-1980s to the early 1990s. These results are not insignificant as log booms covered a substantial proportion of the littoral habitat at the North end of Morrison Arm, which is used by juvenile sockeye in the first month after their migration from Morrison River. The increase in viable habitat availability for juvenile sockeye may have been a factor in the Morrison River sockeye escapement upward trend observed since the early 1990s (Figure 11).

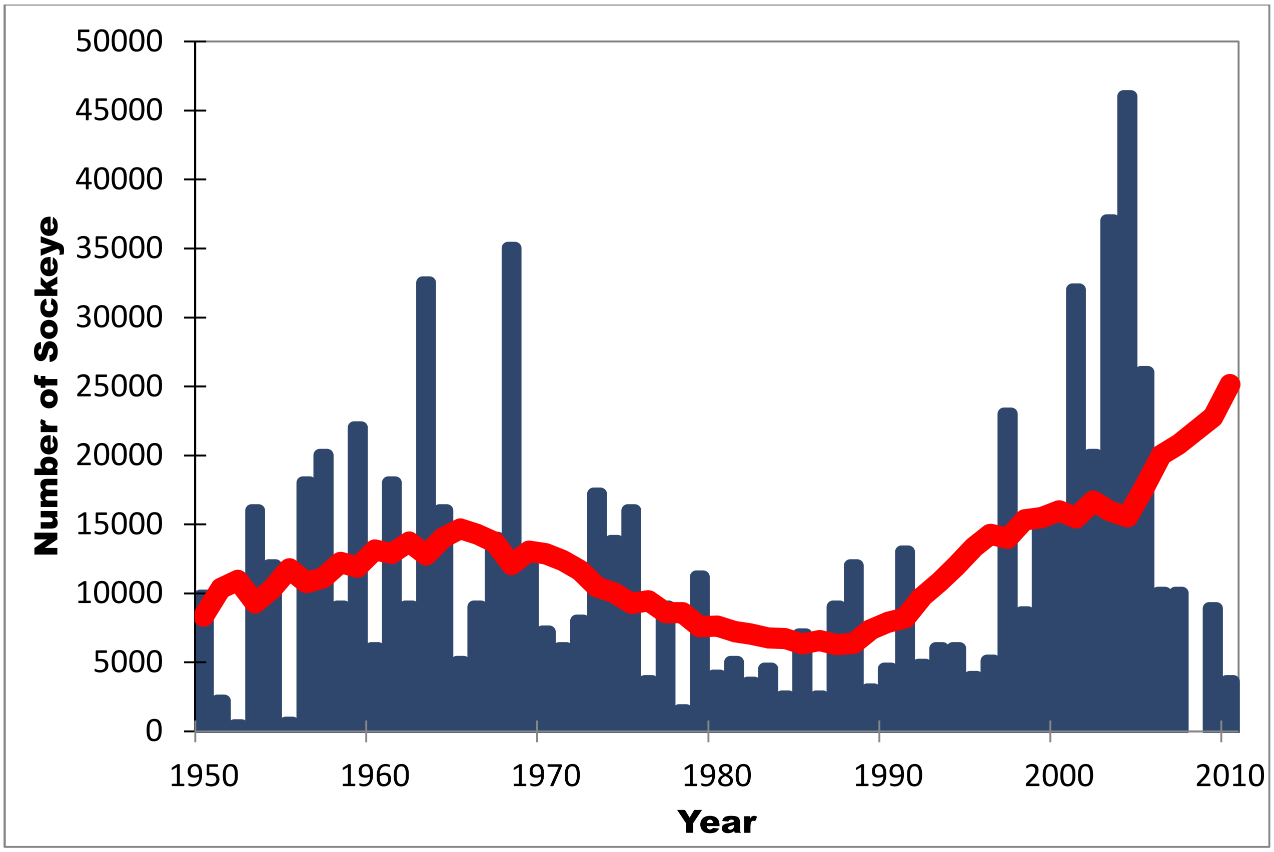

Figure 11. Graph showing sockeye escapement to the Morrison River from 1950 to 2010. The red line shows a Lowess regression.

