INTERNAL REPORT 141

RESPIRATORY ELECTRON TRANSPORT SYSTEM ACTIVITY MEASUREMENTS FROM FOUR LAKES IN THE LAKE WASHINGTON DRAINAGE

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INTRODUCTION

During 1973 we have continued monitoring the respiratory electron transport system activity (ETS) distribution in Lake Washington and Lake Sammamish. In addition, we have initiated the study of ETS activity distribution in Lakes Chester Morse and Findley. These studies have been designed to answer specific questions we feel are important to the understanding of an aquatic ecosystem, such as: (1) What is the relative importance of the phytoplankton, zooplankton and bacterial respiration? (2) How much of the primary productivity of the phytoplankton community is oxidized by that community in order to meet cellular energy requirements? (3) Which is more important in the cycling of nutrients, bacteria or zooplankton? (4) What are the relationships between ETS activity and ^{14}C-uptake, ETS activity and chlorophyll concentrations, etc.? (5) What are the cycles of ETS activity, both diel and temporal? In order to construct a realistic simulation model of the carbon flow, designed to predict the influence of both natural and man-induced perturbations of an aquatic ecosystem, these questions must be answered.

METHODS

The sampling of Lake Washington was done from the R/V *Onar* (Department of Oceanography, University of Washington, Seattle, Washington). Lakes Sammamish, Chester Morse and Findley were sampled from small boats. Water samples were secured by either six-liter Scott-Richards or Niskin (R) sampling bottles, both of all PVC construction. Zooplankton samples were taken with an 0.3m 212µ net towed vertically at approximately 10 m/min. Water samples from Lakes Washington and Sammamish were prefiltered through a 212µ net into polyethylene bottles which were kept on ice in the dark and returned immediately to the laboratory for analysis. Zooplankton and water samples from Lakes Chester Morse and Findley were filtered through glass fiber filters at the lake site and quick-frozen in liquid nitrogen. These samples were then stored under liquid nitrogen for from 4 to 48 hours before analysis at the laboratory.

The ETS activity was determined by the tetrazolium reduction method (Packard, 1971) with one modification; 0.15 m zinc acetate was used in place of $FeCL_2$ to precipitate proteins and nucleotides.

RESULTS AND DISCUSSION

Preliminary results are presented in this report in both tabular and graphical formats.

Table 1 lists the sampling stations, dates and type of data taken, and is projected through 31 December 1973. Preliminary ETS activity data from the four lakes in the Lake Washington drainage is tabulated in Tables 4-7. This data, along with data taken in 1972, has also been entered on the permanent file maintained by the program.

Figures 1 and 2 show the integrated ETS activity in the euphotic zone of the four lakes as a function of time. Both Lakes Findley and Chester Morse have low ETS activity when compared to the other two lakes. Lake Findley shows a minimum in August, while Lake Chester Morse displays a maximum. Averaged over the sampling period the integrated ETS activity at Lake Findley is slightly less than that at Lake Chester Morse, both of which are considerably lower than that of either Lake Washington or Lake Sammamish, which show a maximum in July. The average and range for each of the lakes is shown below in descending order.

Lake	*Average*	*Range*
Findley	9 $mgO_2hr^{-1}m^{-2}$	17-4 $mgO_2hr^{-1}m^{-2}$
Chester Morse	13 $mgO_2hr^{-1}m^{-2}$	22-8 $mgO_2hr^{-1}m^{-2}$
Washington	55 $mgO_2hr^{-1}m^{-2}$	80-29 $mgO_2hr^{-1}m^{-2}$
Sammamish	62 $mgO_2hr^{-1}m^{-2}$	93-30 $mgO_2hr^{-1}m^{-2}$

This is presumably due to the more oligotrophic nature of the two lakes in the Chester Morse watershed, along with possible man-induced inputs into Lakes Washington and Sammamish. In fact, based on a study off the White's Point sewage outfall of Los Angeles, Packard and Harmon (1972) have suggested that in vivo incubation measurements to determine BOD can be replaced by the in vitro ETS determination. If this approach proves reliable, one could consider Lake Sammamish the most polluted of the four lakes, with Lakes Findley and Chester Morse being much "cleaner."

Presented in Figures 3 and 4 are four selected vertical ETS activity profiles for each lake. It is difficult, at present, to evaluate the significance, if any of these profiles. We plan to do this, however, when the necessary support data, namely nutrients, ^{14}C-uptake, and chlorophyll become available.

