Analysis of continuous dissolved oxygen data from Oregon's Mid Coast Rivers in 2008 and implications for TMDL development

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November 26, 2014

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1 Executive Summary

Within the past decade, 27 stream and river segments across Oregon's Mid Coast (4th field Hydrologic Unit Codes (HUCs) 17100204, 17100205, 17100206, and 17100207) have failed to meet dissolved oxygen (DO) benchmarks set primarily to ensure survival and reproduction of threatened and endangered salmonids. Total maximum daily loads (TMDLs) for factors influencing DO concentrations are therefore needed in these segments according to the Oregon Department of Environmental Quality's 2012 Integrated Report.

In 2008, Oregon DEQ monitored DO concentrations continuously (15 minute intervals) over 3-4 day periods on 14 of the rivers segments eventually listed in the 2012 Integrated Report for failing to meet DO benchmarks. In this report, we analyze these data and propose a strategy to develop implementation-ready TMDLs for DO on these rivers and other river segments in the Mid Coast that have failed to meet DO benchmarks.

On each river segment, we estimated values for three parameters that control DO concentrations in lotic ecosystems: reaeration (K_{O_2}), gross primary production (GPP), and ecosystem respiration (ER) for one representative 24-hour cycle (sunrise - sunrise) during the monitored period. Reaeration and ecosystem respiration rates were estimated using the night-time regression technique [3]. Daily rates of reaeration and ecosystem respiration rates were estimated by scaling each rate with rate-specific coefficients and observed temperatures. Daily rates of GPP were estimated by taking the difference of observed DO and temperature corrected values of reaeration and ER. Daily summaries net daily metabolism (NDM; GPP + ER) and P/R (ratio of GPP to ER) were calculated for each monitored stream and river to provide baselines for comparisons with alternative management scenarios and for sensitivity analyses of factors controlling DO dynamics on each system.

Twelve of the 14 sites had data amenable for estimation of daily reaeration, ER, and GPP rates. At these sites, reaeration rates ranged from 2 d^{-1} to 17.99 d^{-1}, GPP ranged from 0.63 mg O_2 L^{-1} d^{-1} to 14.76 mg O_2 L^{-1} d^{-1}, and ER ranged from -17.32 mg O_2 L^{-1} d^{-1} to -1.21 mg O_2 L^{-1} d^{-1}. NDM ranged from -9.95 mg O_2 L^{-1} d^{-1} to 4.91 mg O_2 L^{-1} d^{-1} and P/R ranged from 0.09 to 2.38.

Results suggest that enough continuous DO data may have already been collected at 12 stations on Mid Coast for modeling current and future scenarios of DO dynamics on Mid Coast river segments. I propose that we conduct a pilot TMDL analysis using existing data for the Yaquina River Basin to assess the feasibility of developing DO TMDLs across the Mid Coast region. The ultimate objectives of the pilot and subsequent analyses will be to evaluate alternative management scenarios (e.g., manipulating stream shading, nutrient inputs, and organic matter abundance) and develop implementation strategies for achieving DO benchmarks.

2 Introduction

Many services provided by freshwater ecosystems depend dissolved oxygen (DO) concentrations [12]. In Oregon, maintaining healthy salmon and trout populations in streams and rivers is an important ecosystem service related to DO. Salmon and trout require well-oxygenated water columns and gravel beds [1, 9, 13]. Human activities in riparian areas and the surrounding watershed can significantly alter DO dynamics in streams and rivers [2, 4] and thus restrict available spawning, rearing, and migration habitat for salmonids [7, 8]. Riparian and watershed restoration activities targeted at meeting DO concentration benchmarks constitutes important components of aquatic ecosystem management in rivers and streams across many regions in the United States and elsewhere [6].

In Oregon's Mid Coast river basins, DO concentrations in 10% of stream length (27 river segments) frequently dip below state standards set to ensure survival and reproduction of native salmonids(Table 1; ODEQ 2012 Integrated Report). Of these segments, 21 were listed for failing to meet benchmarks during salmon/steelhead spawning periods while 6 failed to meet benchmarks for migration and rearing (year-round).

On stations representing 14 of these river segments, Oregon DEQ deployed datasondes to record DO concentrations at 15-minute intervals over 3 - 4 day periods during late spring, early summer, or fall (corresponding to times of benchmark failures on each river segment) in 2008. Instantaneous (grab) measurements

of flow, nutrients (N and P species), pH, biological oxygen demand (BOD), and other water quality parameters were also collected at least once during continuous DO monitoring on each station.

To characterized DO dynamics in monitored river segments, we used an approach in which three parameters - reaeration (K_{O_2}), ecosystem respiration (ER), and gross primary production (GPP) - were estimated from continuous DO concentration data [11]. These parameters are influenced by a number of physical, chemical, and biological factors in riparian areas, hill slopes, and watersheds [4].

Reaeration describes the exchange of oxygen between gaseous and dissolved phases. Reaeration depends on several factors, including level of oxygen saturation in the water column (which determines the directional flow of oxygen between the atmosphere and the water column), temperature (which determines oxygen solubility), and channel roughness (which determines potential for oxygen exchange between the water column and atmosphere).

The balance of GPP and ER control the biological consumption and production of DO. A variety of autotrophic organisms (cyanobacteria, diatoms, soft algae, macrophytes, etc.) perform GPP [15]. ER consumes DO largely through aerobic respiration performed by both autotrophic (e.g., algae) and heterotrophic (decomposers) organisms [17]. Other microbial and chemical processes consume DO in lotic environments, such as nitrification and iron oxidation; but these processes usually have small influences in river reaches that do not have major wastewater treatment plants, industrial effluent discharge points, or other point source inputs (as in this study [15]). Land use activities that alter riparian and/or watershed conditions, such as forestry, agriculture, and urban development, can influence rates of GPP and ER by reducing shade, increasing temperature, increasing nutrient loading, increasing loading of labile (readily-decomposable) organic matter, and through other effects [4, 5, 16].

Objectives of this review were to estimate reaeration, GPP, and ER on Mid Coast rivers in 2008 and use this analysis to propose a strategy for developing implementation-ready TMDLs that address DO 303(d) listings for DO concentrations in Mid Coast. Sound estimates of reaeration and river metabolism metrics provide a basis for modeling factors that control DO dynamics in rivers and streams, which in turn can be used to evaluate riparian and watershed management strategies for meeting DO benchmarks.

Table 1: Applicable criteria for dissolved oxygen in Oregon mid-coast basins.

Dissolved Oxygen Criteria
Spawning: Not less than 11.0 mg/L or 95% of saturation
Cold water: Not less than 8.0 mg/l or 90% of saturation

3 Site Description

The region covered in this report includes Pacific Ocean drainages bracketed on the north by the Salmon River and on the south by the Siuslaw River (4th field Hydrologic Unit Codes (HUCs) 17100204, 17100205, 17100206, and 17100207). Across these basins, 27 stream and river segments have been placed on the 303(d) Category 5 list for failing to meet DO concentration benchmarks (Table 2; Figure 1).

DO dynamics were modeled at 12 stations on larger rivers listed for DO impairments Table 3. DO concentrations were measured continuously at three additional stations on the Yaquina River, North Fork Beaver Creek, and Siuslaw River; but could not be used for estimating reaeration and metabolism metrics because of variable discharge due to presumed storm events (Yaquina and North Fork Beaver) or tidal exchange (Siuslaw).

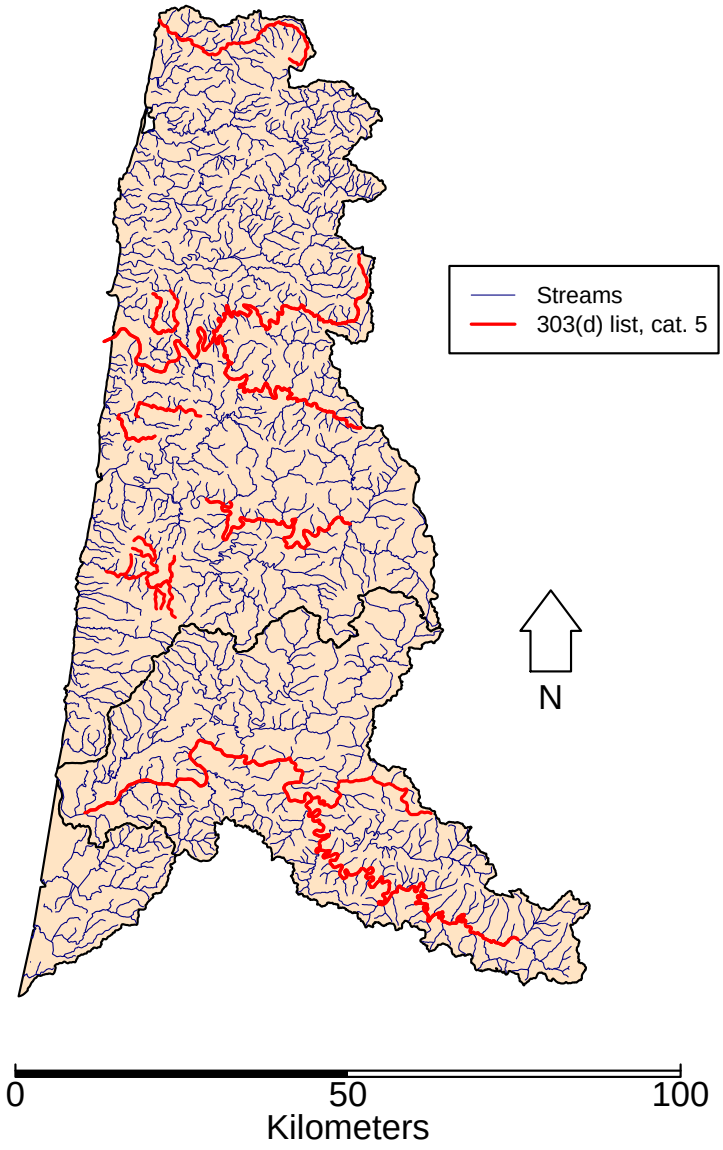

Figure 1: Map of Oregon Mid Coast basins and stream segments listed as water quality limited fro dissolved oxygen (303(d) list, category 5) by the Oregon Department of Environmental Quality's 2012 Integrated Report.

Table 2: Dissolved oxygen listings for the Oregon's Mid Coast.