Logging in the Morrison Arm Watershed has decreased considerably since the 1990s, and logs are not stored in Morrison Arm anymore. The deleterious effects of log storage observed by Levy *et al.* (1990) and Power and Northcote (1991) were localized and of short duration. Considering that no signs of impact from log storage could be observed in the spring of 2012, no habitat remediation work is necessary at the North end of Morrison Arm.

Acknowledgements

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References

Davis J. C. 1975. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: a review. Journal of the Fisheries Research Board of Canada. 32: 2295-2332.

Levy D., Yesaki I., and Christensen B. 1990. Impacts of Log Storage upon Epilimnetic Dissolved Oxygen and Juvenile Sockeye Salmon in Babine Lake, British Columbia. Water Research. Vol. 24, No. 3, pp. 337-343.

Power, E. 1987. Effects of Log Storage on zooplankton and juvenile salmon in Babine Lake, British Columbia. M.Sc. thesis University of British Columbia, Department of Zoology. 132 p.

Power E. A. and Northcote T. G. 1991. Effect of Log Storage on the Food Supply and Diet of Juvenile Sockeye Salmon. North American Journal of Fisheries Management. 11:413-423.

McDonald J. G. (1969) Distribution, growth and survival of sockeye fry *(Oncorhynchus nerka)* produced in natural and artificial stream environments. Journal of the Fisheries Research Board of Canada. 26: 229-267.

McKinnell, S. and D. Rutherford. 1994. Some Sockeye Salmon are Reported to Spawn Outside the Babine Lake Watershed in the Skeena Drainage. PSARC Working Paper S94-1:52p.

Appendix

Appendix 1 – Dissolved oxygen concentration (mg/l) and percentage of saturation (%), and temperature (T°C) measurements profile at Transects 1, 2, and 3, May and June 2012.

May 13, 2012 – Transect 1

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
A	mg/l	10.42	10.33	10.31	10.42	10.29	10.29		
	%	85.5	84.1	83.9	84.9	82.9	81.7		
	T°C	6.7	6.7	6.5	6.4	5.9	5.8		
B	mg/l	10.43	10.39	10.34	10.32	10.30	10.40	10.34	10.31
	%	84.6	84.3	83.7	82.1	81.9	82.6	82.3	81.3
	T°C	6.4	6.4	6.3	5.8	5.6	5.5	5.4	5.4
C	mg/l	10.27	10.34	10.23	10.20	10.17	10.11	10.14	10.11
	%	83.0	83.6	82.5	81.2	80.7	80.3	80.2	79.7
	T°C	6.3	6.3	6.2	5.7	5.5	5.4	5.4	5.4
D	mg/l	10.21	10.14	10.14	10.11	10.08	10.05	10.03	
	%	82.7	82.0	81.5	80.6	80.0	79.4	79.4	
	T°C	6.3	6.2	6.0	5.7	5.6	5.5	5.5	
E	mg/l	10.23	10.20	10.14	10.11	10.09	9.99		
	%	82.7	82.5	82.0	81.1	80.6	80.1		
	T°C	6.3	6.2	6.2	6.0	5.7	5.5		

May 14, 2012 – Transect 2

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
F	mg/l	10.92	10.89	10.88	10.86	10.80	10.75	10.68	
	%	91.3	90.5	89.5	88.4	86.8	86.6	85.1	
	T°C	7.8	7.3	7.1	6.5	6.1	6.1	5.9	
G	mg/l	11.04	10.95	10.93	10.87	10.90	10.90	10.85	10.89
	%	91.4	89.9	89.5	88.2	88.0	87.3	86.6	86.6
	T°C	7.1	6.9	6.8	6.6	6.1	6.0	5.9	5.7
H	mg/l	10.95	10.94	10.87	10.83	10.88	10.82	10.82	10.87
	%	89.0	88.7	87.3	87.5	87.1	87.1	87.1	87.0
	T°C	6.6	6.3	6.2	6.1	6.1	6.0	5.9	5.8
I	mg/l	10.94	10.84	10.88	10.89	10.86	10.86	10.85	10.86
	%	89.4	88.6	87.9	87.5	86.9	86.9	86.9	86.7
	T°C	6.8	6.3	6.2	6.1	6.0	5.8	5.8	5.7