In Table 2 the total integrated euphotic zone ETS activity in Lakes Chester Morse and Findley has been broken down into a nanoplankton fraction (<212μ) and a netplankton (>212μ) fraction. In addition, the percentages of each fraction and nanoplankton/netplankton ratio have been calculated. As evidenced from the data, the percentage of the total ETS activity attributable to the nanoplankton and consequently the nanoplankton/netplankton ratio, in Lake Chester Morse is considerably greater than that of Lake Findley. This is presumably due to the differences in food webs between the two lakes. Lake Chester Morse contains a large number of fish, while Lake Findley is completely devoid of any fish population. Although our data start rather late in the year and apparently do not include samples taken during the spring phytoplankton bloom, the nanoplankton/netplankton ratios show the later development of a zooplankton population in Lake Chester Morse. In Lake Findley the same phenomenon seems to be occurring except, as mentioned, the netplankton contribution to the total ETS activity is much greater.

Vertical profiles of ^{14}C-uptake and ETS activity for two dates from Lake Washington are presented in Figure 5. The ETS activities have been converted to carbon equivalents using an R/Q of 0.85. There is no immediate conclusion to be drawn from these data. When the data for other dates and lakes become available we plan to do a more detailed analysis of freshwater distribution, since ETS activity has been shown to be related to ^{14}C-uptake in the ocean (Packard, Harmon and Boucher, in press). It is interesting to note, however, that of the total integrated ^{14}C-uptake, approximately 28 percent and 57 percent are respired within the nanoplankton community on 4 May and 13 June respectively; which is in good agreement with oceanographic observations (Packard et al. 1973).

In Table 3 are listed the respiration, ammonia and phosphate regeneration rates for the euphotic zone netplankton, as calculated from ETS activities. The respiration rate was obtained by multiplying the ETS activity by 1.96, an experimentally determined factor (Packard, Harmon and Boucher, in press). The nutrient regeneration rates were calculated from the respiration rates using a factor of 4.47×10^{-3} for ammonia, and $0.395 \times 10^{-3}$for phosphate. These factors are based on the relationship between respiration and ammonia excretion as derived by Conover and Corner (1968), and the relationship between ammonia and phosphate excretion as derived by Beers (1964). A combination of these studies yields an O:N:P ratio of 226:11:3.1 by atoms. We have calculated the turnover time of these nutrients in Lake Findley assuming a steady state and that netplankton respiration is the major pathway of nutrient regeneration. Using the calculated rates (Table 3) and nutrient data from 24 July (Arni Litt, personal communication), we calculate turnover times of ammonia and phosphate of 68 and 10 days respectively. This indicates that phosphate is cycled approximately 7 times faster than ammonia. It must be emphasized here that these estimates are based on some very bold assumptions and much more detailed analysis is needed. They do, however, serve to demonstrate the type of data analysis we plan to undertake when the other necessary data become available.

FUTURE RESEARCH

In the coming year we plan to improve our coordination with other investigators, focus field work on short term variations and the size fractionation of the ETS activity distribution, and extensively analyze the data we have already collected.

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Table 1. Forest Biome LTS Sampling Schedule.

Date	Lake sampled	Station	Data type	Depths
6 Mar 73	Washington	1	phytoplankton } new assay zooplankton } oxygen	0, 2, 4, 7, 14, 37, 60 0-15, 0-60
4 May 73	Washington	1	phytoplankton zooplankton oxygen	0, 2, 4, 7, 14 0-14, 63-0
11 May 73	Sammamish	612	phytoplankton	0, 2, 3, 6, 12
18 June 73	Washington	1	phytoplankton	0, 1, 3, 4.5, 9
20 June 73	Chester Morse	1	phytoplankton	0, 3.4, 6.6, 11, 22.4
25 June 73	Sammamish	612	phytoplankton	0, 1, 2, 3.5, 7.5
5 July 73	Findley	1	phytoplankton zooplankton	0, 5, 10, 15, 23 0-23
13 July 73	Sammamish	612	phytoplankton	0, 1, 2, 3, 6.5
24 July 73	Chester Morse	1	phytoplankton zooplankton	0, 2.5, 7, 13, 33 0-27
26 July 73	Findley	1	phytoplankton zooplankton	0, 5, 10, 15, 24 0-23
27 July 73	Sammamish	612	phytoplankton Fractionation study (bacteria)	0, 1, 2, 3, 6.5, 15, 30
14 Aug 73	Chester Morse	1	phytoplankton zooplankton	0, 1.7, 3.5, 13.5, 27 0-13.5
16 Aug 73	Findley	1	phytoplankton zooplankton	0, 5, 10, 15, 20, 25 0-25
23 Aug 73	Washington	1	phytoplankton	0, 0.9, 2, 4, 9.5
24 Aug 73	Sammamish	612	phytoplankton	0, 0.9, 2.1, 7.8, 15
28 Aug 73	Chester Morse	1	phytoplankton zooplankton	0, 7, 10, 11.5, 25 0-11.5
11 Sept 73	Chester Morse	1	phytoplankton zooplankton	0, 4, 7, 14.5, 25 0-14.5
13 Sept 73	Findley	1	phytoplankton zooplankton	0, 5, 10, 15, 25 0-23
28 Sept 73	Sammamish	612	phytoplankton	0.2, 1.1, 2.4, 9.2
25-26 Sept 73	Washington	1 (24 hr diurnal)	phytoplankton zooplankton Chlor	0, 1, 2, 4, 7, 12, 30, 58 0-12, 12-21 0, 1, 2, 4, 7, 12
4 Oct 73	Findley	1	phytoplankton zooplankton	0, 5, 10, 15, 20 0-20
9 Oct 73	Chester Morse	1	phytoplankton zooplankton	0, 1.5, 5, 17, 25 0-17
Projected:				
18 Oct 73	Sammamish	612	phytoplankton	
25 Oct 73	Washington	1		
7 Nov 73	Sammamish	612		
13 Nov 73	Chester Morse	1		
21 Nov 73	Washington	1		
29 Nov 73	Findley	1		
5 Dec 73	Sammamish	612		
11 Dec 73	Chester Morse	1		
13 Dec 73	Findley	1		
18 Dec 73	Washington	1		
20 Dec 73	Washington	1		