Stream	River miles	Listing period	Criteria
Alsea River	27 to 47.4	September 1 - June 15	Spawning
Alsea River	15.7 to 47.4	Year Around	Cold water
Alsea River	15.7 to 27	September 15 - June 15	Spawning
Beamer Creek	0 to 2.1	October 15 - May 15	Spawning
Beaver Creek	0 to 7.3	October 15 - May 15	Spawning
Beaver Creek	0 to 7.3	Year Around	Cold water
Big Elk Creek	0 to 29.5	Year Around	Cold water
Big Elk Creek	5.3 to 29.5	October 15 - May 15	Spawning
Big Elk Creek	0 to 5.3	January 1 - May 15	Spawning
Depot Creek	0 to 4.5	Year Around	Cold water
Keller Creek	0 to 2.6	October 15 - May 15	Spawning
North Fork Beaver Creek	0 to 9.5	October 15 - May 15	Spawning
North Fork Yachats River	0 to 6.3	October 15 - May 15	Spawning
Salmon River	0 to 23.1	September 15 - May 31	Spawning
School Fork	0 to 3.2	October 15 - May 15	Spawning
Siuslaw River	5.7 to 105.9	September 15 - May 31	Spawning
Siuslaw River	5.7 to 105.9	June 1 - September 14	Cold water
South Fork Beaver Creek	0 to 6	October 15 - May 15	Spawning
South Fork Beaver Creek	0 to 6	Year Around	Cold water
Stump Creek	0 to 2	October 15 - May 15	Spawning
Wildcat Creek	0 to 18.8	October 15 - May 15	Spawning
Williamson Creek	0 to 2.7	October 15 - May 15	Spawning
Yachats River	3.4 to 16.6	October 15 - May 15	Spawning
Yaquina River	0 to 26.9	January 1 - May 15	Spawning
Yaquina River	26.8 to 53.9	October 15 - May 15	Spawning
Yaquina River	0 to 56.8	Year Around	Cold water

Table 3: Descriptions, dates, and flow conditions of stations where dissolved oxygen dynamics were measured. NA = Not Available

Station	Description	Dates	Flow (L s^{-1})
11241	Salmon River at Old Scenic Hwy 101 (Otis)	14-15 Oct 2008	NA
34454	Yaquina River at Clem Road bridge	13-14 May 2008	2661
34456	Yaquina River at Elk City Road bridge near Pioneer	15-16 Oct 2008	424
11476	Yaquina River at Trapp Road (Chitwood)	14-15 May 2008	2661
11476	Yaquina River at Trapp Road (Chitwood)	15-16 Oct 2008	424
33644	North Fork Beaver Creek at Ona Grange river mile 4.8	19-20 Nov 2008	NA
34764	North Fork Beaver Cr above Peterson Cr (Mid Coast)	19-20 Nov 2008	NA
33996	South Beaver Creek at 1st S Beaver Cr Rd Bridge RM 0.9 (Mid Coast)	25-26 June 2008	NA
34001	South Beaver Creek Below Oliver Creek (Mid Coast)	25-26 June 2008	NA
34227	Alsea River at Salmonberry Road	24-25 Sep 2008	2293
10585	Alsea River at Five Rivers Bridge	23-24 Sep 2008	2321
11263	Alsea River at Thissell Road (Mike Bauer Park)	23-24 Sep 2008	2321

4 Methods

At each station, we estimated reaeration and ecosystem metabolism metrics for a single 24 hour cycle selected from the 3 - 4 day monitoring period. To be suitable for parameter estimation, systems needed to be lotic (non-tidal) and have a cyclical patterns of a day time DO maximum and a night time minimum. When two days met these criteria within the monitoring period, we used the diel cycle that showed the smallest diurnal swing in DO concentrations over a 24 hour period (sunrise - sunrise).

4.1 *Night-time regression method*

Baseline reaeration (K_{O_2N}) and ecosystem respiration rates (ER_N) were estimated with the night-time regression method [11]. To do this, we calculated interval changes in DO concentrations (ΔDO) across time t steps:

$$\Delta DO_t = \frac{DO_t - DO_{t-1}}{t-(t-1)} \tag{1}$$

where ΔDO_t is DO concentration in mg L^{-1} at time t and t-1 is the time step before the current one. The set of DO values between sunset and sunrise were then regressed against the paired DO saturation deficit at time t (DO_{dt}) [11].

$$DO_{dt} = \frac{DO_{100\%} - DO_t}{DO_{100\%}} \tag{2}$$

Where $\mathrm{DO}_{100\%}$ is DO concentration at theoretical 100% saturation given the temperature and elevation [10].

In the night-time regression technique, the linear slope is equivalent to K_{O_2N} for the period analyzed, in units of min^{-1} while the intercept is an estimate of ecosystem respiration rate (ER_N; mg L^{-1} min^{-1}). Note that ER_N is negative, indicating DO consumption.

4.2 *Estimation of Metabolism Metrics*

Daily rates of GPP and ER were estimated by scaling basal estimates of K_{O_2N} and ER_N from the night-time regression method using parameter-specific scaling coefficients and temperature (T) at the time of sampling (t):

$$K_{O_2t} = K_{O_2N} 1.024^{(T_t - T_N)} \tag{3}$$

$$ER_t = ER_N 1.07^{(T_t - T_N)} \tag{4}$$

Where T_t and T_N are temperature at the time of sampling and average temperature during the period in which K_{O_2N} and ER_N were determined, respectively (in units of °C).

Flux rate of DO to or from the atmosphere due to reaeration was estimated with the following equation:

$$F_{O_2t} = K_{O_2t} DO_{dt} \tag{5}$$

When DO_{dt} is positive, there is flux of O_2 from the gaseous phase in the atmosphere into the dissolved phase in the water column; when negative, there is flux of DO from the water column to the atmosphere.

From sunrise to sunset, we calculated instantaneous GPP, GPP_t, assuming only positive values of GPP_t were possible, as:

$$GPP_t = \begin{cases} 0 & \text{when } GPP_t < 0 \\ DO_t - F_{O_2t} - ER_t & \text{when } GPP_t \geq 0. \end{cases} \tag{6}$$

Daily rates of GPP (GPP_d) and ER (ER_d) were calculated as:

$$GPP_d = \sum_{i=1}^{n} \left(\frac{GPP_t + GPP_{t-1}}{2} \right) (t - (t-1)) \tag{7}$$

$$ER_d = \sum_{i=1}^{n} \left(\frac{ER_t + ER_{t-1}}{2} \right) (t - (t-1)) \tag{8}$$

Following estimation of daily rates we calculated ratio of production to respiration (P/R) and net daily metabolism (NDM; net production or consumption of DO in mg L^{-1} min^{-1}):

$$\frac{P}{R} = -\left(\frac{GPP_d}{ER_d} \right) \tag{9}$$

$$NDM = GPP_d + ER_d \tag{10}$$

Reaeration and metabolic parameter estimates for each station reflects influences from a distance of 0.003 $\times$ v/K_{O_2} km upstream, where K_{O_2} is in units of s^{-1} and v is mean stream velocity (m s^{-1}) [5]. Where v was not measured during the monitoring period, we assume a mean v of 0.5 m s^{-1}, which is commonly used for regional and global hydrologic modeling [14].

5 Results

Of the rivers monitored continuously in 2008, 12 had continuous DO data that were suitable for estimation of k_{O_2}, GPP_d, and ER_d (Figure 2). These sites represent 46% of stream segments listed on as 303(d), category 5 for DO concentrations in the 2012 Integrated Report.

At the 12 sites where reaeration and metabolism parameters were estimated, minimum DO concentrations ranged from 7.86 to 10.65 mg O_2 L^-1 during the 24 cycle in which reaeration and metabolism parameters were estimated (Table 4). Maximum DO concentrations ranged from 9.69 to 11.24 mg O_2 L^-1 (Table 4). DO saturation levels ranged from minimums of 74 to 99% while maximums ranged from 87 to 107% (Table 4). At station 11476 (Yaquina River at Trapp Road (Chitwood)), DO concentrations or saturation levels never fell below the benchmarks of 11 mg O_2 L^-1 and 95%, respectively, during the 24 cycle.

Reaeration rates (K_{O_2}) ranged from 2 to 17.99 d^-1 (Table 5). GPP ranged from 0.63 to 14.76 mg O_2 L^-1 d^-1 while ER ranged from -17.32 to -1.21 mg O_2 L^-1 d^-1 (Table 5).

NDM ranged from -9.95 to 4.91 mg O_2 L^-1 d^-1 across the monitored sites (Table 5) while P/R ranged from 0.09 to 2.38. With the exception of three stations (11476, 34001, and 34227), NDM was consistently negative across stations and P/R was < 1. This suggests that ER exceeded GPP in most rivers regardless of season (spring/early summer or fall) or flow conditions (Table 3 5).

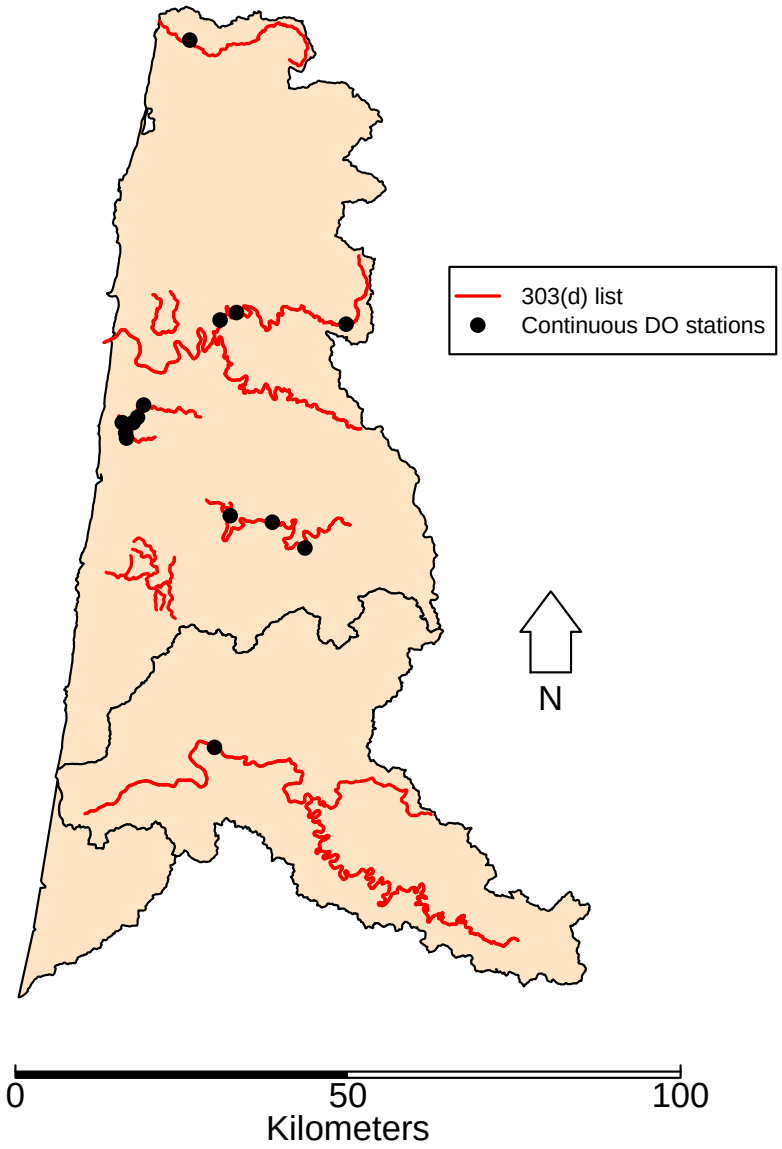

Figure 2: Map of Oregon Mid Coast basins and stream segments appearing on the 2010 Integrated Report as water quality limited for dissolved oxygen.

