LIMNOLOGICAL AND FISHERY INVESTIGATIONS CONCERNING SOCKEYE SALMON PRODUCTION IN SIXMILE LAKES, ELMENDORF AIR FORCE BASE, ALASKA

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INTRODUCTION

Sixmile Lake on Elmendorf Air Force Base, Anchorage, Alaska, supports anadromous populations of sockeye salmon (*Oncorhynchus nerka*), coho salmon (*Oncorhynchus kisutch*), and pink salmon (*Oncorhynchus gorbuscha*). The sockeye population is the largest of the three salmon stocks. An assessment of the adult sockeye salmon population was initiated in 2001 and continued in 2002 (Gotthardt 2003). However, little is understood about the population characteristics of juvenile sockeye salmon rearing in the Sixmile Lake system. As part of a comprehensive assessment of the Sixmile sockeye stock, a study of smolt outmigration and an assessment of lake limnological characteristics was conducted in 2003 to complement the 2001-02 study on the adult salmon population.

The objectives of this study were to determine: 1) absolute abundance and timing of the sockeye salmon smolt outmigration; 2) age and length characteristics of the sockeye salmon smolt outmigration; and 3) abundance and timing of other downstream migrants. Limnological investigations were conducted to assess the health of the Sixmile Lake system in relation to rearing habitat. The combined results of this study will be used to make recommendations to managers about smolt outmigration abundance and timing, in-lake productivity, and limnology-based habitat capacity estimates.

STUDY SITE DESCRIPTION

This study occurred over spring and summer, 2003, on Upper and Lower Sixmile Lakes, Elmendorf Air Force Base, Anchorage, Alaska (Figure 1). The Sixmile Creek Basin, which includes Sixmile Creek, Lower Sixmile Lake, and Upper Sixmile Lake, occupies a valley created by an old channel of the Eagle River. The system is charged primarily by springs entering the south side of Upper Sixmile Lake. The creek is now flooded for most of its length by the waters of Upper and Lower Sixmile Lakes, which were created by damming Sixmile Creek in 1951. Improvements to Talley Avenue crossing the upper portion of the system in 1996 included the addition of a fish ladder-culvert easing fish access into Upper Sixmile Lake. Much of the old creek channel is still visible in the lakes. Sixmile Creek is approximately 1.5 kilometers long and flows into Cook Inlet.

METHODS

<u>Fisheries Assessment</u>

At Lower Sixmile Lake, emigrating smolts were captured with a fyke trap at the lake outlet, positioned just above the fish ladder and extending to just beneath the edge of the bridge above Sixmile Creek. Smolts entered the trap through a 1.5-m^2 tunnel that narrowed to a cylindrical entrance to the trap. The trap was rectangular in shape with 1.0 m x 0.85 m x 0.80 m (L x W x H) dimensions and with a funnel-shaped entrance positioned on the upstream side. Meshed wings attached to the fyke trap extended from each side of the tunnel entrance to shore, effectively fishing the entire stream width. The area fished was approximately 5 m wide with a maximum depth of 0.5 m. The fyke net was installed on 14 May and began fishing at 1300 hr. The fyke system fished continuously until 23 June when it was removed from the creek at 0900 hr.

Figure 1. Map of Upper and Lower Sixmile Lakes, Elmendorf Air Force Base, Anchorage, Alaska.

Throughout the outmigration period all smolt exiting the system were enumerated. Smolt were counted by hand and identified to species. A sampling goal of 600 smolt over the duration of outmigration was established to measure length and weight. Fork length was measured from the tip of the snout to the fork of the tail to the nearest 0.1 mm and mass was measured to the nearest 0.1 g. Scale samples were taken from the preferred area (below the posterior insertion of the dorsal fin and above the lateral line), mounted on microscope slides, and labeled. Smolt were anesthetized prior to collecting size information and scale samples. Scale aging was accomplished using a microfiche reader and a dissecting microscope.

Limnological Assessment

During 2003, we conducted four limnological surveys at Upper and Lower Sixmile Lakes. A canoe was used during sampling trips. Within each lake, four stations were sampled in areas of maximum depth (Figure 2). Anchored buoys were deployed at each sampling station to insure that stations remained consistent throughout the sampling period. Data were collected approximately every 4 weeks between early June and late September at each station. We measured water column temperatures, dissolved oxygen levels, conductivity, and pH. Vertical profiles of these parameters were measured at .3 m increments from the surface of the lake to the bottom using a Hydrolab water quality multi-probe. Water transparency was measured with a 20 cm black and white Secchi dish. Zooplankton samples were collected by vertical tows from 1m above the bottom to the surface using a 153-μm-mesh conical net 0.2 or 0.5 m in diameter.

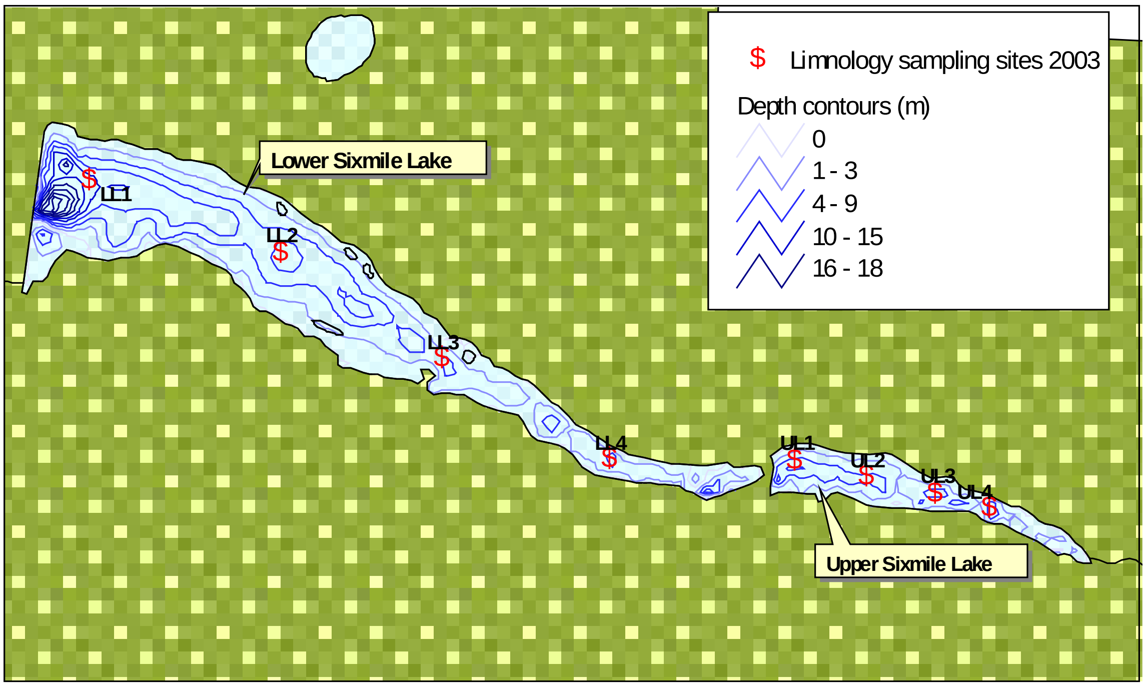

Figure 2. Limnological sampling station locations, Upper and Lower Sixmile Lakes, 2003.