Table 2. Total respiratory electron transport activity in the euphotic zone of Lakes Chester Morse and Findley, the ETS activity of the nanoplankton (<212μ), the netplankton (>212μ), the percentage of total for each of the two fractions, and the ratio of the nanoplankton to netplankton. Units for ETS activity are Mg0 hr^{-1} $^{-2}$.

Date	Total ETS	Nanoplankton ETS	Netplankton ETS	Percent nanoplankton	Percent netplankton	Nanoplankton/netplankton
Lake Chester Morse						
20 June 73		13.91				
24 July 73	22.05	21.50	0.56	98	2	38.7
14 Aug 73	18.01	16.83	1.18	93	7	13.7
28 Aug 73	12.29	11.27	1.02	92	8	12.1
11 Sept 73	11.05	9.57	1.48	86	14	6.5
9 Oct 73	13.32	12.60	0.72	94	6	17.5
Lake Findley						
5 July 73	18.93	17.02	1.91	90	10	1.00
26 July 73	13.42	7.75	5.67	58	42	1.36
16 Aug 73	11.52	5.32	6.20	46	54	4.92
13 Sept 73	11.98	9.94	2.40	83	17	4.92
4 Oct 73	10.84	8.36	2.49	77	23	3.55

Table 3. Respiration ammonia and phosphate regeneration rates attributable to the netplankton (>212μ) in the euphotic zone of Lakes Chester Morse and Findley. See text for further explanation.

Lake	Date	Respiration $mgO_2hr^{-1}m^{-2}$	Ammonia regeneration rate $\mu g\text{-at } hr^{-1}m^{-2}$	Phosphate regeneration rate $\mu g\text{-at } hr^{-1}m^{-2}$
Findley	5 July 73	3.744	11.83×10^{-3}	1.04×10^{-3}
Findley	26 July 73	11.113	34.95×10^{-3}	3.08×10^{-3}
Findley	16 Aug 73	12.152	38.28×10^{-3}	3.38×10^{-3}
Findley	13 Sept 73	4.00	12.61×10^{-3}	1.11×10^{-3}
Findley	4 Oct 73	4.88	15.33×10^{-3}	1.35×10^{-3}
Chester Morse	24 July 73	1.098	3.42×10^{-3}	0.302×10^{-3}
Chester Morse	14 Aug 73	2.313	7.27×10^{-3}	0.642×10^{-3}
Chester Morse	28 Aug 73	2.00	6.31×10^{-3}	0.557×10^{-3}
Chester Morse	11 Sept 73	2.90	9.11×10^{-3}	0.805×10^{-3}
Chester Morse	9 Oct 73	1.41	4.47×10^{-3}	0.395×10^{-3}

Table 4. Electron transport ctivity in the euphotic zone of Lake Washington.

Date	Depth (m)	ETS activity ($mgO_2 hr^{-1} m^{-3}$)	ETS activity* ($mgC\ hr^{-1} m^{-3}$)
4 May 73	0	2.25	0.72
	2	2.10	0.67
	4	2.48	0.79
	7	2.19	0.70
	14	1.23	0.39
18 June 73	0	7.36	2.35
	1	6.16	1.97
	3	6.23	1.99
	4.5	4.75	1.51
	9.0	5.12	1.63
31 July 73	0	11.84	3.77
	1	12.54	4.00
	2	12.48	3.98
	3.5	15.76	5.03
	6.5	9.64	3.07
23 Aug 73	0	3.16	1.00
	0.9	7.04	2.24
	2	7.82	2.49
	4	9.79	3.11
	9.5	8.34	2.62
26 Sept 73	0	3.59	1.14
	1	3.70	1.18
	2	2.73	0.87
	4	3.90	1.24
	7	3.44	1.09
	12	4.41	1.40

*Carbon equivalents have been calculated using an R/Q of 0.85 .