Table 4: Minimum and maximum dissolved oxygen (DO) concentrations and saturation levels observed during the 24-hour cycle used to estimate reaeration and metabolism metrics for Oregon Mid Coast rivers in 2008.

Station	Dates	Min DO (mg O_2 L^{-1})	Max DO (mg O_2 L^{-1})	Min DO %	Max DO %
11241	14-15 Oct 2008	10.65	11.17	93	98
34454	13-14 May 2008	10.33	10.63	92	95
34456	15-16 Oct 2008	10.04	10.64	89	95
11476	14-15 May 2008	10.61	11.24	99	105
11476	15-16 Oct 2008	9.34	9.70	84	87
33644	19-20 Nov 2008	10.34	10.55	92	94
34764	19-20 Nov 2008	10.39	10.64	92	94
33996	25-26 June 2008	7.86	9.69	74	93
34001	25-26 June 2008	9.77	10.22	90	97
34227	24-25 Sep 2008	9.40	10.68	88	107
10585	23-24 Sep 2008	9.11	10.23	87	101
11263	23-24 Sep 2008	9.29	9.96	91	100

Table 5: Estimates of reaeration and metabolism metrics from Oregon Mid Coast rivers in 2008.

Station	Dates	Reaeration (d^{-1})	GPP (mg O_2 L^{-1} d^{-1})	ER (mg O_2 L^{-1} d^{-1})	NDM (mg O_2 L^{-1} d^{-1})	P/R
11241	14-15 Oct 2008	11.61	3.62	-7.86	-4.24	0.46
34454	13-14 May 2008	17.99	10.39	-14.31	-3.92	0.73
34456	15-16 Oct 2008	6.16	2.32	-10.44	-8.12	0.22
11476	14-15 May 2008	2.59	2.89	-1.21	1.68	2.38
11476	15-16 Oct 2008	4.38	1.31	-8.18	-6.87	0.16
33644	19-20 Nov 2008	6.29	0.63	-5.51	-4.88	0.11
34764	19-20 Nov 2008	14.34	1.04	-10.99	-9.95	0.09
33996	25-26 June 2008	5.60	8.79	-17.32	-8.53	0.51
34001	25-26 June 2008	2.00	14.76	-9.84	4.91	1.50
34227	24-25 Sep 2008	7.39	7.52	-4.98	2.54	1.51
10585	23-24 Sep 2008	4.78	4.50	-6.40	-1.89	0.70
11263	23-24 Sep 2008	3.21	1.86	-3.33	-1.47	0.56

6 Conclusions and Proposed Strategy

Our analysis shows that parameters controlling diel DO dynamics can be modeled with high degree of confidence on 12 of the 14 stations monitored in 2008. This suggests that factors controlling reaeration, gross primary production, and ecosystem respiration can be examined to determine the degree to which environmental characteristics such as solar input, nutrient loading, and channel complexity can altered to influence DO concentrations. Additionally, the spatial and temporal scale needed to influence DO dynamics in a particular reach can be directly calculated from discharge measurements and reaeration estimates. Through understanding the influence of different factors on DO dynamics and the scale at which the influence occurs, we can evaluate combinations of different management activities that could be enacted to shift DO concentrations above minimum benchmark thresholds. However, DO dynamics in tidally-influenced river segments, such as the reach reflected on station 33642 on the Siuslaw River, will need to be evaluated using a different approach (one that incorporates estuary dynamics).

I propose that we develop a pilot TMDL analysis for the main stem Yaquina River. This river had 4 stations with high quality data collected in September of 2008, all of which occur in sequence on the main stem river. Remotely sensed data on riparian and watershed land cover and land use, as well as reach-specific data such as nutrient concentrations, biochemical oxygen demand (BOD), and discharge, are all available for this river, facilitating the use of a mechanistic model for TMDL development. Models available for such assessment include QUAL2Kw, AQUATOX, and HSPF. These models could be incorporated into a TMDL assessment and be used to guide alternative management implementation strategies. Further discussion and consultation is needed to determine which model will be used in the proposed analysis. Additionally, we may need to link the selected mechanistic model with watershed-level statistical models, such as SPARROW, for source assessments of nutrients and sediments.

Following pilot TMDL analyis in the Yaquina basin, I envision that we would evaluate benefits and shortcomings of using the modeling and analysis approaches in other 4th field HUCs and modify as needed. In river segments listed for failing to meet DO benchmarks but without continuous DO data during the period of concern, we would consult with stakeholders on how best to apply TMDLs developed for other Mid Coast rivers to these basins.

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A Appendix

In this appendix, we present detailed descriptions of the dissolved oxygen analysis summarized in the results section from the main document.

A.1 Siletz-Yaquina (17100204)

In the Siletz-Yaquina 4th field HUC, two rivers had continuous DO data suitable for estimating reaeration and metabolism metrics. DO concentrations on the Salmon River at Old Scenic Hwy 101 (Otis) (11241) were monitored at 15 minute intervals from 2008-10-13 12:46:00 to 2008-10-16 13:16:00. On the Yaquina River, DO concentrations were monitored continuously at two locations in different seasons. For Station 34454 (Yaquina River at Clem Road bridge), monitoring occurred from 2008-05-12 11:46:00 to 2008-05-15 10:46:00. Monitoring at Station 34456 (Yaquina River at Elk City Road bridge near Pioneer) occurred from 2008-10-13 15:46:00 to 2008-10-16 09:46:00.

A.1.1 *Salmon River*

The Salmon River from river mile 0 to 23.3 was placed on the 303(d) list for failing to meet dissolved oxygen benchmarks of 11.0 mg L^{-1} or 95% of saturation from September 15th - May 15th. The listing resulted from an assessment in 2002 that showed that 13% of samples taken at LASAR station 11241 fell below the benchmarks.

Data collected from 2008-10-13 12:46:00 to 2008-10-16 13:16:00 suggested that dissolved oxygen concentrations fell below the spawning criteria during each of the night time periods measured (to 10.5 mg O_2 L^{-1} and 93%; Figure 3). Peak DO concentrations occurred during midday and were recorded as 12.3 mg O_2 L^{-1} and 105% (Figure 3). Temperatures ranged from 7.6 to 11.4°C during the monitoring period. Discharge at the time of monitoring was 400 L s^{-1}.

We estimated reaeration, gross primary production, and ecosystem respiration rates for the 24 hour period encompassing sunrise to sunrise on 14-15 October 2008. Sunrise for both days was 07:31 while sunset was 18:32. Baseline rates of K_{O_2N} and ER_N determined from the night-time regression were 11.6 d^{-1} and -7.6 mg O_2 L^{-1} d^{-1}, respectively (Figure 4).

We calculated daily rates of GPP and ER as 3.62 and -7.86 mg O_2 L^{-1} d^{-1}, respectively, translating into a P/R of 0.46 and a NDM of -4.24 mg O_2 L^{-1} d^{-1}. These results suggest that the reach upstream represented by the monitoring station (10 km) was heterotrophic, driven by decomposition of organic matter.

A.1.2 *Yaquina River*

Sections of the Yaquina River encompassing river mile 0 to 56.9 were placed on the 303(d) list for failing to meet dissolved oxygen benchmarks of 11.0 mg L^{-1} or 95% of saturation from September 15th - May 15th or January 1st - May 15th. The listing resulted from the 2012 Integrated Report that stated that 40 and 18% of samples taken at LASAR stations 34456 (1/16/08 - 11/7/08) and 11476 (3/22/94 - 11/4/03) fell below DO benchmarks of 11 mg O_2 L^{-1} or 95% saturation for spawning, respectively, and that 15% of samples taken at station 11476 (6/21/1994 - 7/16/03) fell below the criteria of 8 mg O_2 L^{-1} or 90% saturation for core cold water habitat (salmonid rearing and migration).

Station 34454: Yaquina River at Clem Road bridge. Data collected from 2008-05-12 11:46:00 to 2008-05-15 10:46:00 suggest that dissolved oxygen concentrations fell below the spawning criteria during each of the night time periods measured (to 9.8 mg O_2 L^{-1} and 91%; Figure 5). Peak DO concentrations occurred during midday and were recorded as 12.7 mg O_2 L^{-1} and 119% (Figure 5). Temperatures ranged from 8.7 to 14.3°C during the monitoring period. Discharge at the time of monitoring was 3000 L s^{-1}.