RESULTS

Fisheries Assessment

A total of 20,113 sockeye salmon smolt were enumerated leaving Lower Sixmile Lake between 14 May and 23 June, 2003 (Figure 3). Other smolt species counted included 49 coho and 7 chinook salmon. One major peak occurred in the daily fyke net catches, between 11 June and 13 June, when 6,272 sockeye smolts were captured (11 June, n = 1,076; 12 June, n = 3,660; 13 June, n = 1,536). Other dates when daily counts exceeded 1,000 smolt were May 23 (n = 1,383), May 31 (n = 1,047), and June 7 (n = 1,104) (Figure 4). Outmigration was about 95% complete by 14 June, but counting was continued until 23 June, when only two fish were captured. During the period of smolt outmigration, stream temperatures at the fyke trap averaged 16.6°C and ranged from 13.0 to 21.0°C. During the peak of outmigration, 11 – 13 June, water temperature was about 19.0°C.

Characteristics of the smolt migration were evaluated from scale samples collected throughout the migration and from measurements of length and weight. A total of 579 sockeye smolts were sampled for age and size estimation. Fish with one freshwater annulus were designated as an age-1 smolt, fish with two freshwater annuli were designated as age-2 smolt, and no evidence of freshwater annuli indicated young-of-the-year (YOY) or fry. Based on these samples and measurements, an estimated 69.7% of the sockeye smolts were age-1, 9.4% were age-2, and 20.9% were YOY. There were no age 3 smolts. The average length and weight of age-1 smolts was 85.6 mm (± 0.46) and 6.6 g (± 0.21); age-2 smolts averaged 99.4 mm (± 2.56) and 10.1 g (± 1.03); and YOY averaged 52.6 mm (± 1.14) and 1.6 g (± 1.14) (Table 1).

Table 1. Age structure, length and weight characteristics of Sixmile sockeye smolt, 2003.

Age Class	**Age Class %**	**Mean length (mm) (range)**	**95% CI**	**Mean weight (g) (range)**	**95% CI**
YOY	20.9	52.6 (37.0 - 79.0)	(± 1.14)	1.6 (0.9 - 3.9)	(± 1.14)
1	69.7	85.6 (78.0 - 100.0)	(± 0.46)	6.6 (4.6 - 10.6)	(± 0.21)
2	9.4	99.4 (84.0 - 115.0)	(± 2.56)	10.1 (6.1 - 14.7)	(± 1.03)
Mean		80.2		6.0	

Based on sampling data, mean smolt size (combination of length and weight) remained relatively constant from 21 May to 9 June. On 10 June, a marked decrease in size was observed. From 10 June throughout the remainder of the outmigration period, 96% of smolts sampled were YOY (Figure 5).

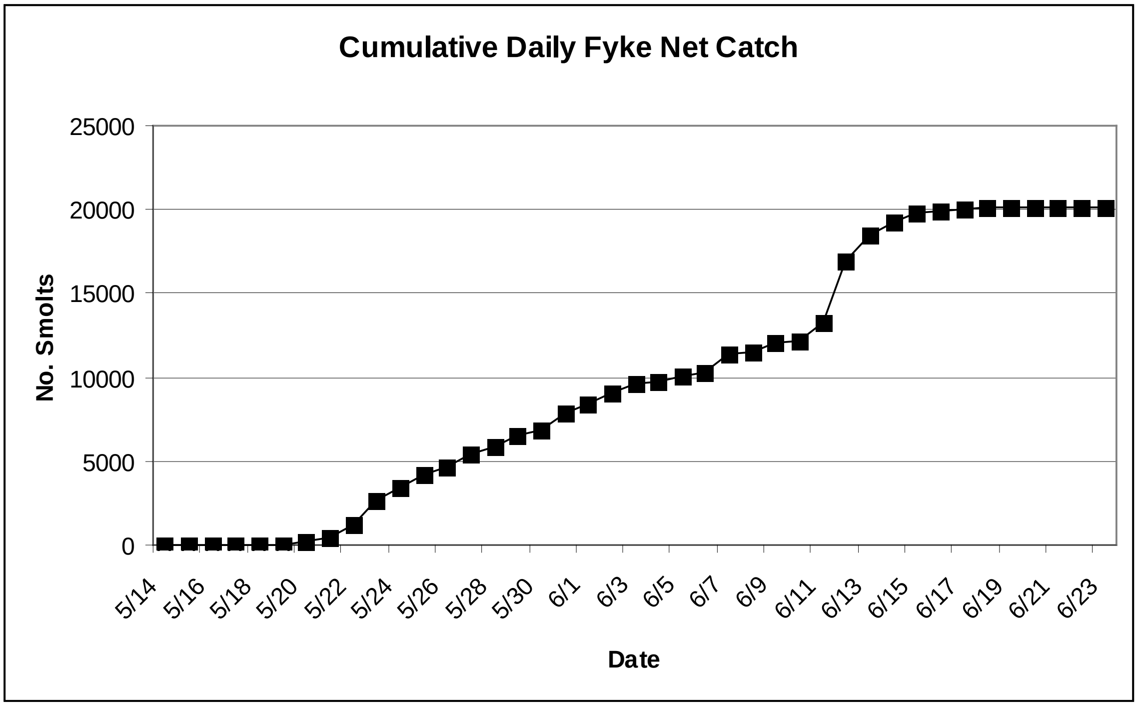

Figure 3. Cumulative daily fyke net catch during 2003 smolt outmigration, Sixmile Lakes.