Table 5. Electron transport activity in the euphotic zone of Lake Sammamish.

Date	Depth (m)	ETS activity ($mgO_2 hr^{-1} m^{-3}$)	ETS activity* ($mgC\ hr^{-1} m^{-3}$)
11 May 73	0	2.86	0.91
	2	2.89	0.92
	3	2.88	0.73
	6	2.46	0.79
	12	2.66	0.85
25 June 73	0	12.11	3.86
	1	19.05	6.07
	2	15.26	4.86
	3.5	7.94	2.53
	7.5	10.68	3.40
13 July 73	0	7.50	2.39
	1	42.22	13.46
	2	7.28	2.32
	3	9.44	3.10
	6.5	9.90	3.16
27 July 73	0	8.49	2.71
	6.5	10.51	3.35
24 Aug 73	0	6.17	1.96
	0.9	7.00	2.23
	2.1	6.04	1.92
	7.8	5.99	1.90
	15.0	1.15	0.37
28 Sept 73	0.2	4.42	1.41
	1.1	5.85	1.86
	2.4	2.58	0.82
	9.2	3.16	1.00

*Carbon equivalents have been calculated using an R/Q of 0.85.

Table 6. Electron transport activity in the euphotic zone of Lake Chester Morse.

Date	Depth (m)	ETS activity ($mgO_2 hr^{-1} m^{-3}$)	ETS activity* ($mgC\ hr^{-1} m^{-3}$)
20 June 73	0	0.76	0.24
	3.4	0.67	0.21
	6.6	0.56	0.18
	11.0	0.45	0.15
	22.4	0.82	0.26
24 June 73	0	0.81	0.26
	2.5	1.66	0.53
	13.0	0.65	0.21
	33.0	0.62	0.20
14 Aug 73	0	1.54	0.49
	1.7	1.56	0.50
	13.5	0.85	0.27
	27.0	0.15	0.05
28 Aug 73	0	1.45	0.46
	7	0.70	0.23
	10	0.83	0.27
	11.5	1.08	0.35
	25	0.20	0.06
11 Sept 73	0	0.44	0.14
	4	0.85	0.27
	7	0.65	0.21
	14.5	0.61	0.20
	25.0	0.09	0.03
9 Oct 73	0	0.83	0.26
	1.5	0.81	0.26
	5	0.92	0.29
	17	0.47	0.15
	25	0.21	0.07

*Carbon equivalents have been calculated using an R/Q of 0.85.

Table 7. Electron transport activity in the euphotic zone of Lake Findley.

Date	Depth (m)	ETS activity ($mgO_2 hr^{-1} m^{-3}$)	ETS activity* ($mgC\ hr^{-1} m^{-3}$)
5 July 73	0	0.93	0.29
	5	1.04	0.33
	10	0.50	0.16
	15	0.68	0.22
	23	0.64	0.20
26 July 73	0	0.18	0.05
	5	0.31	0.10
	10	0.40	0.13
	15	0.19	0.06
	24	0.53	0.17
16 Aug 73	0	0.75	0.24
	5	0.20	0.06
	10	0.20	0.06
	15	0.12	0.04
	20	0.09	0.03
	25	0.15	0.05
13 Sept 73	0	0.51	0.16
	5	0.62	0.20
	10	0.39	0.12
	15	0.25	0.08
	25	0.20	0.06
4 Oct 73	0	0.48	0.15
	5	0.62	0.20
	10	0.23	0.07
	15	0.42	0.13
	20	0.32	0.10

*Carbon equivalents have been calculated using an R/Q of 0.85.