We estimated reaeration, gross primary production, and ecosystem respiration rates for the 24 hour period encompassing sunrise to sunrise on 13-14 May 2008. Sunrise for both days was 05:48 while sunset

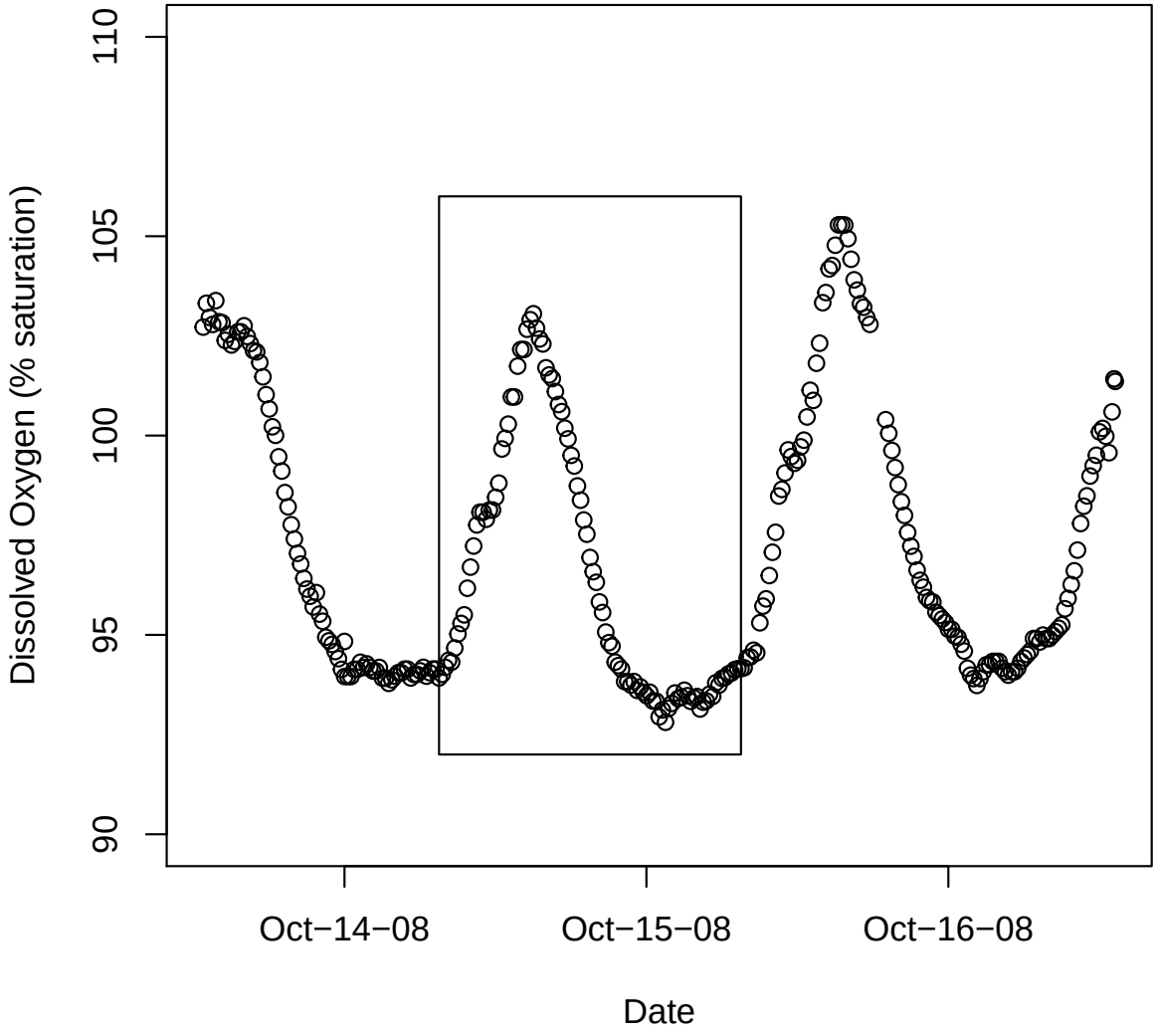

Figure 3: Diel dissolved oxygen (DO) dynamics on the Salmon River at Old Scenic Hwy 101 (Otis) (LASAR station 11241). Reaeration, gross primary production (GPP), and ecosystem respiration (ER) were estimated for the 24 hour period within the the rectangle.

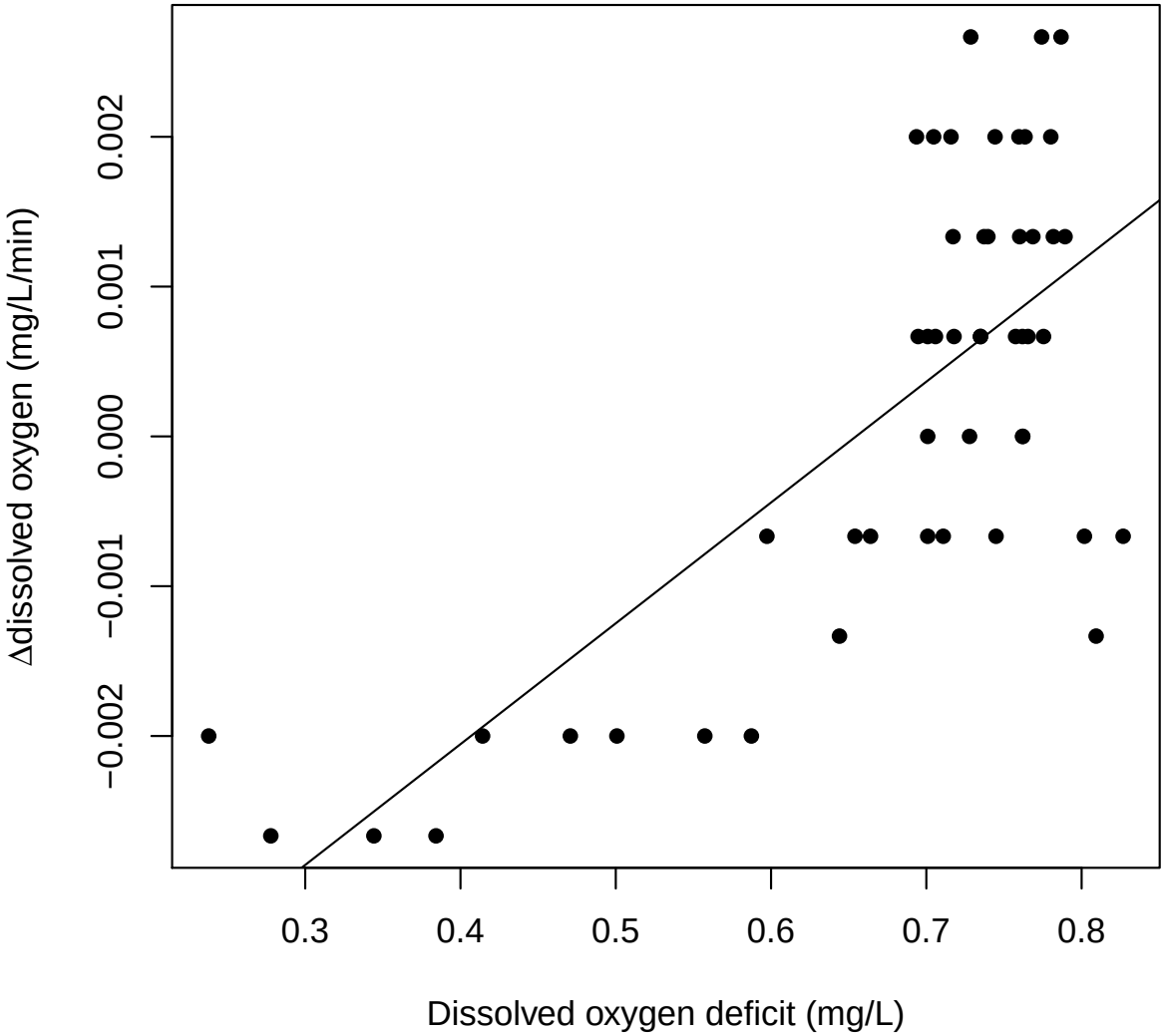

Figure 4: Results from the night time regression of the change in dissolved oxygen concentration vs. dissolved oxygen deficit on the Salmon River at Old Scenic Hwy 101 (Otis) (LASAR station 11241). Regression equation is: y=-0.0053+0.0081x; adjusted r^2=0.52; p=2.3e-09.

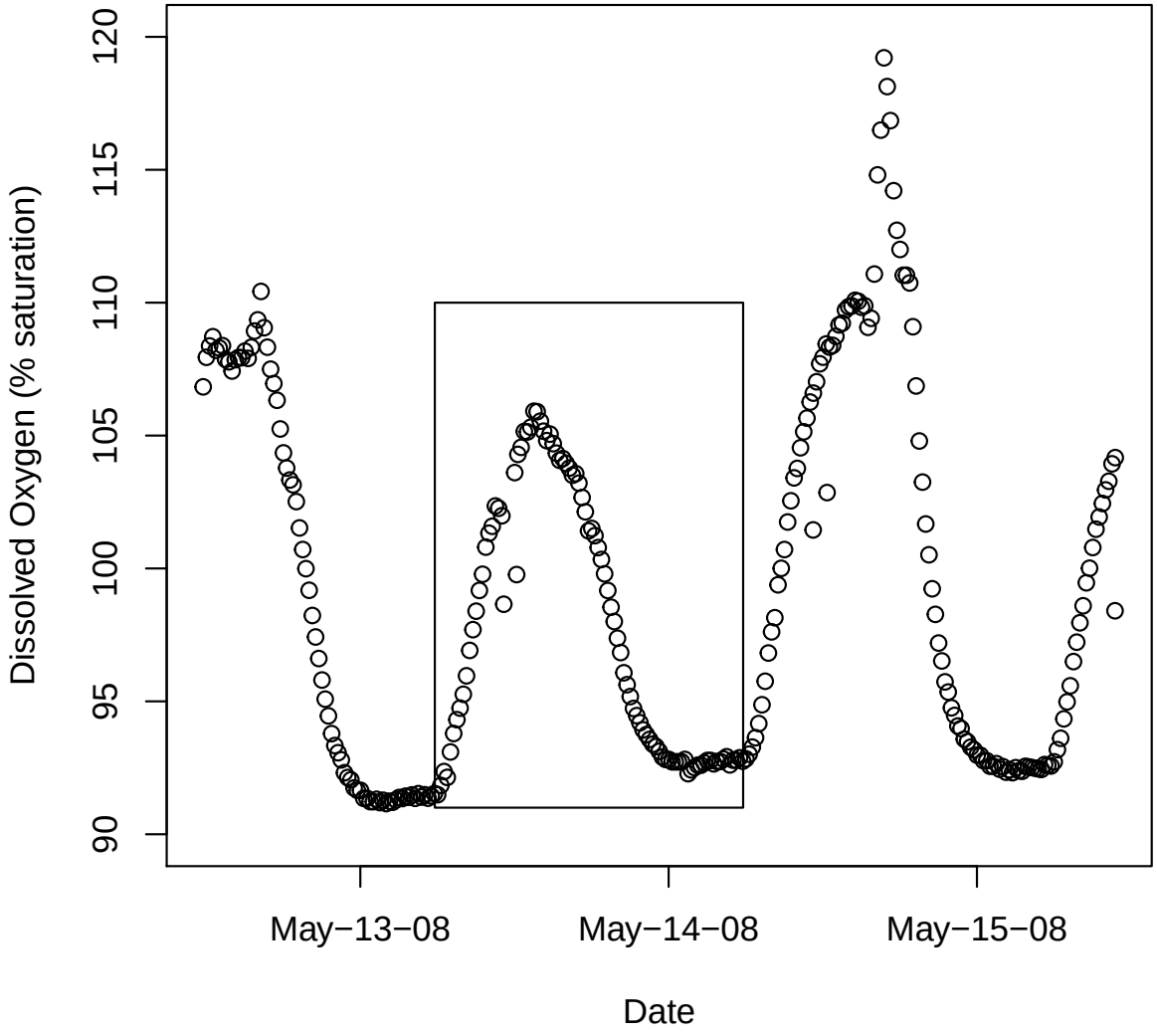

Figure 5: Diel dissolved oxygen (DO) dynamics on the Yaquina River at Clem Road bridge (LASAR station 34454). Reaeration, gross primary production (GPP), and ecosystem respiration (ER) were estimated for the 24 hour period within the the rectangle.

was 20:34. Baseline rates of K_{O_2N} and ER_N determined from the night-time regression were 6.74 d^{-1} and -7.86 mg O_2 L^{-1} d^{-1}, respectively (Figure 6).