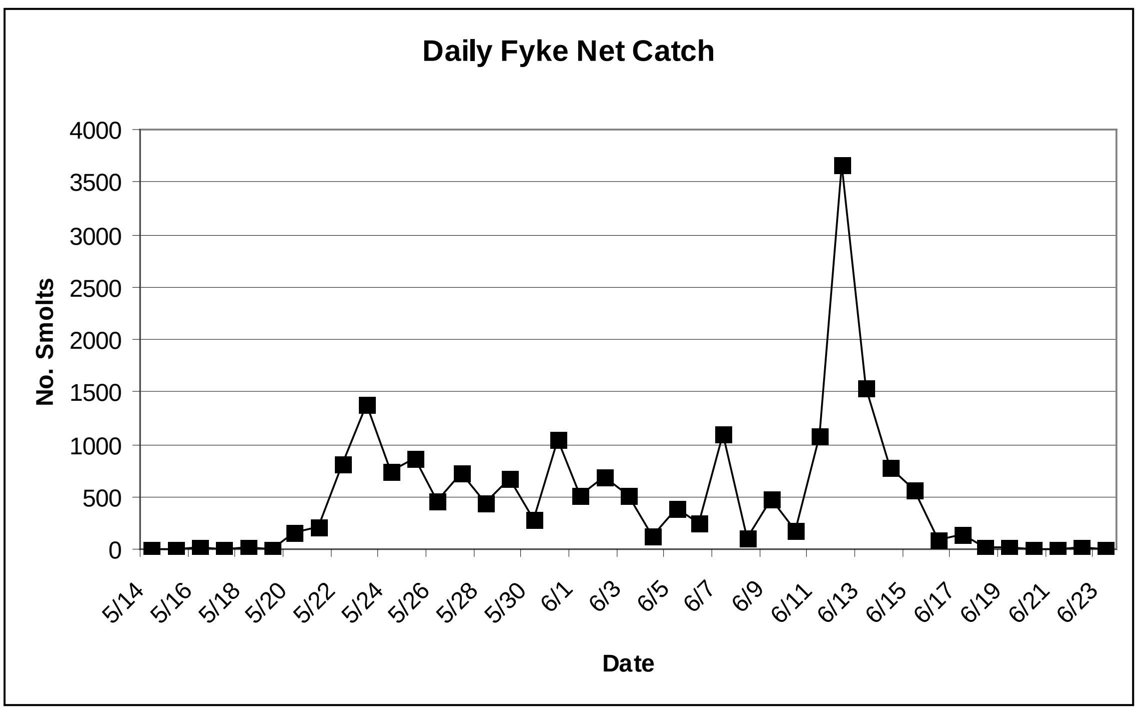

Figure 4. Daily fyke net catch during 2003 smolt outmigration, Sixmile Lakes.

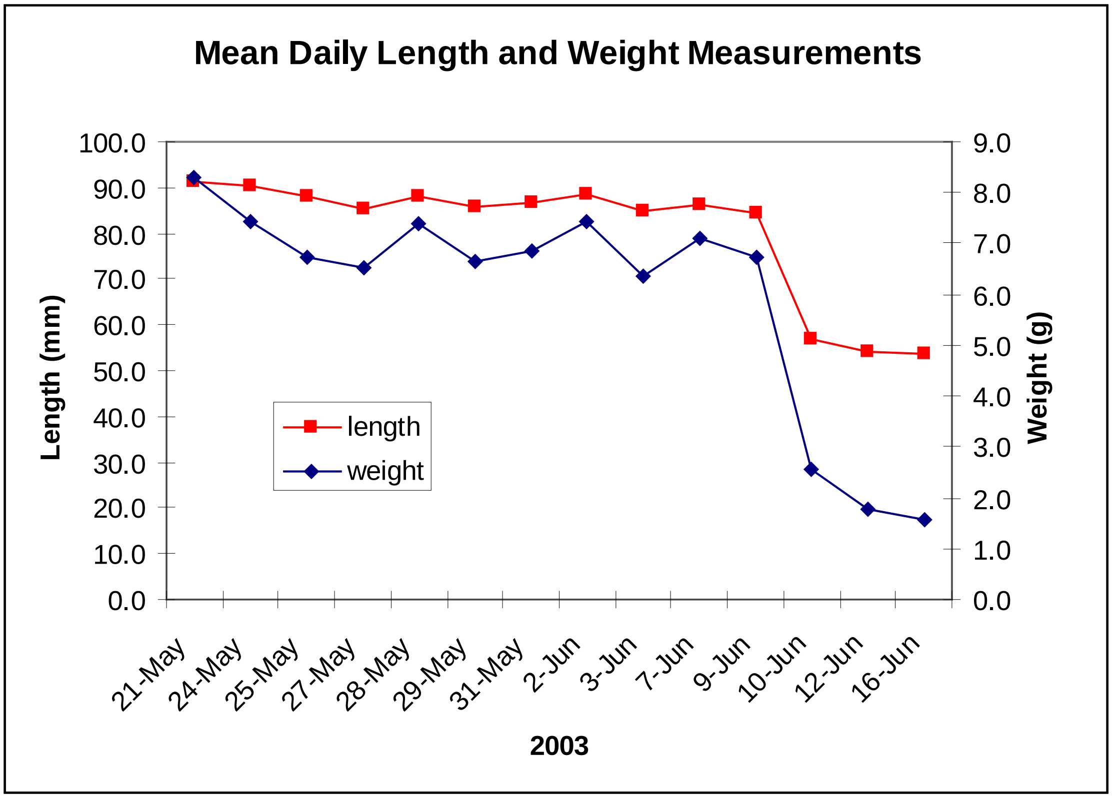

Figure 5. Mean daily length and weight measurements for Sixmile Lakes sockeye smolts, spring 2003.

Limnological Assessment

Morphometry and Physical Environment

Lower Sixmile Lake has a surface area of 48.9 hectares, a mean depth of 1.9 m, a maximum depth of 5.5 m, and a volume of 96.6 x 10^3 m^3. Upper Sixmile Lake is smaller than Lower Sixmile and has an area of 10.4 hectares, a mean depth of 1.1 m, a maximum depth of 2.7 m, and a volume of 17.44 x 10^3 m^3 (see Gotthardt 2003). A culvert connects Upper Sixmile Lake to Lower Sixmile Lake, allowing fish to move between the two lakes. Lower Sixmile Lake empties into Sixmile Creek, which flows into Cook Inlet in the Knik Arm (Rothe et al. 1983).

Limnological Characteristics

Limnological conditions were fairly consistent between lakes throughout the study (Table 2). Both Upper and Lower Sixmile Lakes were quite clear between spring and fall, 2003. Secchi transparencies were to the bottom at all stations during each of the sampling periods, except for the deepest station LL4 (approximately 4 m deep) where Secchi recordings were only to 3 m.