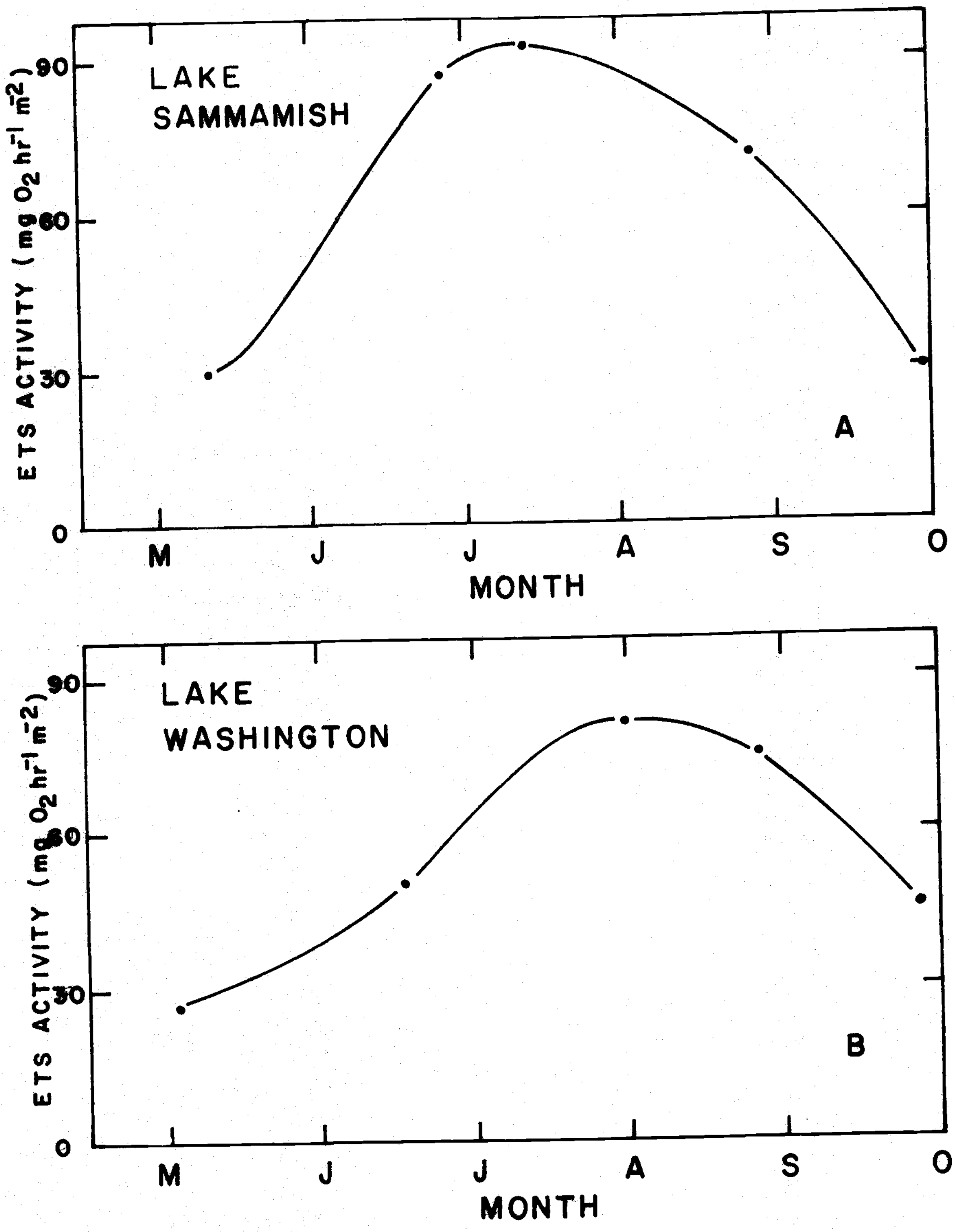

Figure 1. Integrated respiratory electron transport activity in the euphotic zones (100%-1% light levels) in Lakes Washington and Sammamish as a function of sampling date.