May 14, 2012 – Transect 3

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
J	mg/l	10.76	10.70	10.80	10.80	10.80			
	%	91.2	89.3	87.2	86.6	85.8			
	T°C	8.2	7.6	6.4	6.0	5.7			
K	mg/l	10.83	10.92	10.96	10.99	10.90	10.87	10.89	10.91
	%	90.8	89.2	88.1	87.0	87.3	86.9	86.6	87.7
	T°C	7.8	7.0	6.1	5.8	5.7	5.7	5.5	5.5
L	mg/l	11.05	11.03	11.07	11.00	11.03	11.05	11.02	11.07
	%	92.1	91.1	89.6	88.3	88.2	88.0	88.1	87.8
	T°C	7.4	7.3	6.2	5.9	5.8	5.8	5.7	5.5
M	mg/l	11.05	11.05	10.98	11.06	11.07	11.15	11.14	11.28
	%	91.7	91.5	90.0	88.9	88.8	89.2	89.4	89.4
	T°C	7.3	7.2	6.4	6.0	5.9	5.8	5.8	5.6
N	mg/l	11.12	11.14	11.07	11.15	11.13	11.15	11.13	11.14
	%	92.6	92.5	91.9	89.4	89.2	88.9	89.0	88.7
	T°C	7.4	7.3	7.1	6.0	5.9	5.9	5.8	5.8

May 17, 2012 – Transect 1

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
A	mg/l	10.62	10.60	10.63	10.61	10.62	10.53	10.57	10.52
	%	88.0	87.6	86.9	84.9	86.3	86.2	85.0	84.7
	T°C	7.2	7.1	6.7	6.5	6.3	6.3	6.1	6.0
B	mg/l	10.72	10.67	10.74	10.73	10.41	10.40	10.28	10.34
	%	88.2	88.1	87.8	87.1	85.3	83.9	82.6	83.0
	T°C	7.0	6.9	6.6	6.4	6.1	6.1	6.0	5.9
C	mg/l	10.68	10.67	10.63	10.65	10.64	10.63	10.61	
	%	87.5	87.5	86.5	85.6	85.8	85.7	85.6	
	T°C	6.8	6.7	6.4	6.2	6.1	6.1	6.0	
D	mg/l	10.64	10.81	10.77	10.79	10.85	10.82	10.86	10.78
	%	88.9	88.3	88.1	87.3	87.5	87.2	87.4	85.9
	T°C	6.8	6.8	6.7	6.2	6.1	6.1	6.1	6.0
E	mg/l	10.68	10.55	10.67	10.64	10.51			
	%	91.2	90.0	87.8	87.0	86.0			
	T°C	6.9	6.8	6.7	6.6	6.5			

May 17, 2012 – Transect 2

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
F	mg/l	11.03	10.96	10.94	10.94	10.93	10.98	11.01	11.01
	%	90.6	89.6	89.3	88.9	88.4	88.8	88.6	88.1
	T°C	6.7	6.7	6.6	6.4	6.1	6.1	6.1	6.1
G	mg/l	10.55	10.53	10.52	10.51	10.54	10.55	10.54	10.54
	%	85.8	85.7	85.6	85.7	85.7	85.6	85.4	85.2
	T°C	6.5	6.5	6.4	6.4	6.4	6.4	6.4	6.2
H	mg/l	10.62	10.59	10.60	10.57	10.59	10.62	10.63	10.53
	%	86.4	86.1	86.1	86.1	86.0	86.3	86.4	85.7

	T°C	6.5	6.4	6.4	6.5	6.4	6.5	6.5	6.5
I	mg/l	10.55	10.44	10.45	10.47	10.47	10.46	10.48	10.45
	%	86.3	85.2	85.3	85.3	85.3	85.1	85.3	85.4
	T°C	6.6	6.5	6.6	6.6	6.6	6.6	6.6	6.6