Thermal stratification was not observed in either lake during the sampling period (see Appendix I for temperature measurements at each station by strata). Because these lakes are relatively shallow (<5.5m), wind action probably keeps them well mixed. Since limnological sampling did not begin until 4 June, it is possible that the lakes turned over completely prior to this date. Maximum surface water temperatures reached 20.0-21.0 °C in both lakes by mid-July. Upper Sixmile Lake was slightly cooler (mean water temperature 13.8 °C for the four month sampling period) than the lower lake, which had a mean temperature of 16.8 °C (Table 2).

Dissolved oxygen values (DO; expressed here as percent saturation) for Lower Sixmile Lake ranged from 72.3% to 141.9%, with a seasonal average of 103.9%. Values for Upper Sixmile Lake were slightly higher, ranging from 104.8% to 146.7%, and averaged 130.5% (Table 2). DO% values were similar throughout the entire water column, reiterating the fact that Sixmile Lakes are not stratified during the summer, likely the result of shallow water and little turbidity (see Appendix I).

Chemical Characteristics

Both lakes were slightly basic with pH values ranging consistently between 8.0 and 8.8. Mean pH for Upper Sixmile Lake for was 8.4, and 8.5 for Lower Sixmile Lake. Both lakes had high ion (dissolved solids) content as evidenced by high conductivity values of 142.0 – 217.1 μmhos/cm (Table 2).

Biological Productivity

In addition to a lake's chemical properties, morphological characteristics also play an important role in biological productivity. The morphoedaphic index (MEI) combines chemical and morphological characteristics to assess lake productivity (Ryder 1965 in Rothe et al. 1983). MEI is defined as total dissolved solids divided by mean lake depth. Conductivity values are correlates of total dissolved solids, and have been used widely in Alaska to determine MEI (Rothe et al. 1983).

Conductivity was measured periodically throughout spring and summer 2003. Here, we use only conductivity values obtained during spring turnover in early June, 2003, to compare to similar measurements taken at Upper and Lower Sixmile Lakes in early spring, 1983. MEI for Lower Sixmile Lake in 2003 was 26.4, slightly lower than 29.1 reported in 1983. Conversely, MEI was higher for Upper Sixmile Lake in 2003 at 56.8 than in 1983 when it was 50.1 (see Rothe 1983).

Zooplankton Species Composition

The macrozooplankton community of both Upper and Lower Sixmile Lakes was relatively simple and composed of cladocerans – *Bosmina* sp., *Daphnia* sp., *Chydorinae* sp., and *Macrothricidae* sp. – and one copepod, *Cyclops* sp. Samples were stored following standard protocols using 100% ethanol solution. When we began to analyze the samples to differentiate species, we realized that many of the samples had become degraded over time. Therefore, we were unable to calculate zooplankton density or biomass for either of the lakes. Based on patterns observed from a limited number of samples, zooplankton numbers were highest during the August sampling period. This is a common pattern of development for cladoceran populations.

Table 2. Summary of limnological measurements taken at Upper and Lower Sixmile Lakes, spring and summer 2003.

		Lower Sixmile Lake				
Site No.	**Date**	**Depth (m)**	**Temp.**	**DO%**	**SPC***	**pH**
LL1	4-Jun	1.0	15.4	137.0	215.5	8.3
	22-Jul	1.0	16.4	83.6	217.1	7.7
	29-Aug	1.0	12.0	108.6	200.1	
	19-Sep	1.0	6.4	99.5	212.2	8.1
	Mean		**12.5**	**107.2**	**211.2**	**8.0**
LL2	4-Jun	1.6	17.7	142.7	162.9	8.8
	22-Jul	1.6	21.0	80.9	168.1	8.0
	29-Aug	1.6	15.1	111.9	163.0	
	19-Sep	1.6	6.4	99.5	212.5	8.2
	Mean		**17.2**	**111.2**	**164.8**	**8.4**
LL3	4-Jun	3.0	17.6	141.9	156.2	8.8
	22-Jul	3.0	21.3	72.3	159.3	8.0
	29-Aug	3.0	15.5	111.5	162.2	
	19-Sep	3.0				
	Mean		**18.5**	**101.1**	**159.7**	**8.2**
LL4	4-Jun	3.3	17.6	123.9	157.1	8.7
	22-Jul	3.3	21.2	83.2	142.0	8.3
	29-Aug	3.3	15.8	100.5	156.0	
	19-Sep	3.3	9.8	98.7	154.1	8.5
	Mean		**16.5**	**100.6**	**145.8**	**8.1**
Total all sites						
	Mean		**16.8**	**103.9**	**165.5**	**8.5**

*SPC = conductivity.

		Upper Sixmile Lake				
Site No.	**Date**	**Depth (m)**	**Temp.**	**DO%**	**SPC**	**pH**
UL1	4-Jun	1.6	14.8	131.9	204.4	8.4
	15-Jul	1.6	19.3	132.1	213.4	8.2
	2-Sep	1.6	13.1	134.1	188.3	
	19-Sep	1.6	7.3	107.4	198.5	8.3
	Mean		**14.0**	**127.4**	**201.3**	**8.3**
UL2	4-Jun	1.3	15.3	135.7	195.6	8.5
	15-Jul	1.3	20.6	110.1	199.6	8.4
	2-Sep	1.3	13.4	146.7	185.9	
	19-Sep	1.3	7.0	132.8	199.4	8.3
	Mean		**14.6**	**132.1**	**194.9**	**8.4**
UL3	4-Jun	1.3	15.6	146.7	193.7	8.6
	15-Jul	1.3	20.8	132.8	198.5	8.4
	2-Sep	1.3	13.0	137.5	183.8	
	19-Sep	1.3	6.5	110.1	199.4	8.3
	Mean		**13.9**	**132.1**	**193.2**	**8.4**
UL4	4-Jun	1.0	13.7	145.8	201.7	8.5
	15-Jul	1.0	16.7	140.8	204.1	8.4
	2-Sep	1.0	11.3	129.4	181.4	
	19-Sep	1.0	4.4	104.8	213.4	8.0
	Mean		**12.1**	**131.4**	**200.6**	**8.3**
Total all sites						
	Mean		**13.8**	**130.5**	**197.3**	**8.4**

DISCUSSION

Fisheries Assessment

Upper and Lower Sixmile Lakes were formed by the construction of a dam across Sixmile Creek in 1951 (Ravenstein 1952). Sockeye salmon colonization took more than twenty years. The first 50 adult fish were observed in 1975, the same year that a fish ladder was installed at the dam spillway of Lower Sixmile. Annual monitoring of returning adult sockeye salmon did not begin until 1988, and since that time escapement has ranged between 663 and 4282 individuals per year. A complete limnological assessment of the Sixmile Lake system was performed in 1983 as part of the Natural Resource Inventory of Elmendorf Air Force Base (Rothe et al. 1983). To our knowledge, this is the first assessment of juvenile sockeye salmon outmigration patterns that has been undertaken for the Sixmile Lake system.