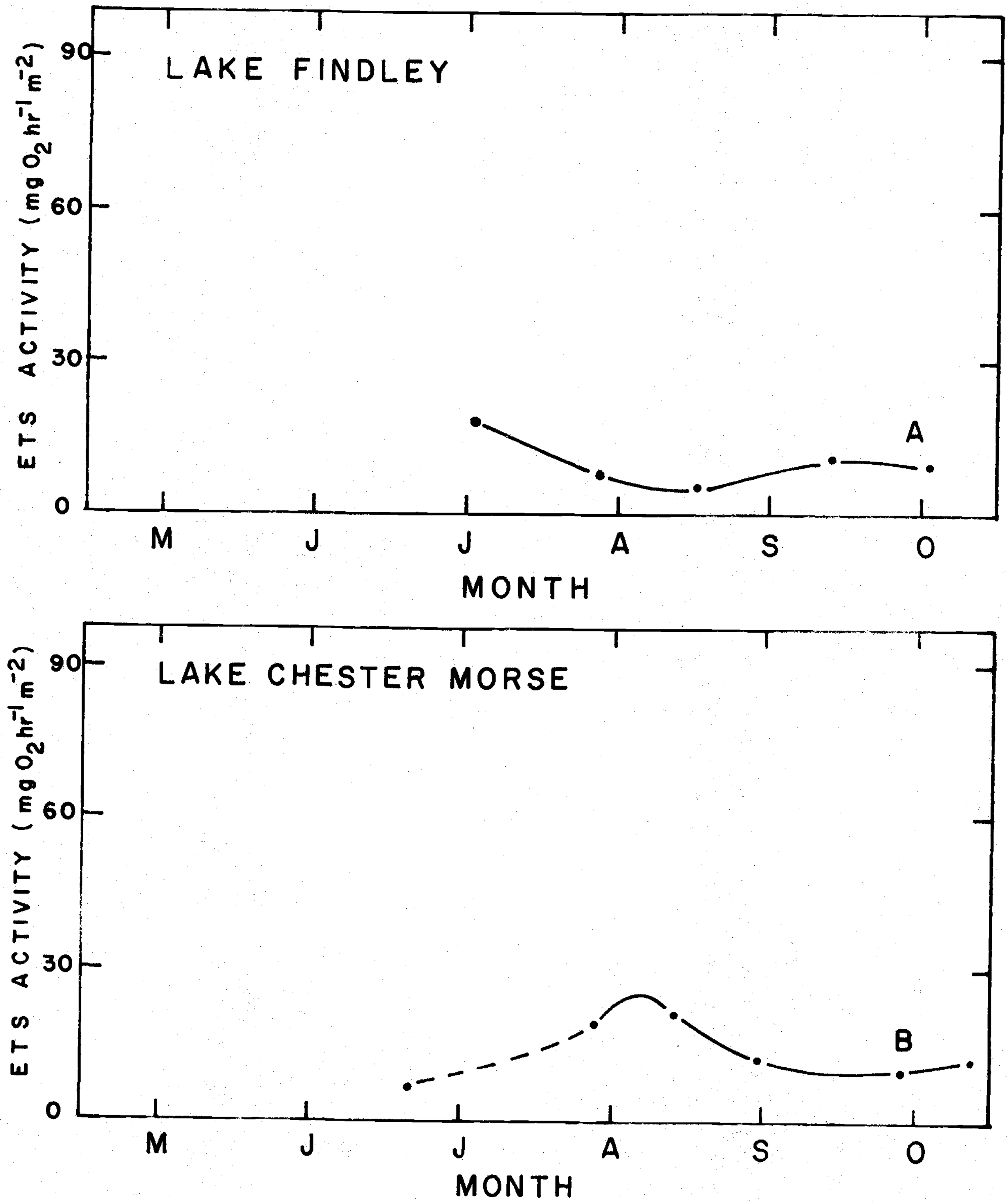

Figure 2. Integrated respiratory electron transport activity in the euphotic zones (100%-1% light levels) of Lakes Findley and Chester Morse as a function of sampling date.