May 18, 2012 – Transect 3

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
J	mg/l	10.38	10.67	10.65	10.69	10.69			
	%	88.6	88.0	87.0	86.8	86.8			
	T°C	8.3	7.5	6.6	6.5	6.5			
K	mg/l	10.36	10.31	10.46	10.48	1.49	1.48	1.45	10.60
	%	87.5	87.0	85.4	85.1	85.1	84.9	84.0	85.0
	T°C	8.0	7.7	6.8	6.5	6.4	6.4	6.2	5.9
L	mg/l	10.86	10.84	10.78	10.90	10.85	10.90	10.87	10.90
	%	91.1	90.3	88.6	88.5	88.5	88.2	87.7	87.4
	T°C	7.6	7.6	6.9	6.4	6.3	6.3	6.1	6.0
M	mg/l	10.70	10.69	10.60	10.66	10.55	10.56	10.66	10.45
	%	88.7	88.6	88.0	86.8	85.9	85.7	85.2	84.2
	T°C	7.5	7.4	7.3	6.5	6.3	6.3	6.2	6.0
N	mg/l	10.58	10.56	10.58	10.65	10.66	10.64	10.68	10.67
	%	89.5	88.6	87.8	87.1	85.8	86.0	86.0	86.2
	T°C	8.0	7.8	7.3	6.8	6.4	6.2	6.2	6.1

May 22, 2012 – Transect 1

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
A	mg/l	10.72	10.66	10.71	10.35	10.42	10.44	10.44	10.25
	%	98.8	96.9	95.2	90.1	87.9	87.3	86.1	
	T°C	11.7	11.0	10.2	9.4	8.0	7.7	7.7	7.2
B	mg/l	10.85	10.84	10.72	10.54	10.37	10.49	10.49	10.56
	%	98.1	97.6	94.3	89.5	88.1	87.4	86.9	86.7
	T°C	10.9	10.8	9.8	8.4	8.1	7.5	7.1	7.0
C	mg/l	10.89	10.72	10.40	10.37	10.33	10.37	10.41	10.27
	%	97.9	95.3	90.1	88.5	86.3	85.8	85.9	84.6
	T°C	10.8	10.6	9.0	8.6	7.4	7.2	7.1	7.0
D	mg/l	10.73	10.55	10.39	10.34	10.32	10.31	10.28	
	%	96.3	94.9	89.3	88.3	85.4	85.4	84.5	
	T°C	10.7	10.2	8.9	8.5	7.4	7.1	7.1	
E	mg/l	10.81	10.76	10.53	10.41	10.64	10.53		
	%	96.5	96.2	90.4	88.6	89.9	87.4		
	T°C	10.7	10.4	8.7	8.1	7.2	7.2		

May 22, 2012 – Transect 2

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
F	mg/l	10.63	10.75	10.35	10.37	10.33	10.32	10.33	
	%	96.0	96.0	88.8	86.5	86.5	86.1	85.2	
	T°C	10.6	10.4	8.5	7.6	7.6	7.5	7.1	

G	mg/l	10.77	10.75	10.40	10.40	10.46	10.42	10.44	10.41
	%	96.9	96.3	90.5	88.1	87.7	87.0	86.2	85.8
	T°C	10.6	10.5	9.0	8.1	7.9	7.5	7.2	7.0
H	mg/l	10.75	10.74	10.40	10.25	10.32	10.30	10.34	10.34
	%	96.7	96.6	89.6	88.5	86.6	86.1	85.7	85.3
	T°C	10.5	10.7	9.6	8.3	7.8	7.4	7.2	6.9
I	mg/l	10.78	10.79	10.63	10.45	10.50	10.44	10.45	10.44
	%	97.5	96.6	92.6	89.8	87.4	87.1	86.4	85.9
	T°C	10.7	10.8	9.4	8.6	7.7	7.4	7.2	6.9