Young sockeye salmon normally reside in their natal lake for one or two years, three years in some regions of Alaska, and rarely to four years, while feeding on pelagic plankton before migrating out to sea as smolts (Miller and Brannon 1982). There seems to be no general rule regarding threshold size for smoltification among populations (Burgner 1987). The majority of smolts that outmigrated from the Sixmile Lake system during 2003 were age-1, less than 10 percent were age-2, and an unexpected 21 percent of outmigrants were YOY. Fry do not typically leave their natal lakes for at least one year, although they do undergo migrations from spawning areas to rearing areas, and fry hatching in creeks have been observed moving upstream or downstream into nursery lakes (Burgner 1987). In British Columbia, McCart (1967) observed that with upstream migrating fry there is an initial downstream movement, a period of holding, and an eventual return upstream, and that upstream movement generally does not begin until the daily mean water temperature exceeds 8°C. Fry were not observed leaving Lower Sixmile Lake until mid- June, once the majority of age-1 and age-2 smolts had already exited the system, and water temperatures at the fyke trap averaged 19°C.

Why YOY fish left the Sixmile system prematurely in 2003 is unknown. It is possible that while feeding in the shallow littoral zone under the Sixmile bridge they were swept toward the lake outlet by currents generated by the fish ladder and were not strong enough to swim upstream, back into the lake. If fry had not been captured in the fyke trap, it is likely that they would have been swept downstream into Sixmile Creek through the fish ladder. Once in the creek, it is unlikely that these young fish would have been able to return to the lake, as the steep angle of the fish ladder makes it impassible to juvenile fishes.

If YOY are excluded from the analysis, the ratio of age-1 to age-2 fish becomes 88% to 12%. This is similar to age structure ratios reported from other sockeye smolt sampled elsewhere in Cook Inlet. In Central Cook Inlet at Hidden Lake, the 28 year (1976-2003) average sockeye return ratio was 91% age-1 to 9% age-2; this same ratio was observed at Big Lake in Upper Cook Inlet during 2002 and 2003 (Dodson 2004a and b). The observed ratio for adult sockeye returning to the Sixmile system during 2002 and 2003 was 77% age-1 and 23% age-2 (Gotthardt 2003), a pattern similar to that observed during outmigration, suggesting that the majority of sockeye salmon leaving the Sixmile system are age-1.

The quality (i.e. age and size) and quantity of smolts are important indicators of lake rearing conditions and eventual production of harvestable adults (Koenings and Burkett 1987). Within age-classes, Sixmile salmon exhibited some variation in size, yet mean sizes were comparable to sockeye smolt from other systems in the Cook Inlet region (Table 3). Sockeye smolt from Sixmile Lakes were of intermediate size compared to nine other Cook Inlet stocks and most similar to smolts from Russian, Kasilof, Packers, and Tustemena Lakes, suggesting that rearing conditions in Sixmile Lakes may be similar to these historically productive salmon runs.

Based on the 2001 escapement estimates (~4,000), which produced the majority of the 2003 outmigration, and average fecundity of 3,500 eggs per female (Manzer and Miki 1986), and using standard freshwater survival estimates (e.g., 10% egg to fry; 10% fry to smolt) (Foerster 1968), the predicted fry recruitment to Sixmile Lake was approximately 700,000, which should have resulted in approximately 70,000 age-1 smolt. However, the actual number of smolts enumerated during outmigration was only about one third of that predicted (20,113), or about 4.4 smolts per spawner. While this ratio seems inherently low, in a similar study conducted at Desire Lake on the Kenai Peninsula, an adult escapement of 15,800 yielded a smolt to spawner ratio of 6:1, while at neighboring Delight Lake the smolt to spawner ratio was 40:1 for the same size escapement (Edmundson et al. 2001). Edmundson et al. (2001) suggested that the lower survival rates reported for Desire Lake compared to Delight Lake were related to decreased in-lake zooplankton availability.

Limnological Conditions Relative to Sockeye Salmon Production

While the Sixmile Lake system is fairly large and has produced adult sockeye salmon returns in excess of 4,000 fish, the annual trend in escapement between years is highly variable. Ocean survival is a major contributor to this variability and is influenced by a suite of factors including temperature and salinity, food availability, predation and interception in commercial and subsistence fisheries. Another factor contributing to interannual variability in stock size is juvenile survival. Juvenile salmonids face a suite of factors within their natal lakes which determine their ability to survive prior to smoltification. Physical conditions affecting growth potential in sockeye lakes include water temperature and thermal stratification, dissolved oxygen concentrations, photoperiod, and turbidity and available light in the water column. Zooplankton availability, intra- and inter-specific competition, and predation also play important roles in smolt survival (Burgner 1987). Based on a limited number of limnological measurements taken during spring and summer 2003, the conditions in Upper and Lower Sixmile Lakes, while not optimal, appeared suitable for juvenile sockeye rearing.

Lake temperature and temperature stratification affect the diel feeding behavior and depth preferences of juvenile sockeye (Burgner 1987). Optimum spawning temperatures for

Table 3. Age structure, length, and weight characteristics of sockeye smolt from various lakes or lake systems in the Cook Inlet basin (adapted from Burgner 1987).