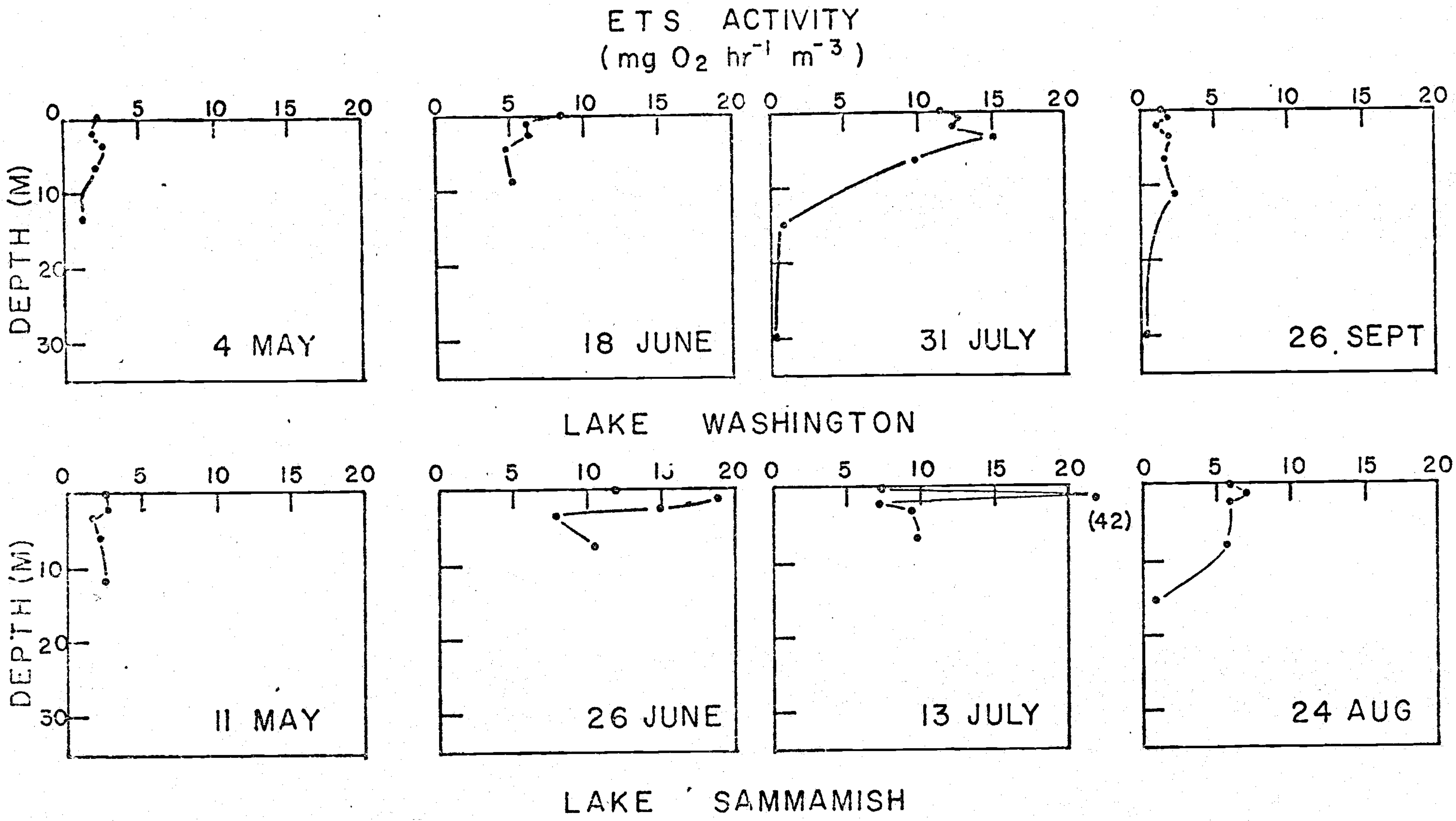

Figure 3. Respiratory electron transport activity *vs.* Depth for four selected dates in Lake Washington (STATION 1) and Lake Sammamish (STATION 612).

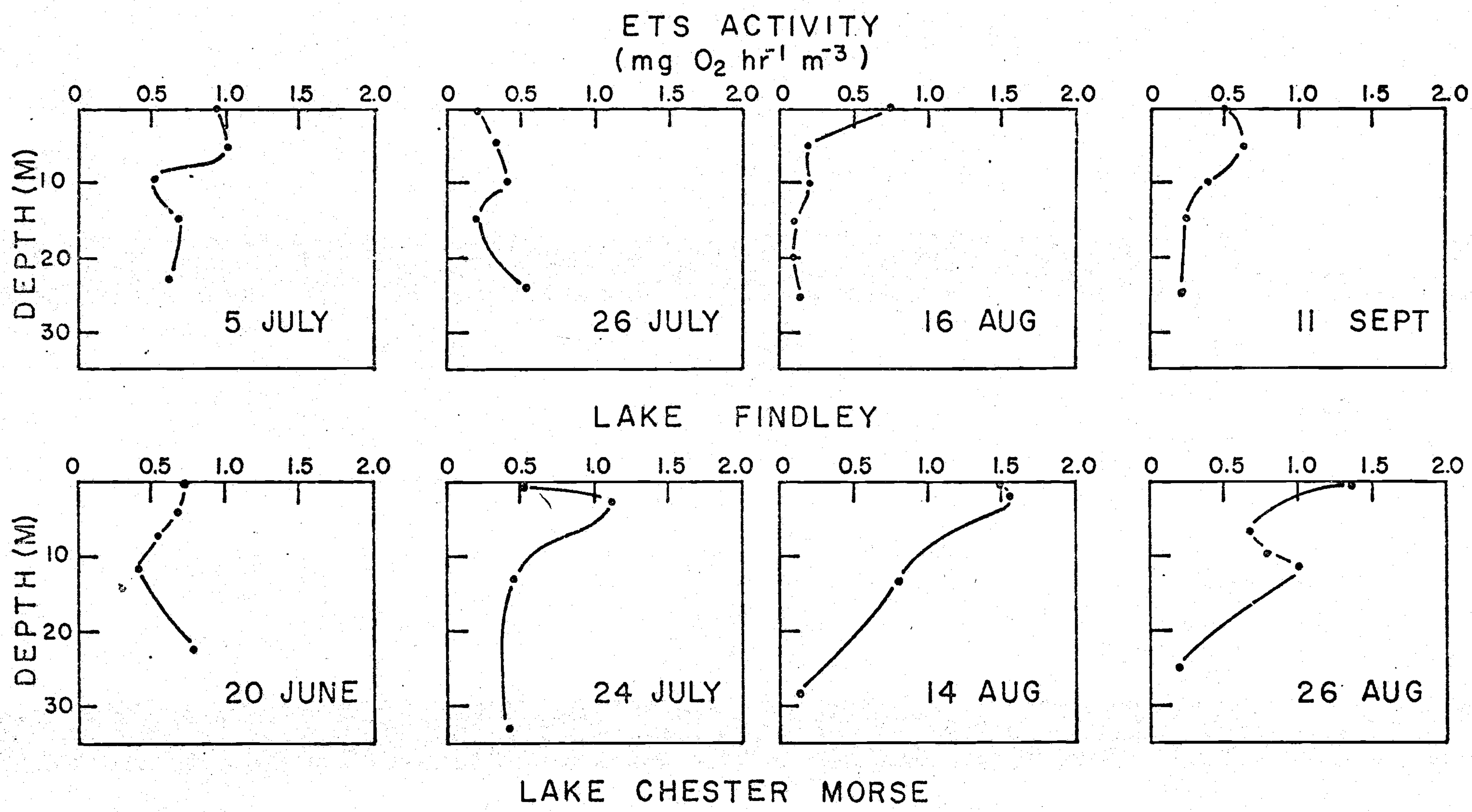

Figure 4. Respiratory electron transport activity *vs*. Depth for four selected dates in Lake Findley (STATION I) and Lake Chester Morse (STATION I).