May 22, 2012 – Transect 3

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
J	mg/l	10.60	10.36	10.40	10.26	10.24	10.04		
	%	92.3	88.6	88.0	86.5	85.9	83.0		
	T°C	9.9	8.5	8.2	7.9	7.7	7.3		
K	mg/l	10.64	10.42	10.42	10.39	10.44	10.46	10.46	10.44
	%	94.8	91.6	88.0	87.6	87.7	87.9	87.4	87.3
	T°C	9.9	9.1	8.0	7.9	7.9	7.7	7.6	7.5
L	mg/l	10.81	10.75	10.63	10.52	10.47	10.56	10.56	10.49
	%	96.6	93.2	89.4	89.2	88.8	88.6	87.6	87.3
	T°C	9.8	9.0	8.4	8.1	8.0	7.6	7.5	7.4
M	mg/l	10.95	10.60	10.63	10.55	10.54	10.66	10.62	10.56
	%	97.6	91.5	90.2	89.6	89.2	89.6	88.5	87.7
	T°C	10.1	9.0	8.5	8.2	8.1	7.8	7.5	7.3
N	mg/l	10.75	10.71	10.43	10.41	10.41	10.48	10.41	10.36
	%	95.6	94.4	88.4	88.8	88.6	88.1	86.2	85.7
	T°C	10.2	9.5	8.4	8.3	8.3	7.8	7.2	7.1

May 25, 2012 – Transect 1

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
A	mg/l	10.88	10.76	9.81	10.14	9.95	9.57		
	%	98.5	97.7	86.1	88.4	86.3	81.5		
	T°C	11.1	10.5	9.6	9.3	9.1	8.4		
B	mg/l	10.12	9.68	9.69	9.61	9.57	9.65	9.62	9.81
	%	92.5	85.8	84.3	84.0	82.5	81.3	80.0	78.8
	T°C	11.1	10.1	9.7	9.5	9.1	8.4	7.5	6.0
C	mg/l	10.25	10.25	10.25	10.15	10.14	10.17	10.25	9.28
	%	94.3	92.5	89.5	88.8	88.1	87.1	85.0	76.0
	T°C	10.9	10.3	9.7	9.5	9.4	8.5	7.5	6.3
D	mg/l	89.3	87.6	85.5	83.6	83.7	81.8	81.7	
	%	9.85	9.79	9.77	9.53	9.61	9.69	9.69	
	T°C	10.7	10.6	9.8	9.5	9.4	8.1	7.7	
E	mg/l	9.86	9.71	9.58	9.54	9.55			
	%	89.3	87.3	84.4	83.4	83.1			
	T°C	10.7	10.5	9.8	9.6	9.3			

May 25, 2012 – Transect 2

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
F	mg/l	10.70	10.51	10.55	10.50	10.41	10.45	10.45	10.29
	%	97.1	94.0	93.1	91.8	89.9	88.2	87.5	86.1
	T°C	10.9	10.1	9.7	9.5	9.0	8.2	7.6	6.2
G	mg/l	10.75	10.54	10.54	10.52	10.48	10.61	10.62	10.70
	%	96.7	94.0	92.8	91.6	89.2	88.2	87.3	87.1
	T°C	10.9	10.3	9.7	9.4	7.8	7.4	7.0	6.5
H	mg/l	10.54	10.51	10.63	10.42	10.26	10.21	10.39	10.44
	%	95.8	93.7	91.5	88.9	86.1	84.9	85.9	86.5
	T°C	10.5	10.3	9.2	8.1	7.8	7.5	7.1	6.9
I	mg/l	10.75	10.73	10.89	10.85	10.95	10.95	11.05	10.98
	%	95.8	96.8	96.1	92.5	91.8	90.8	91.0	89.2
	T°C	10.5	10.2	9.6	8.7	7.8	7.5	7.1	6.6

May 25, 2012 – Transect 3

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
J	mg/l	10.38	10.27	10.28	10.19	10.51	10.60		
	%	93.6	93.2	89.0	86.5	85.6	85.9		
	T°C	10.9	10.9	9.4	8.1	7.6	6.3		
K	mg/l	10.86	10.89	10.77	10.67	10.80	11.00	11.17	11.26
	%	98.6	97.7	94.8	91.5	90.0	89.1	88.5	87.5
	T°C	10.9	10.8	9.6	8.9	7.4	6.5	5.6	5.1
L	mg/l	10.84	10.92	10.78	10.68	10.74	11.05	11.15	11.12
	%	98.2	97.2	94.4	92.4	90.5	89.4	88.2	86.4
	T°C	10.7	10.3	9.6	9.3	7.6	6.5	5.2	5.0
M	mg/l	10.66	10.89	10.90	11.12	11.11	11.30	11.51	10.74
	%	96.0	96.3	96.9	96.5	91.2	90.5	90.0	84.3
	T°C	10.8	10.1	9.8	9.4	7.3	6.0	5.2	5.0
N	mg/l	10.30	10.34	10.46	10.16	10.42	10.48	10.60	10.66
	%	92.4	92.0	91.7	86.9	85.9	85.2	83.6	84.2
	T°C	10.8	10.2	9.7	8.8	7.0	6.4	5.4	5.3