Lake or lake system	**Age**	**Mean length (mm)**			**Mean weight (g)**			**Source**
		No. yr.	**Avg.**	**Range**	**No. yr.**	**Avg.**	**Range**	
Sixmile	1	1	86		1	6.6		this study
	2	1	99		1	10.0		
Larson	1	1	77		1	3.7		Lebida 1984
Hidden	1		143			27.3		Koenings et al. 1984
	2		200			83.9		
Hidden	1	28	136		28	21.6		Dodson 2004a
	2	28	181		28	57.3		
Big	1		132			25.5		Koenings et al. 1984
	2		166			48.1		
Big	1	2	126		2	22.0		Dodson 2004b
	2	2	161		2	41.2		
Bear	1	24	113		24	13.3		Dodson 2004c
	2	24	147		24	33.3		
Russian	1		84			5.1		Koenings et al. 1984
	2		93			6.5		
Kenai	1		62			2.1		Koenings et al. 1984
	2		72			3.1		
Crescent	1	2	69	68-69	2	2.8	2.7-2.8	Koenings et al. 1984
	2	2	76	76-76	2	3.7	3.6-3.8	
Kasilof	1	5	70	68-73	5	2.9	2.7-3.3	Flagg et al. 1985
	2	5	85	82-90	5	5.1	4.8-5.3	
Packers	1	3	83	74-96	3	5.2	3.4-7.9	Koenings and Burkett 1987
	2	3	97	88-104	3	7.5	5.4-9.4	
	3	1	113		1	11.6		
Tustemena	1	5	70	68-73	5	2.9	2.8-3.3	Koenings and Burkett 1987
	2	5	85	82-88	5	5.1	4.8-5.2	

sockeye salmon range between 10.6 and 12.2°C, while incubation temperatures for successful hatching are between 4.4 and 13.3°C (Reiser and Bjomn 1979). Donaldson and Foster (1941) found that fingerling growth rates were fastest and mortalities lowest at water temperatures between 8.9 and 10.0°C. Low temperatures of 3.9-7.2°C as well as high temperatures above 23°C produced poor growth, low food utilization, and high mortality. Brett (1971) described the physiological optimum for sockeye salmon as 15°C and although they may tolerate temperatures to 24°C, sockeye are generally limited at temperatures above 18°C.

Water temperature in Sixmile Lakes was generally favorable for fry growth during summer 2003. Upper Sixmile Lake was slightly cooler than the lower lake, with an average temperature of 13.8°C (range 7.0-20.8°C) compared to 16.8°C (range 6.4-21.3°C). While these averages were within optimal ranges, water temperatures during July did exceed 20°C in both lakes. Additionally, temperature stratification did not occur during summer 2003, thereby limiting the availability of cooler deeper water generally present in stratified systems. Constant high temperatures have been correlated with slower growth in juvenile salmon because of energy loss from high respiration rates (Biette and Geen 1980a). Diel migration in thermally stratified lakes has been shown to increase the growth rate as a consequence of exposure to a 24-hour cycle of variation in temperature compared to juvenile fish exposed to constant high or low temperatures (Biette and Geen 1980b). High water temperatures and lack of thermal stratification could limit fry growth and overall juvenile productivity, especially during peak summer months or during exceptionally warm years.

Dissolved Oxygen levels are important indicators of a water body's ability to support aquatic life. Generally, DO levels of 80 – 125% are excellent for most aquatic organisms. DO levels in Lower Sixmile Lake were optimal for sockeye rearing (average 103.9%) and indicative of a healthy system, while levels in the upper lake were substantially higher (average 130.5%). Similar to water temperature measurements, DO levels were fairly uniform throughout the water column. The high DO levels recorded in Upper Sixmile Lake may be the result of an influx of cold, oxygentated water entering the lake from numerous freshwater springs located along the southern shore. Photosynthesis of vegetation may also infuse oxygen into the water. The fact that Upper Sixmile Lake is fairly shallow (mean depth 1.1 m) with abundant aquatic vegetation may also have contributed to the observed high DO values.

The morphoedaphic index has been used to estimate potential yield of commercial fishes in both Canadian and U.S. lakes (Ryder 1965). Assuming that sockeye salmon can survive equally well in high or low productivity lakes, fish growth can be directly correlated to MEI (Rothe et al. 1983). Based on MEI values calculated during this study, fish growth rate would be expected to be higher (by over 50%) in Upper Sixmile Lake than in the lower lake. MEI values calculated in 1983 were similar to those obtained during this study (Lower Sixmile values slightly lower in this study, Upper Sixmile values slightly higher), suggesting that sockeye production in Sixmile Lakes has not changed noticeably over the past twenty years. Adult escapement counts, recorded since

1988, support this observation. Although counts have fluctuated between years, the Sixmile sockeye salmon return has remained small, averaging 2,100 returning adults, and ranging from returns of 663 (1999) to 4,282 (1995).

Juvenile salmon are pelagic schooling fish and are largely planktivorous. Their primary foods depend on the availability of seasonal zooplankton populations (Woodey 1972). Edmundson and Mazumder (2001) reported that food was the strongest single predictor of smolt size (mean length and weight), and that growth of juvenile salmon is directly related to zooplankton availability and temperature and inversely related to fish population density. Although we were unable to calculate zooplankton biomass estimates due to sample degradation, the average size of Sixmile Lake smolt in comparison to other highly productive sockeye stocks in the Cook Inlet basin (Table 3) suggests there is sufficient food to maintain adequate growth. Because the water column did not stratify during summer 2003, rearing sockeye juveniles were potentially able to utilize the entire water column for foraging. Furthermore, light penetration into Sixmile Lake was to the bottom in most cases, providing zooplankton with little refuge from visually attuned planktivores.

Limnological data suggest that juvenile salmon rearing conditions were comparable between Upper and Lower Sixmile Lakes, and that these conditions, overall, have changed little if any over the past 20 years (see Rothe et al. 1983). Both lakes were slightly basic, with pH values averaging 8.0 – 8.5, the same as those reported for Lower Sixmile Lake in 1982 (Rothe et al. 1983). Summer temperature stratification did not occur during 1982 and 1983 nor in 2003. During 2003, Upper Sixmile Lake was slightly cooler than the lower lake as a result of freshwater input from feeder creeks; this resulted in higher DO% concentrations which were considered favorable for fry growth. While slightly warmer, Lower Sixmile Lakes' DO% concentrations were within optimal ranges. DO values reported during 1982 were also high (>90%), with values for Upper Sixmile Lake being slightly higher (Rothe et al. 1983). In this study and in 1982, both lakes had high MEI values, suggesting they have high productivity potential, with Upper Sixmile Lake being the more productive of the two.