We calculated daily rates of GPP and ER as 10.4 and -14.3 mg O_2 L^{-1} d^{-1}, respectively, translating into a P/R of 0.73 and a NDM of -3.92 mg O_2 L^{-1} d^{-1}. These results suggest that the reach upstream represented by the monitoring station (8 km) was heterotrophic, driven by decomposition of organic matter.

Station 34456: Yaquina River at Elk City Road bridge near Pioneer. Data collected from 2008-10-13 15:46:00 to 2008-10-16 09:46:00 suggest that dissolved oxygen concentrations fell below the spawning criteria during each of the night time periods measured (to 9.9 mg O_2 L^{-1} and 88%; Figure 7). Peak DO concentrations occurred during midday and were recorded as 11.1 mg O_2 L^{-1} and 100% (Figure 7). Temperatures ranged from 9.2 to 11.6°C during the monitoring period. Discharge at the time of monitoring was 400 L s^{-1}.

We estimated reaeration, gross primary production, and ecosystem respiration rates for the 24 hour period encompassing sunrise to sunrise on 15-16 October 2008. Sunrise for both days was 07:32 while sunset was 18:30. Basal rates of reaeration and ecosystem respiration determined from the night-time regression were 6.16 d^{-1} and -7.34 mg O_2 L^{-1} d^{-1}, respectively (Figure 8).

We calculated daily rates of GPP and ER as 2.32 and -10.4 mg O_2 L^{-1} d^{-1}, respectively, translating into a P/R of 0.22 and a NDM of -8.12 mg O_2 L^{-1} d^{-1}. These results suggest that the reach upstream represented by the monitoring station (20 km) was heterotrophic, driven by decomposition of organic matter.

Station 11476 (May): Yaquina River at Trapp Road (Chitwood). Data collected from 2008-05-13 09:00:00 to 2008-05-15 11:40:00 suggest that dissolved oxygen concentrations fell somewhat below the spawning criteria during each of the night time periods measured (to 9.9 mg O_2 L^{-1} and 93%; Figure 9). Peak DO concentrations occurred during midday and were recorded as 11.6 mg O_2 L^{-1} and 109% (Figure 9). Temperatures ranged from 10.7 to 14.2°C during the monitoring period. Discharge at the time of monitoring was 3000 L s^{-1}.

We estimated reaeration, gross primary production, and ecosystem respiration rates for the 24 hour period encompassing sunrise to sunrise on 13-14 May 2008. Sunrise for both days was 07:32 while sunset was 18:30. Baseline rates of K_{O_2N} and ER_N determined from the night-time regression were 2.59 d^{-1} and -1.25 mg O_2 L^{-1} d^{-1}, respectively (Figure 10).

We calculated daily rates of GPP and ER as 2.89 and -1.21 mg O_2 L^{-1} d^{-1}, respectively, translating into a P/R of 2.4 and a NDM of 1.68 mg O_2 L^{-1} d^{-1}. These results suggest that the reach upstream represented by the monitoring station (50 km) was autotrophic, driven by internal organic matter production by algae and/or other aquatic plants.

Station 11476 (October): Yaquina River at Trapp Road (Chitwood). Data collected from 2008-10-13 16:45:40 to 2008-10-16 11:30:40 suggest that dissolved oxygen concentrations fell below the spawning criteria during each of the night time periods measured (to 9.3 mg O_2 L^{-1} and 83%; Figure 11). Peak DO concentrations occurred during midday and were recorded as 10.4 mg O_2 L^{-1} and 94% (Figure 11). Temperatures ranged from 10.1 to 11.4°C during the monitoring period. Discharge at the time of monitoring was 400 L s^{-1}.

We estimated reaeration, gross primary production, and ecosystem respiration rates for the 24 hour period encompassing sunrise to sunrise on 15-16 may 2008. Sunrise for both days was 07:32 while sunset was 18:30. Baseline rates of K_{O_2N} and ER_N determined from the night-time regression were 4.38 d^{-1} and -8.25 mg O_2 L^{-1} d^{-1}, respectively (Figure 12).

We calculated daily rates of GPP and ER as 1.31 and -14.5 mg O_2 L^{-1} d^{-1}, respectively, translating into a P/R of 0.16 and a NDM of -6.87 mg O_2 L^{-1} d^{-1}. These results suggest that the reach upstream represented by the monitoring station (30 km) was heterotrophic, driven by decomposition of allochthonous (terrestrial) organic matter.

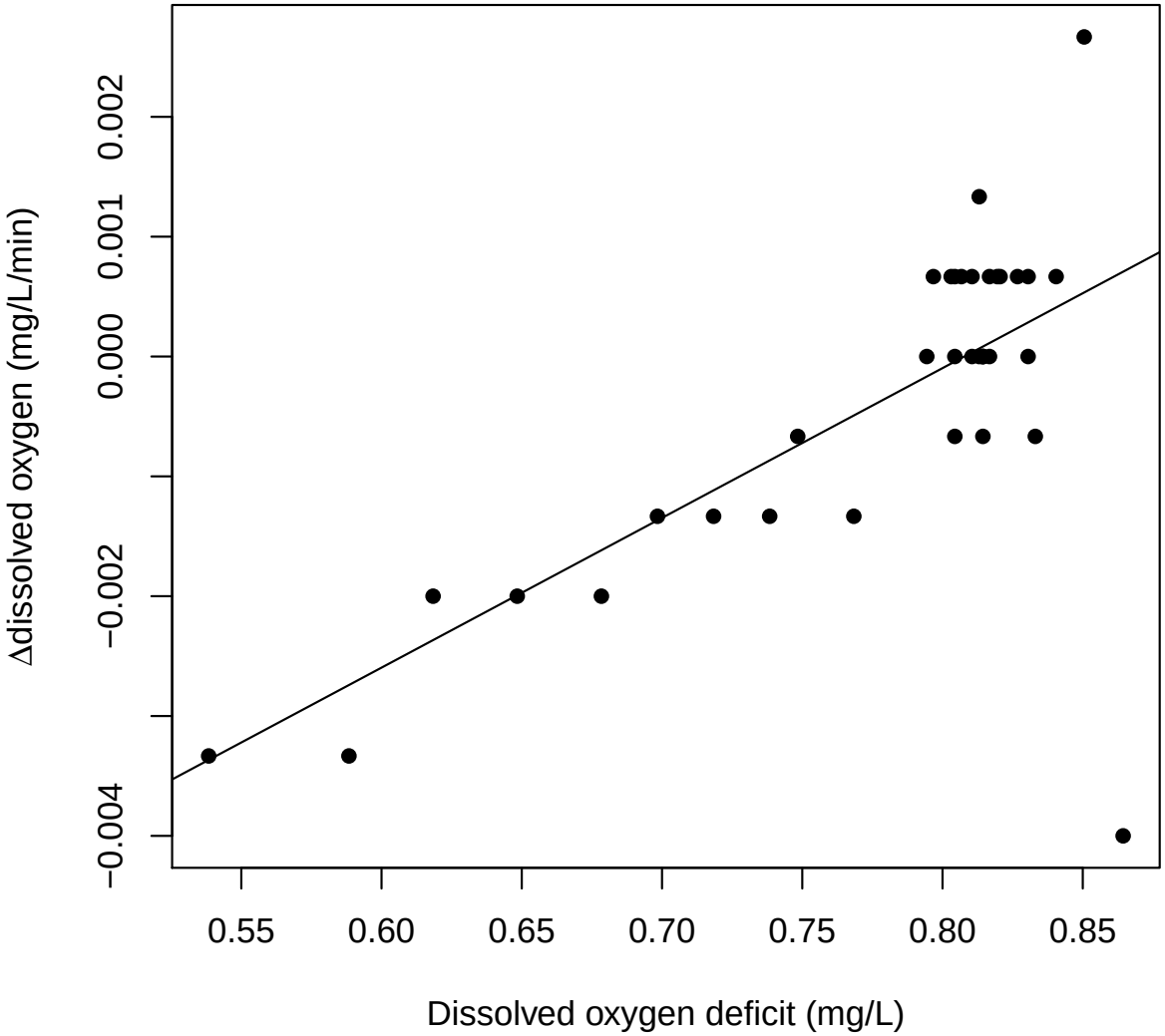

Figure 6: Results from the night time regression of the change in dissolved oxygen concentration vs. dissolved oxygen deficit on the Yaquina River at Clem Road bridge (LASAR station 34454). Regression equation is: y=-0.0055+0.0047x; adjusted r^2=0.54; p=1.3e-09.