May 29, 2012 – Transect 1

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
A	mg/l	10.22	10.14	10.05	10.17	10.12	10.05	9.97	
	%	98.8	97.9	96.8	90.9	90.6	89.0	88.0	
	T°C	13.9	13.8	12.9	10.5	10.3	10.1	9.8	
B	mg/l	10.30	10.15	10.35	10.38	10.15	10.11	10.19	10.33
	%	99.6	98.3	96.7	93.3	89.5	89.6	90.2	90.2
	T°C	13.8	13.7	11.9	10.6	10.3	10.1	9.8	9.4
C	mg/l	10.21	10.23	10.26	10.38	10.29	10.12	10.15	10.05
	%	98.0	98.8	100.1	94.8	92.3	88.9	88.6	88.6
	T°C	13.7	13.7	12.5	11.3	10.5	10.1	9.5	9.3
	mg/l	10.53	10.19	10.17	9.85	10.01	9.88	9.73	

D	%	102.1	98.2	96.0	89.4	89.0	87.6	85.4	
	T°C	13.9	13.8	12.5	10.7	10.4	9.9	9.8	
E	mg/l	10.24	10.19	10.15	10.02	10.09	10.03		
	%	99.5	99.2	94.4	91.3	89.6	89.0		
	T°C	13.9	13.8	12.2	11.5	10.2	10.1		

May 29, 2012 – Transect 2

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
F	mg/l	10.13	10.09	10.05	9.89	9.85	9.90	9.86	9.86
	%	97.3	97.0	92.3	91.0	89.1	88.5	87.2	87.2
	T°C	13.5	13.5	11.8	11.6	10.9	10.3	10.1	9.8
G	mg/l	10.15	10.08	10.12	10.00	9.94	9.92	9.95	10.01
	%	96.1	96.0	94.6	92.3	89.8	89.6	89.4	89.8
	T°C	13.2	12.9	12.1	11.7	11.1	10.8	10.7	10.5
H	mg/l	10.07	10.43	10.12	10.15	10.15	10.19	10.30	10.28
	%	97.0	97.2	93.9	92.7	93.3	93.7	92.5	91.8
	T°C	13.6	13.0	11.9	11.5	11.3	11.2	10.2	10.0
I	mg/l	10.06	9.91	9.89	9.90	9.90	9.90	9.83	9.85
	%	94.3	93.4	93.8	91.8	91.0	90.1	89.2	87.4
	T°C	13.0	12.6	12.3	12.1	11.8	11.2	10.7	10.1

May 29, 2012 – Transect 3

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
J	mg/l	9.84	9.86	9.80	9.72	9.67	9.57		
	%	93.6	93.1	91.6	90.0	89.7	88.2		
	T°C	13.3	12.7	12.3	12.1	11.9	11.6		
K	mg/l	9.81	10.00	10.25	10.35	10.20	9.95	9.87	9.92
	%	94.6	95.2	95.4	97.0	94.0	90.9	88.9	87.5
	T°C	13.6	13.6	12.4	12.2	11.6	11.5	10.4	10.0
L	mg/l	9.70	9.69	9.72	9.82	9.66	9.68	9.64	9.63
	%	93.6	92.0	91.4	91.6	90.0	87.6	87.2	85.6
	T°C	13.6	13.2	12.3	12.1	12.1	11.2	11.1	10.1
M	mg/l	10.64	10.11	10.12	10.06	10.00	9.96	9.88	9.92
	%	96.4	95.9	96.0	94.0	93.1	92.3	89.6	88.1
	T°C	13.5	13.4	13.2	12.2	12.1	12.0	10.9	10.2
N	mg/l	10.18	10.38	10.35	10.34	10.29	10.10	9.86	10.02
	%	98.5	99.5	98.0	96.1	96.6	93.9	91.2	88.8
	T°C	13.2	13.3	12.8	12.6	12.4	12.2	11.6	10.2