CONCLUSIONS AND RECOMMENDATIONS

Biological measurements (age and size) of smolt taken at outmigration during 2003 suggest healthy juvenile rearing conditions in the Sixmile Lake system. Sixmile smolts were average-sized compared to other runs in the Cook Inlet basin, and the majority were age-1, also similar to other Cook Inlet stocks. Limnological measurements from both lakes also suggest favorable conditions for juvenile rearing, and were largely similar to those recorded 20 years ago by Rothe et al. (1983). However, the low smolt survival ratios reported here suggest that some factor or combination of factors within Sixmile Lakes is limiting sockeye fry productivity. This study did not assess whether competition or predation were significant factors in fry survival, and suggest that they warrant further study. Zooplankton measurements taken during 2003 were inconclusive and should be repeated. Low smolt survival ratios reported from Desire Lake on the Kenai Peninsula were attributed to low zooplankton production, and the authors suggested nutrient enhancement to increase growth and survival potential. Temperature may also be a limiting variable to fry growth and production in the Sixmile system, mainly during summer when these shallow lakes heat up evenly throughout the water column. Continued monitoring of smolt outmigration is recommended, especially considering the unseasonably warm, dry summer that occurred in 2004. Fry rearing throughout 2004 should outmigrate during spring 2005. It will be interesting to note if higher than average water temperatures recorded during summer 2004 will have noticeable affects on size and productivity of age-1 and age-2 outmigrants in 2005.

Another factor that may limit juvenile survival is the density of sockeye fry themselves. The adult sockeye return, while variable between years, has remained at about 4,000 fish or less since 1988. It may be that the Sixmile Lake sockeye salmon stock is currently at carrying capacity and will not get any larger unless factors that are limiting populations are identified and remediation efforts undertaken. That is, of course, if the goal of management is to increase the size of the adult run available to sport-fishermen. Conversely, if there is no management mandate to increase the strength of the sockeye run, current lake conditions appear capable of supporting a small, self-sustaining run and current levels of sport harvest.

The number of fry that out-migrated during 2003 is of concern. It is possible that these fish were confused or following the current, and were swept out through the fish ladder accidentally. During summer 2001 and 2002 the author observed fry trying to jump and/or swim up the concrete foot of the fish ladder to return to the lake without success. A fish ladder that allows for fry/smolt passage into the lake is highly recommended.

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APPENDIX I

Appendix 1: Limnological measurements, by station and date, Upper and Lower Sixmile Lakes, June – September, 2003.

Lower Sixmile Lake

SITE	DATE	DEPTH_FT	TEMP(*C)	DO%	SPC	PH
LL1	6/4/2003	1.0	15.70	132.2	212.0	8.26
LL1	6/4/2003	2.0	15.59	135.7	212.3	8.27
LL1	6/4/2003	3.0	14.78	143.1	222.3	8.30
LL1	7/22/2003	1.0	17.69	86.9	198.9	7.84
LL1	7/22/2003	2.0	16.81	81.9	206.1	7.76
LL1	7/22/2003	3.0	14.63	82.1	246.3	7.54
LL1	8/29/2003	1.0	12.10	112.3	197.1	
LL1	8/29/2003	2.0	12.00	101.8	200.4	
LL1	8/29/2003	3.0	11.90	111.7	202.8	
LL1	9/19/2003	1.0	6.38	97.4	212.0	8.14
LL1	9/19/2003	2.0	6.35	99.5	212.1	8.15
LL1	9/19/2003	3.0	6.35	101.7	212.5	8.18
LL2	6/4/2003	1.0	17.83	139.9	160.6	8.74
LL2	6/4/2003	2.0	17.84	136.0	160.7	8.75
LL2	6/4/2003	3.0	17.83	132.9	160.3	8.76
LL2	6/4/2003	4.0	17.79	136.2	159.8	8.78
LL2	6/4/2003	5.0	17.27	168.6	163.4	8.89
LL2	7/22/2003	1.0	21.35	80.0	156.5	8.06
LL2	7/22/2003	2.0	21.08	76.9	159.2	7.99
LL2	7/22/2003	3.0	20.90	77.1	161.6	7.95
LL2	7/22/2003	4.0	20.85	82.8	163.2	7.90
LL2	7/22/2003	5.0	20.84	87.5	164.1	7.90
LL2	8/29/2003	1.0	15.30	111.1	162.0	
LL2	8/29/2003	2.0	15.30	107.2	161.9	
LL2	8/29/2003	3.0	15.20	112.8	161.7	
LL2	8/29/2003	4.0	15.10	115.2	161.0	
LL2	8/29/2003	5.0	14.80	113.4	168.4	
LL2	9/19/2003	3.0	6.35	101.7	212.5	8.18
LL3	6/4/2003	1.0	17.67	140.0	156.5	8.76
LL3	6/4/2003	2.0	17.66	140.6	156.5	8.78
LL3	6/4/2003	3.0	17.60	142.5	156.5	8.79
LL3	6/4/2003	4.0	17.58	141.1	156.0	8.82
LL3	6/4/2003	5.0	17.59	145.3	155.7	8.84
LL3	7/22/2003	1.0	21.36	81.3	144.7	8.16
LL3	7/22/2003	2.0	21.35	81.6	143.8	8.18
LL3	7/22/2003	3.0	21.34	79.4	144.8	8.15
LL3	7/22/2003	4.0	21.33	80.3	144.4	8.16
LL3	7/22/2003	5.0	21.33	82.6	143.3	8.18
LL3	7/22/2003	6.0	21.33	80.5	143.8	8.19
LL3	7/22/2003	7.0	21.33	80.3	143.7	8.15
LL3	7/22/2003	8.0	21.32	81.9	144.2	8.08

Appendix I. (continued)