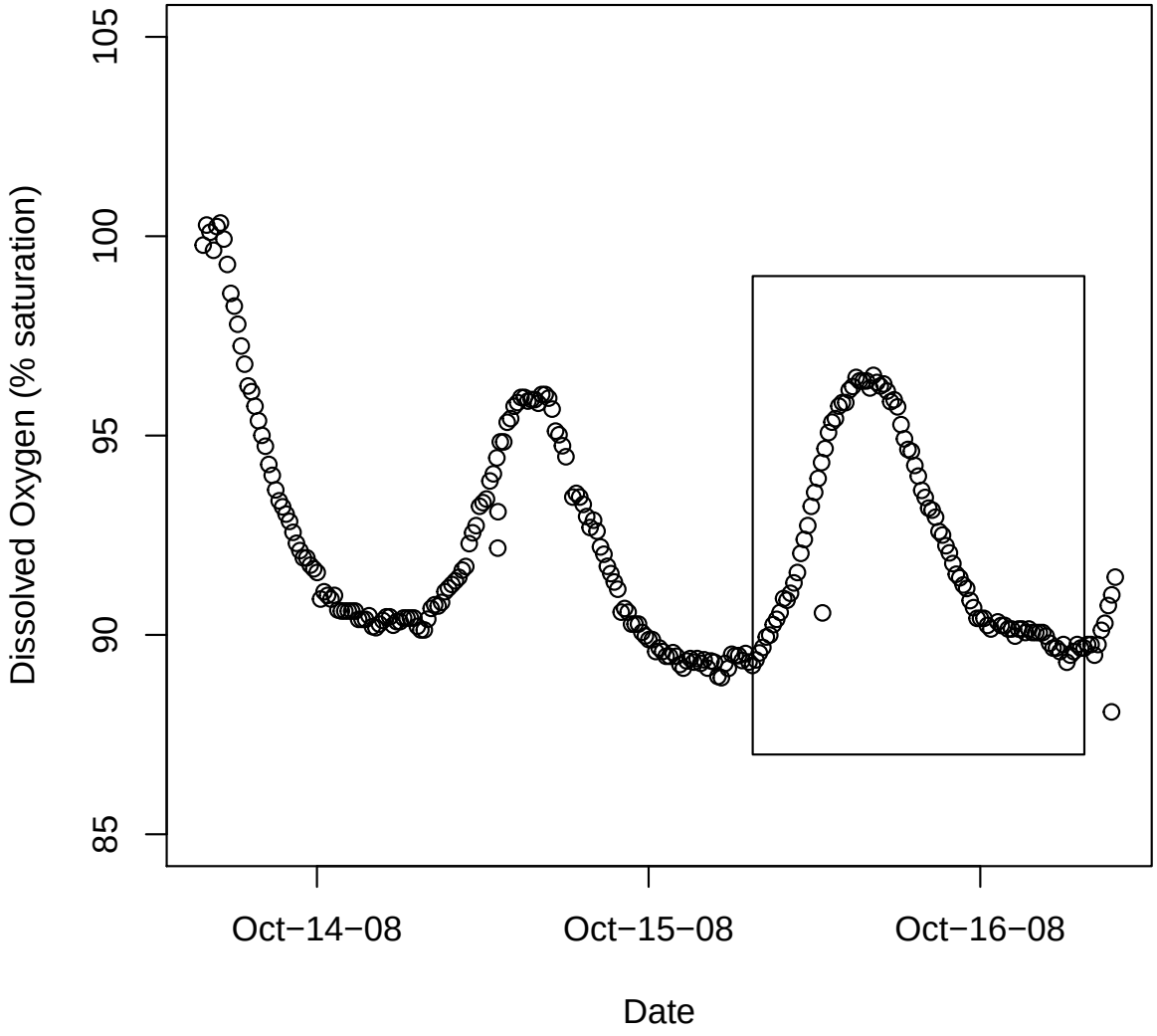

Figure 7: Diel dissolved oxygen (DO) dynamics on the Yaquina River at Elk City Road bridge near Pioneer (LASAR station 34456). Reaeration, gross primary production (GPP), and ecosystem respiration (ER) were estimated for the 24 hour period within the the rectangle.

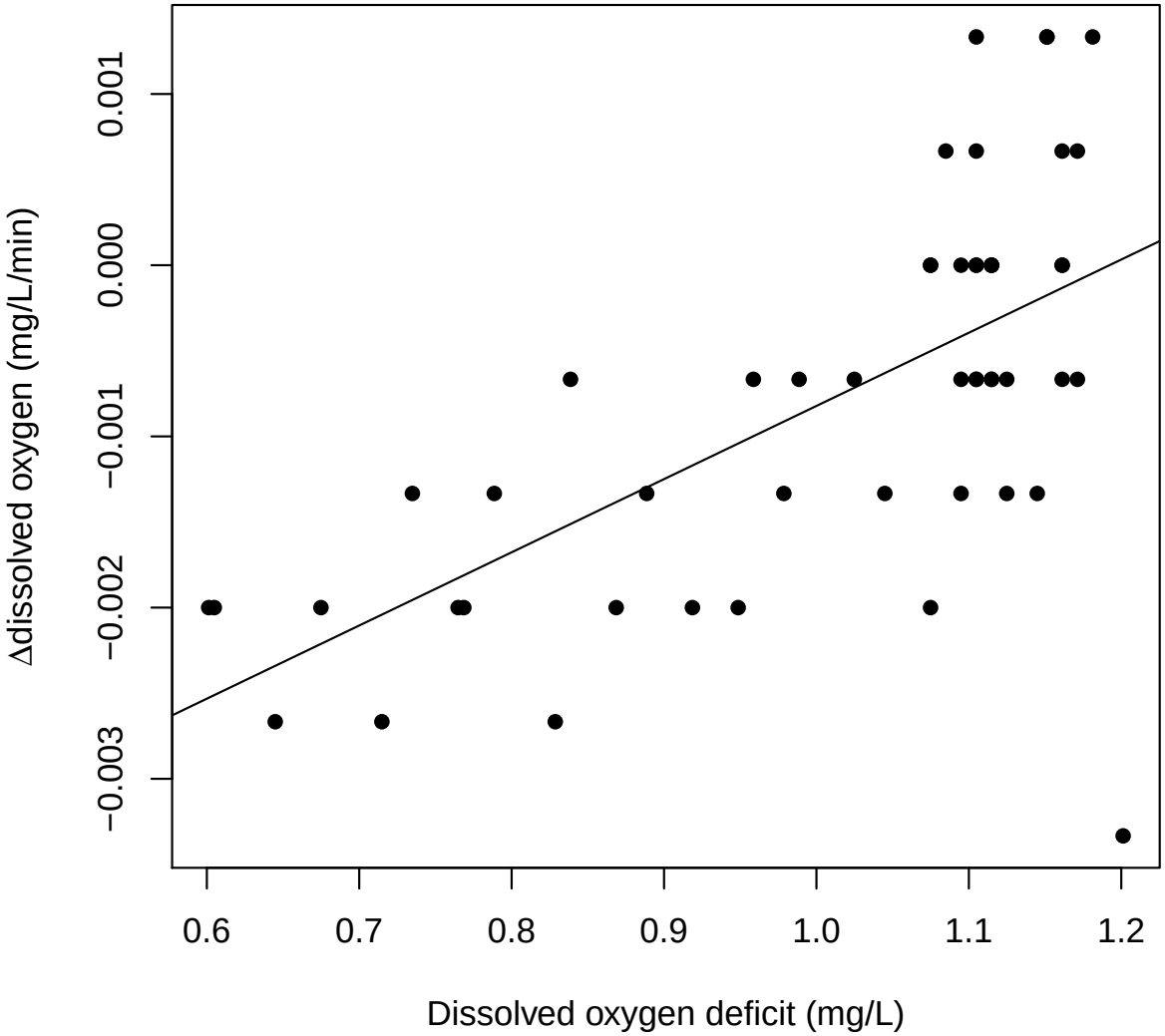

Figure 8: Results from the night time regression of the change in dissolved oxygen concentration vs. dissolved oxygen deficit on the Yaquina River at Elk City Road bridge near Pioneer (LASAR station 34456). Regression equation is: y=-0.0051+0.0043x; adjusted r^2=0.4; p=4.5e-07.

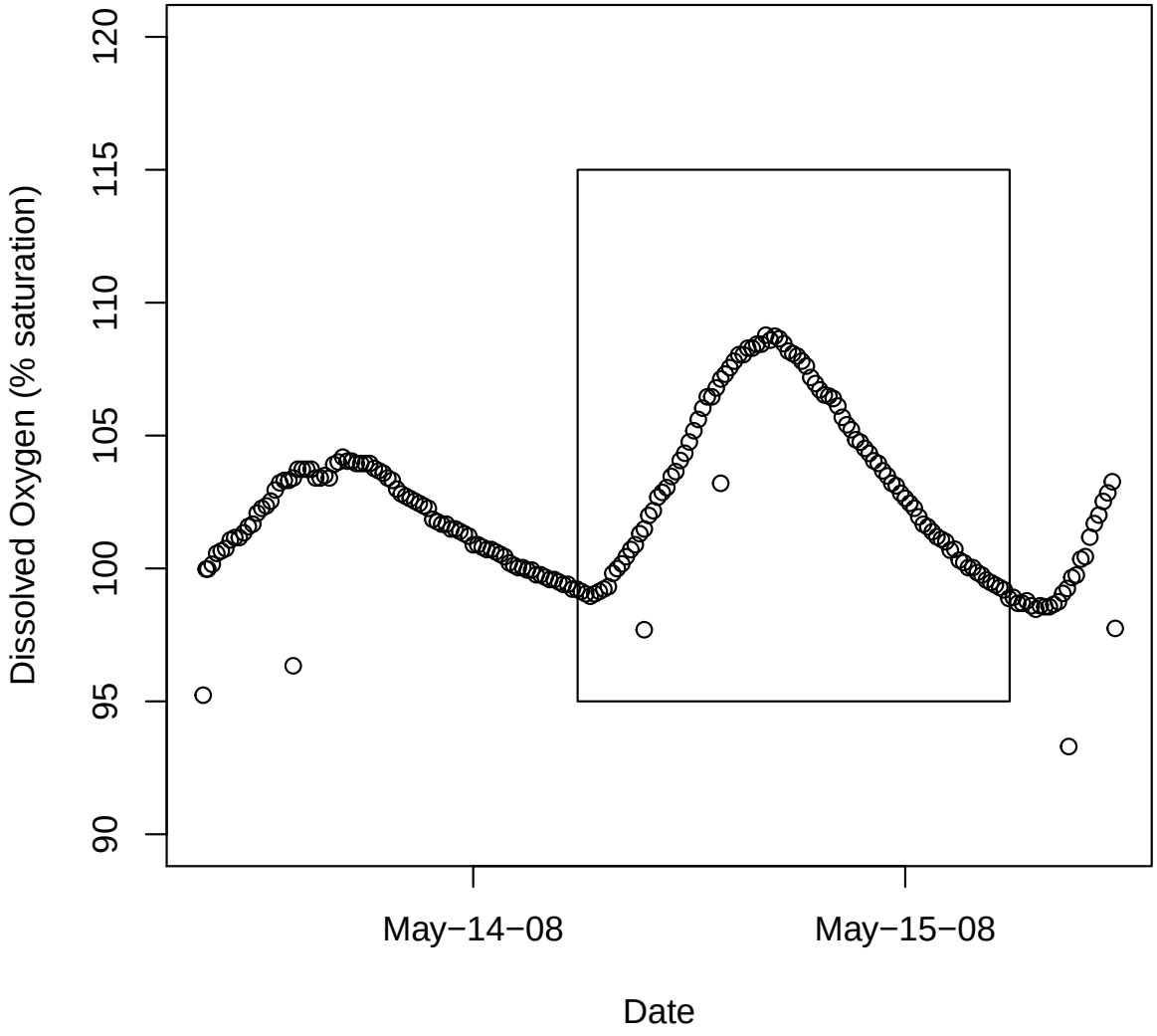

Figure 9: Diel dissolved oxygen (DO) dynamics on the Yaquina River at Trapp Road (Chitwood) (LASAR station 11476) in May. Reaeration, gross primary production (GPP), and ecosystem respiration (ER) were estimated for the 24 hour period within the the rectangle.