June 2, 2012 – Transect 1

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
A	mg/l	9.83	9.87	9.75	9.62	9.52	9.7	9.58	9.88
	%	94.0	94.3	92.0	87.5	84.2	81.7	79.0	78.2
	T°C	13.5	13.4	12.7	12.0	9.7	8.8	7.0	5.5
B	mg/l	10.60	10.62	10.62	10.19	10.35	10.40	10.49	10.78
	%	101.3	101.3	99.8	95.3	90.4	88.1	86.2	85.3

	TºC	13.4	13.4	12.8	11.9	9.6	8.2	7.1	5.6
C	mg/l	10.45	10.51	10.50	10.10	10.26	10.22	10.41	10.50
	%	100.4	100.0	98.7	91.4	89.5	87.8	84.3	84.0
	TºC	13.5	13.5	12.8	10.8	9.4	8.8	7.1	5.9
D	mg/l	10.58	10.64	10.61	10.11	10.32	10.32	10.14	
	%	100.4	100.5	99.9	91.5	90.5	88.0	83.9	
	TºC	13.1	13.1	12.8	11.0	9.6	8.8	7.7	
E	mg/l	10.76	10.95	10.94	10.10	10.45			
	%	101.4	104.1	102.9	96.6	90.8			
	TºC	13.5	13.0	12.8	10.8	9.6			

June 2, 2012 – Transect 2

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
F	mg/l	10.38	10.81	10.50	10.30	10.03	10.03	10.41	10.65
	%	98.5	100.3	99.5	94.9	88.2	86.0	85.3	84.7
	TºC	13.3	13.2	13.0	12.6	9.2	8.4	6.7	5.8
G	mg/l	10.25	10.00	9.93	10.76	9.81	10.31	10.16	10.85
	%	95.4	95.5	95.6	95.9	85.8	97.3	92.8	87.0
	TºC	13.3	13.2	12.8	11.3	9.5	8.7	7.2	5.9
H	mg/l	10.32	10.21	10.36	10.62	10.32	10.53	10.31	10.56
	%	97.3	100.0	98.4	100.	89.0	90.5	87.5	85.4
	TºC	13.3	13.2	12.8	10.8	9.5	8.4	7.7	5.9
I	mg/l	10.78	10.71	10.71	9.94	9.74	9.99	10.15	10.26
	%	102.8	103.0	101.5	90.5	86.2	85.3	83.7	83.5
	TºC	13.2	13.1	12.8	11.6	9.4	8.6	7.1	6.3

June 2, 2012 – Transect 3

		Surface	1 m	2 m	3 m	4 m	5 m	6 m	7 m
J	mg/l	10.15	10.25	10.20	10.19	10.06	10.18	10.30	
	%	98.9	97.9	96.5	87.4	86.5	85.8	84.5	
	TºC	13.5	12.9	12.7	9.4	8.8	8.3	7.0	
K	mg/l	10.04	10.00	9.94	10.24	10.11	10.15	10.21	10.44
	%	96.0	94.7	94.0	89.5	86.6	85.5	85.2	83.1
	TºC	13.1	12.9	12.6	9.4	8.7	8.0	7.5	5.9
L	mg/l	9.96	10.06	10.36	10.11	10.31	10.35	10.72	11.03
	%	95.2	99.9	97.4	89.0	90.0	88.1	87.0	87.2
	TºC	13.1	12.7	12.6	9.8	9.2	8.4	6.2	5.3
M	mg/l	9.89	9.90	9.75	9.80	9.80	9.89	9.95	10.37
	%	94.5	92.7	90.7	87.1	85.7	83.5	82.5	81.6
	TºC	12.8	12.6	11.9	10.4	9.6	8.0	6.9	5.3
N	mg/l	10.07	10.11	10.34	10.26	10.34	10.00	10.32	10.58
	%	94.5	95.6	93.0	92.0	90.3	87.4	86.0	85.4
	TºC	12.8	12.9	12.2	10.3	10.0	9.5	7.6	6.4