SITE	DATE	DEPTH_FT	TEMP(*C)	DO%	SPC	PH
LL3	7/22/2003	9.0				
LL3	7/22/2003	10.0	21.22	58.0	168.2	7.41
LL3	7/22/2003	11.0	20.86	17.1	272.6	7.00
LL3	8/29/2003	1.0	15.60	105.9	160.2	
LL3	8/29/2003	2.0	15.60	100.6	160.2	
LL3	8/29/2003	3.0	15.60	101.0	160.1	
LL3	8/29/2003	4.0	15.60	111.1	160.3	
LL3	8/29/2003	6.0	15.60	115.5	160.3	
LL3	8/29/2003	7.0	15.50	110.8	160.1	
LL3	8/29/2003	8.0	15.40	114.7	163.1	
LL3	8/29/2003	9.0	15.30	133.0	173.0	
LL4	6/4/2003	1.0	17.28	124.7	157.8	8.63
LL4	6/4/2003	2.0	17.27	123.5	156.7	8.65
LL4	6/4/2003	3.0	17.27	122.3	156.6	8.67
LL4	6/4/2003	4.0	17.23	124.9	156.8	8.68
LL4	6/4/2003	5.0	17.19	122.8	157.0	8.69
LL4	6/4/2003	6.0	17.11	127.2	157.4	8.70
LL4	6/4/2003	7.0	16.96	124.2	157.6	8.71
LL4	6/4/2003	8.0	16.97	121.2	157.1	8.72
LL4	7/22/2003	1.0	21.29	85.5	141.2	8.36
LL4	7/22/2003	2.0	21.29	82.3	141.2	8.38
LL4	7/22/2003	3.0	21.29	81.5	141.3	8.38
LL4	7/22/2003	4.0	21.29	86.1	141.3	8.37
LL4	7/22/2003	5.0	21.27	82.4	141.3	8.37
LL4	7/22/2003	6.0	21.25	81.3	141.3	8.36
LL4	7/22/2003	7.0	21.24	78.7	141.3	8.30
LL4	7/22/2003	8.0	21.18	82.8	142.7	8.15
LL4	7/22/2003	9.0	21.03	86.5	144.0	8.08
LL4	7/22/2003	10.0	20.99	85.1	144.9	7.87
LL4	8/29/2003	4.0	15.70	100.0	155.5	
LL4	8/29/2003	5.0	15.80	100.8	156.1	
LL4	8/29/2003	6.0	15.80	99.8	156.3	
LL4	8/29/2003	7.0	15.80	99.1	156.2	
LL4	8/29/2003	8.0	15.80	103.0	156.1	
LL4	9/19/2003	3.0	9.85	99.5	154.4	8.50
LL4	9/19/2003	4.0	9.86	100.2	154.3	8.50
LL4	9/19/2003	5.0	9.83	97.0	154.1	8.49
LL4	9/19/2003	6.0	9.83	98.5	154.0	8.49
LL4	9/19/2003	7.0	9.82	98.0	153.8	8.47

Upper Sixmile Lake

UL1	6/4/2003	1.0	15.08	128.9	201.3	8.41
UL1	6/4/2003	2.0	14.90	129.7	203.1	8.41
UL1	6/4/2003	3.0	14.78	132.3	203.8	8.39
UL1	6/4/2003	4.0	14.70	133.0	205.3	8.38

Appendix I. (continued)

SITE	DATE	DEPTH_FT	TEMP(*C)	DO%	SPC	PH
UL1	6/4/2003	5.0	14.64	135.8	208.3	8.35
UL1	7/15/2003	1.0	20.21	121.4	203.6	8.24
UL1	7/15/2003	2.0	19.72	132.8	208.9	8.20
UL1	7/15/2003	3.0	19.01	132.6	215.8	8.12
UL1	7/15/2003	4.0	18.84	138.3	218.8	8.14
UL1	7/15/2003	5.0	18.80	135.4	219.9	8.14
UL1	9/2/2003	1.0	13.5	140.90	188.70	
UL1	9/2/2003	2.0	13.2	133.30	187.70	
UL1	9/2/2003	3.0	13.0	128.00	187.00	
UL1	9/2/2003	4.0	13.0	137.00	189.00	
UL1	9/2/2003	5.0	13.0	131.50	188.90	
UL1	9/19/2003	1.0	7.36	105.4	198.5	8.34
UL1	9/19/2003	2.0	7.35	107.7	198.3	8.33
UL1	9/19/2003	3.0	7.36	107.0	198.9	8.32
UL1	9/19/2003	4.0	7.32	109.4	198.4	8.31
UL2	6/4/2003	1.0	15.60	138.9	195.9	8.53
UL2	6/4/2003	2.0	15.44	141.8	195.4	8.53
UL2	6/4/2003	3.0	15.25	144.1	195.4	8.54
UL2	6/4/2003	4.0	15.20	145.4	195.6	8.54
UL2	7/15/2003	1.0	20.73	124.7	199.0	8.37
UL2	7/15/2003	2.0	20.68	134.3	199.0	8.38
UL2	7/15/2003	3.0	20.68	138.7	200.0	8.37
UL2	7/15/2003	4.0	20.70	140.8	200.7	8.36
UL2	9/2/2003	1.0	13.60	137.9	187.0	
UL2	9/2/2003	2.0	13.60	134.9	186.8	
UL2	9/2/2003	3.0	13.30	135.0	185.4	
UL2	9/2/2003	4.0	13.20	135.2	184.5	
UL2	9/19/2003	1.0	7.04	110.1	199.2	8.34
UL2	9/19/2003	2.0	7.04	109.6	199.1	8.35
UL2	9/19/2003	3.0	7.05	110.7	199.9	8.33
UL3	6/4/2003	1.0	15.90	138.9	193.3	8.52
UL3	6/4/2003	2.0	15.87	144.8	193.9	8.53
UL3	6/4/2003	3.0	15.74	141.0	194.2	8.55
UL3	6/4/2003	4.0	14.96	162.0	193.2	8.60
UL3	7/15/2003	1.0	20.99	129.0	198.2	8.33
UL3	7/15/2003	2.0	20.95	130.9	198.6	8.33
UL3	7/15/2003	3.0	20.86	132.2	199.0	8.34
UL3	7/15/2003	4.0	20.21	139.1	198.3	8.38
UL3	9/2/2003	1.0	13.60	137.5	186.5	
UL3	9/2/2003	2.0	13.50	137.0	185.9	
UL3	9/2/2003	3.0	13.10	134.0	184.3	
UL3	9/2/2003	4.0	12.40	139.0	182.0	
UL3	9/2/2003	5.0	12.20	140.0	180.5	

Appendix I. (continued)

SITE	DATE	DEPTH_FT	TEMP(*C)	DO%	SPC	PH
UL3	9/19/2003	1.0	6.58	111.3	199.6	8.27
UL3	9/19/2003	2.0	6.59	106.8	199.3	8.25
UL3	9/19/2003	3.0	6.58	101.0	199.3	8.24
UL3	9/19/2003	4.0	6.46	121.1	199.3	8.25
UL4	6/4/2003	1.0	15.10	136.0	195.8	8.38
UL4	6/4/2003	2.0	12.30	155.6	207.5	8.52
UL4	7/15/2003	1.0	19.10	128.2	200.3	8.25
UL4	7/15/2003	2.0	15.40	148.5	206.0	8.48
UL4	7/15/2003	3.0	15.69	145.8	205.9	8.48
UL4	9/2/2003	1.0	12.00	134.7	186.1	
UL4	9/2/2003	2.0	10.50	124.1	176.6	
UL4	9/19/2003	1.0	3.93	104.0	212.2	8.07
UL4	9/19/2003	2.0	4.60	105.5	214.6	8.01