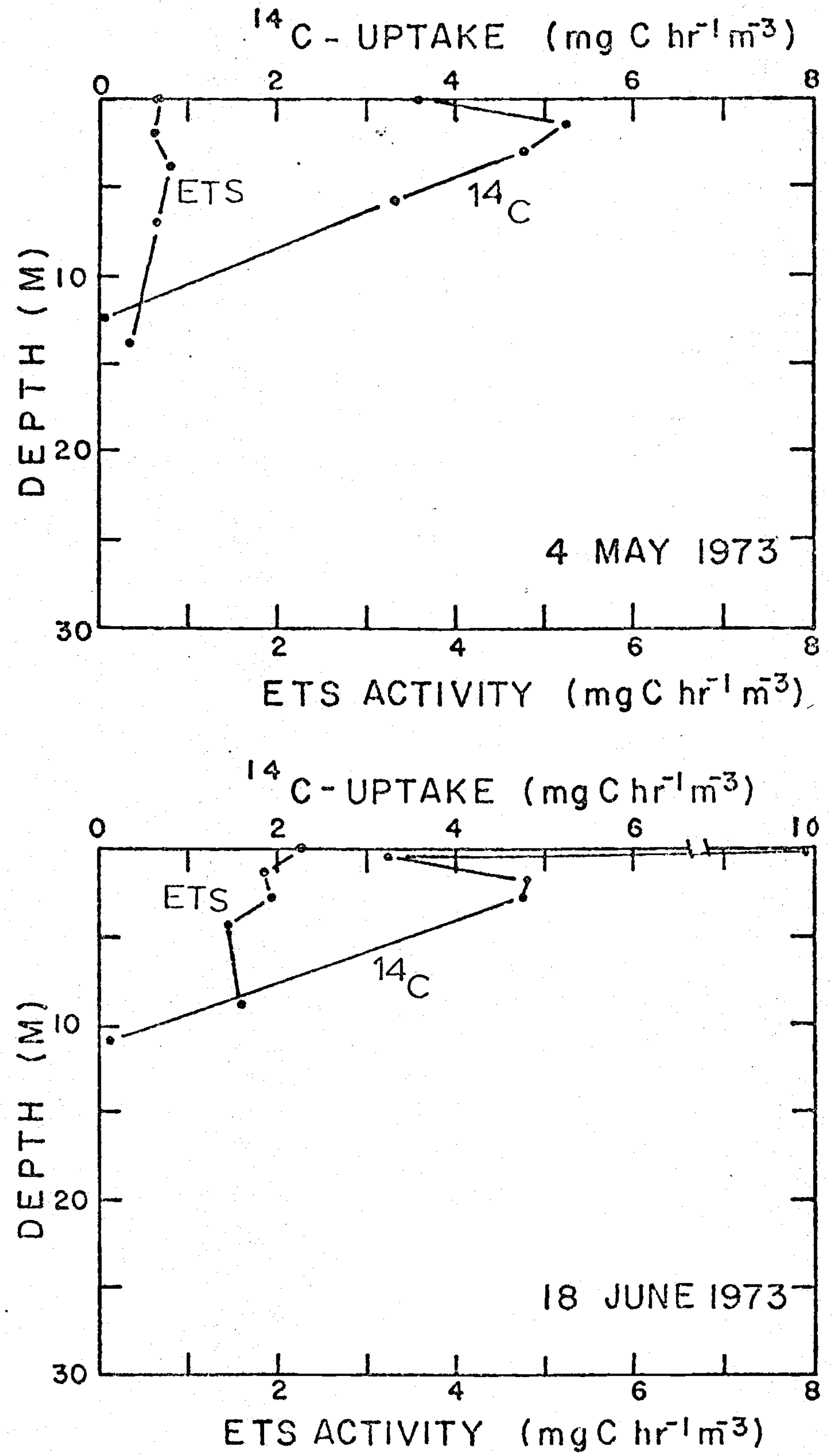

Figure 5. Respiratory electron transport (ETS) activity and ^{14}C-uptake at Lake Washington Station I on 4 May and 18 June 1973. ETS activities have been converted to carbon equivalents using an R/Q of 0.85.