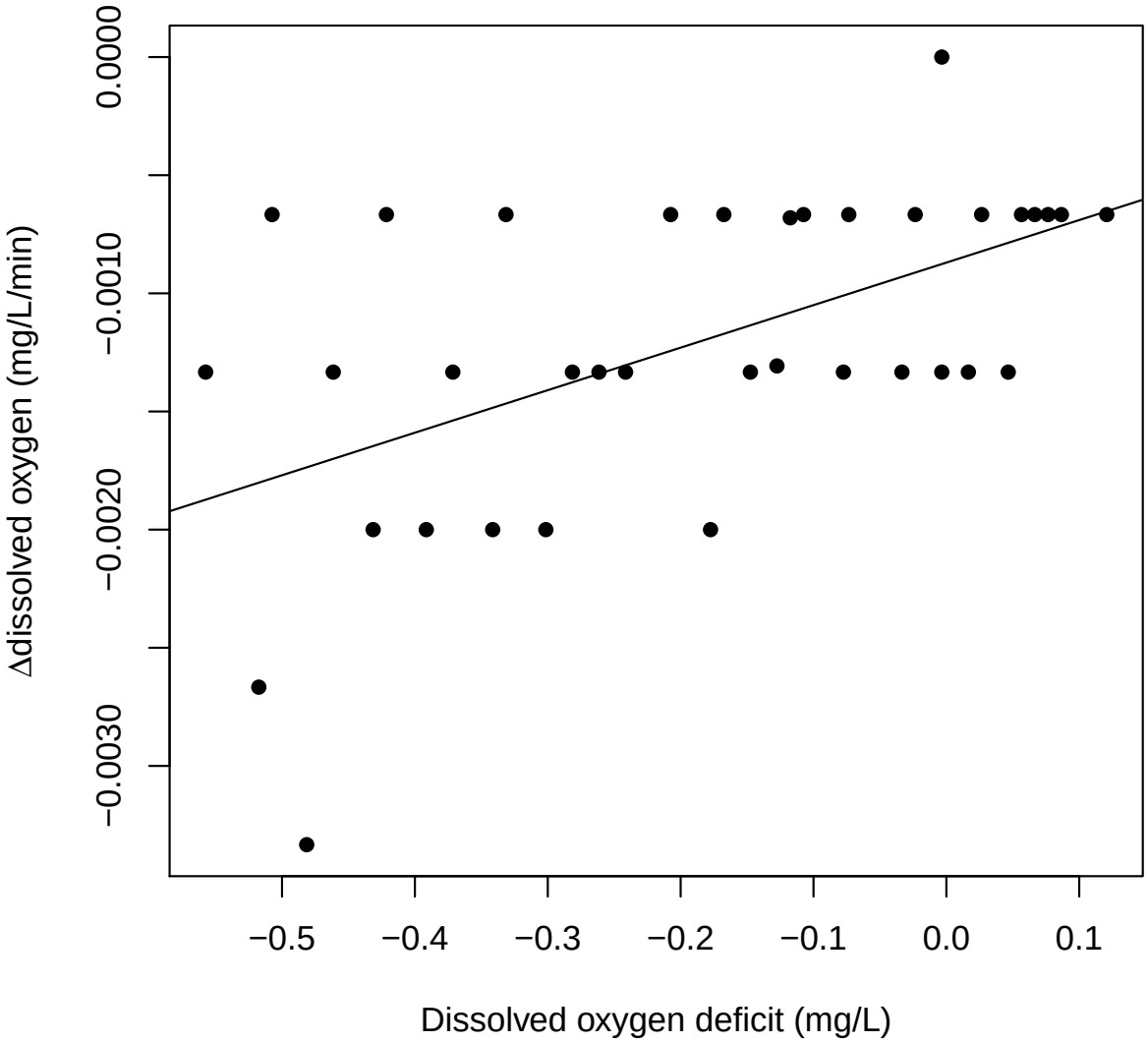

Figure 10: Results from the night time regression of the change in dissolved oxygen concentration vs. dissolved oxygen deficit on the Yaquina River at Trapp Road (Chitwood) (LASAR station 11476) in May. Regression equation is: y=-0.00087+0.0018x; adjusted r^2=0.27; p=0.00062.

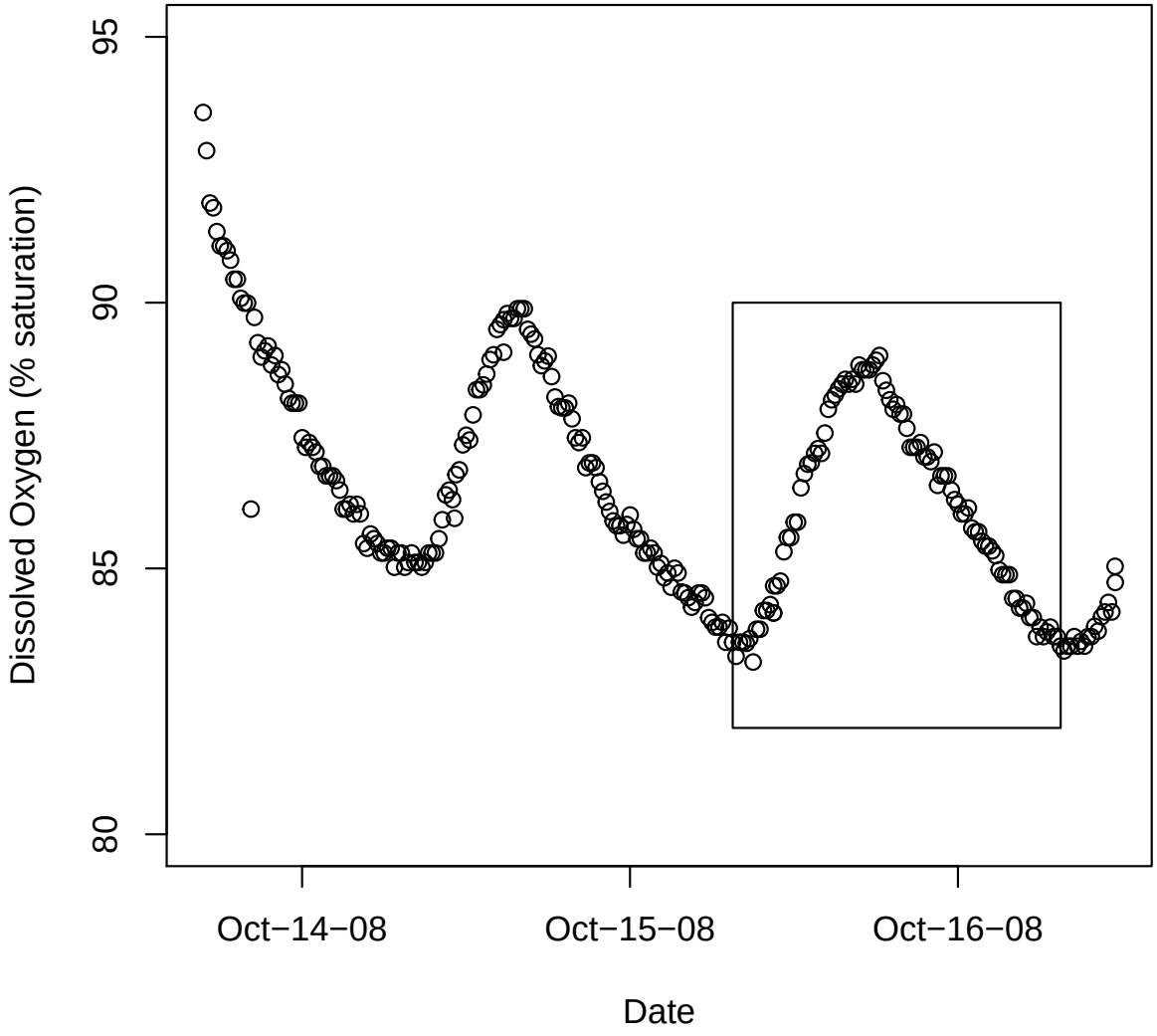

Figure 11: Diel dissolved oxygen (DO) dynamics on the Yaquina River at Trapp Road (Chitwood) (LASAR station 11476) in October. Reaeration, gross primary production (GPP), and ecosystem respiration (ER) were estimated for the 24 hour period within the the rectangle.

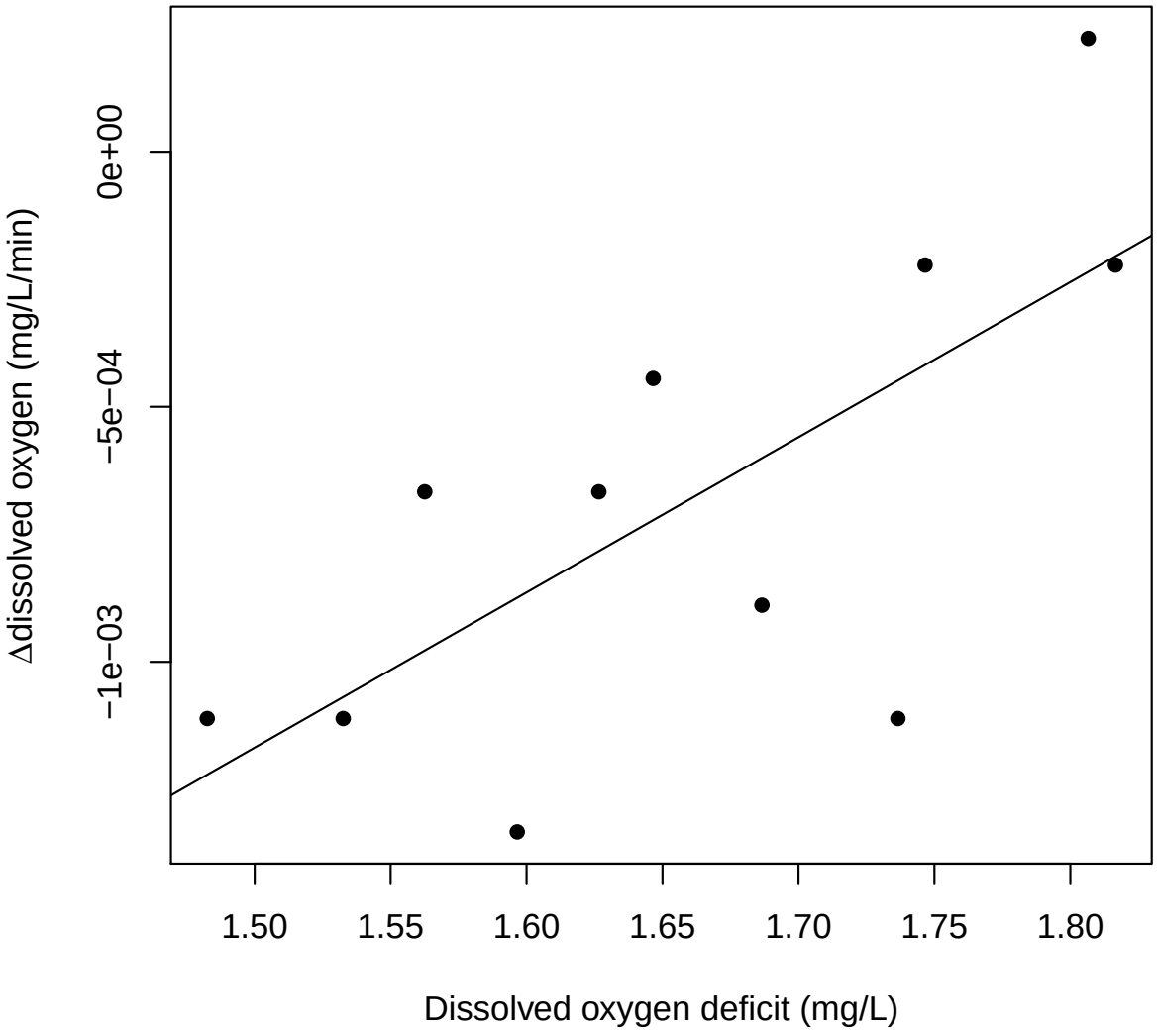

Figure 12: Results from the night time regression of the change in dissolved oxygen concentration vs. dissolved oxygen deficit on the Yaquina River at Trapp Road (Chitwood) (LASAR station 11476) in October. Regression equation is: y=-0.0057+0.003x; adjusted r^2=0.43; p=0.017.The number of points in the regression have been reduced to exclude outliers.

A.2 Alsea (17100205)

In the Alsea 4th field HUC, five rivers had continuous monitoring sites. On North Fork Beaver Creek, DO concentrations were monitored continuously at two locations in the fall. DO concentrations on North Fork Beaver Cr above Peterson Cr (34764) were monitored at 15 minute intervals from 2008-11-17 15:01:00 to 2008-11-20 09:30:00. DO concentrations on North Fork Beaver Creek at Ona Grange river mile 4.8 (33644) were monitored at 15 minute intervals from 2008-11-17 14:46:00 to 2008-11-20 09:00:00.

On South Fork Beaver Creek, DO concentrations were monitored continuously at two locations in June. For Station 33996 (South Beaver Creek at 1st S Beaver Cr Rd Bridge RM 0.9 (Mid Coast)), monitoring occurred from 2008-06-24 12:16:00 to 2008-06-26 14:01:00. At Station 34001 (South Beaver Creek Below Oliver Creek (Mid Coast)), monitoring happened from 2008-06-24 11:05:00 to 2008-06-26 13:00:00.

On the Alsea River, DO monitoring also occurred at three separate stations in the fall. Monitoring at Station 34227 (Alsea River at Salmonberry Road) occurred from 2008-09-22 13:46:00 to 2008-09-25 11:31:00. For Station 10585 (Alsea River at Five Rivers Bridge), monitoring occurred from 2008-09-22 14:16:00 to 2008-09-25 11:01:00. At Station 11263 (Alsea River at Thissell Road (Mike Bauer Park)), monitoring happened from 2008-09-22 14:31:00 to 2008-09-25 10:30:00.

A.2.1 *North Fork Beaver Creek*

Station 34764: North Fork Beaver Cr above Peterson Cr Data collected from 2008-11-17 15:01:00 to 2008-11-20 09:30:00 suggest that dissolved oxygen concentrations fell below the spawning criteria during each of the night time periods measured (to 10.4 mg O_2 L^{-1} and 92%; Figure 13). Peak DO concentrations occurred during midday and were recorded as 11.1 mg O_2 L^{-1} and 97% (Figure 13). Temperatures ranged from 9.6 to 10.9°C during the monitoring period. Discharge at the time of monitoring was not recorded.

We estimated reaeration, gross primary production, and ecosystem respiration rates for the 24 hour period encompassing sunrise to sunrise on 15-16 October 2008. Sunrise for both days was 07:18 while sunset was 16:44. Basal rates of reaeration and ecosystem respiration determined from the night-time regression were 14.3 d^{-1} and -11 mg O_2 L^{-1} d^{-1}, respectively (Figure 14).

We calculated daily rates of GPP and ER as 1.04 and -11 mg O_2 L^{-1} d^{-1}, respectively, translating into a P/R of 0.094 and a NDM of -9.95 mg O_2 L^{-1} d^{-1}. These results suggest that the reach upstream represented by the monitoring station (9 km) was heterotrophic, driven by decomposition of allochthonous (terrestrial) organic matter.

Station 33644: North Fork Beaver Creek at Ona Grange river mile 4.8 Data collected from 2008-11-17 14:46:00 to 2008-11-20 09:00:00 suggest that dissolved oxygen concentrations fell below the spawning criteria during each of the night time periods measured (to 10 mg O_2 L^{-1} and 88%; Figure 15). Peak DO concentrations occurred during midday and were recorded as 10.9 mg O_2 L^{-1} and 97% (Figure 15). Temperatures ranged from 9.9 to 10.7°C during the monitoring period. Discharge at the time of monitoring was not recorded.

We estimated reaeration, gross primary production, and ecosystem respiration rates for the 24 hour period encompassing sunrise to sunrise on 15-16 October 2008. Sunrise for both days was 07:18 while sunset was 16:44. Basal rates of reaeration and ecosystem respiration determined from the night-time regression were 6.29 d^{-1} and -5.53 mg O_2 L^{-1} d^{-1}, respectively (Figure 16).

We calculated daily rates of GPP and ER as 0.631 and -5.51 mg O_2 L^{-1} d^{-1}, respectively, translating into a P/R of 0.11 and a NDM of -4.88 mg O_2 L^{-1} d^{-1}. These results suggest that the reach upstream represented by the monitoring station (20 km) was heterotrophic, driven by decomposition of allochthonous (terrestrial) organic matter.

A.2.2 *South Fork Beaver Creek*

Station 33996: South Beaver Creek at 1st S Beaver Cr Rd Bridge RM 0.9 (Mid Coast) Data collected from 2008-06-24 12:16:00 to 2008-06-26 14:01:00 suggest that dissolved oxygen concentrations fell

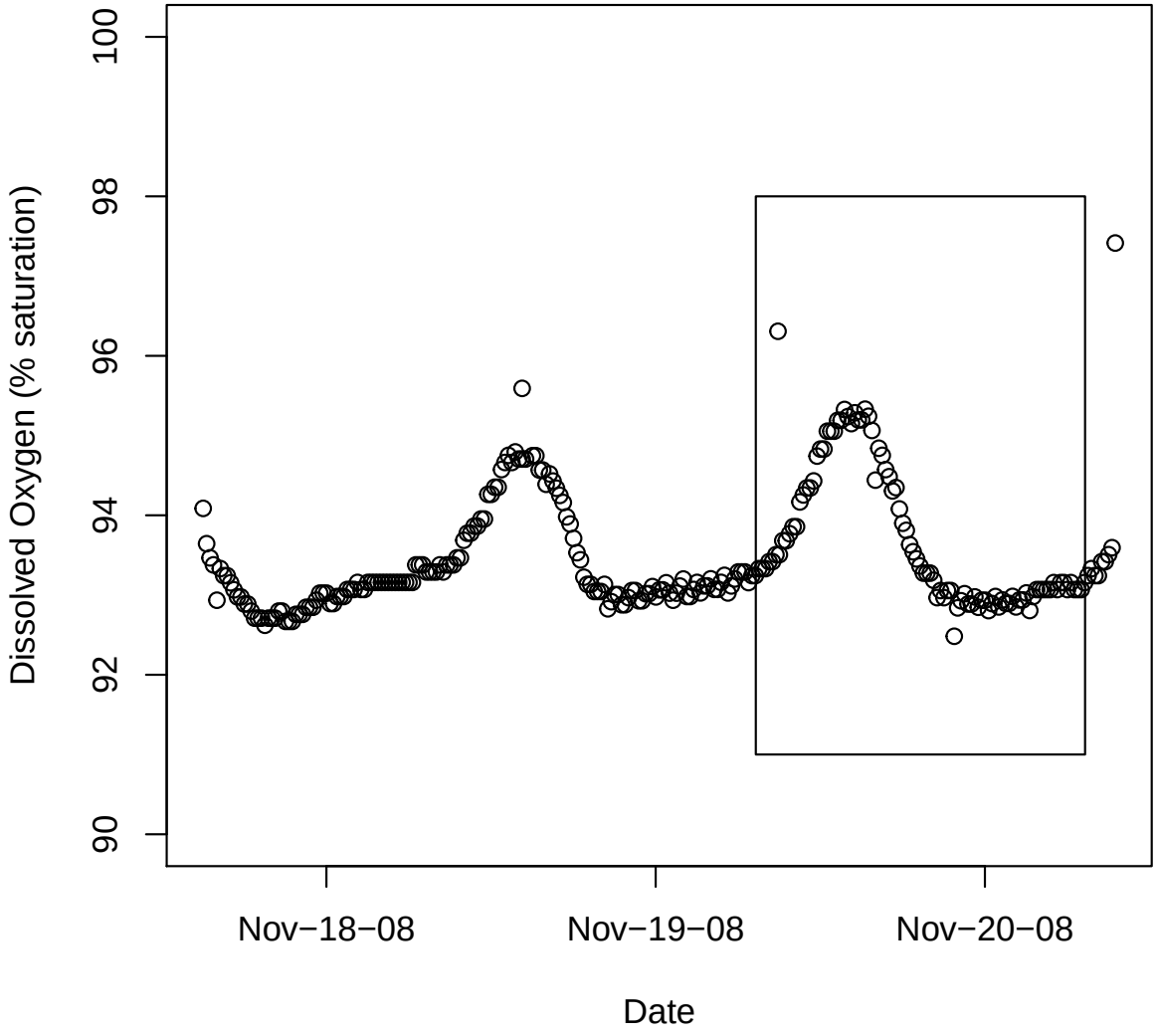

Figure 13: Diel dissolved oxygen (DO) dynamics on the North Fork Beaver Cr above Peterson Cr (LASAR station 34764). Reaeration, gross primary production (GPP), and ecosystem respiration (ER) were estimated for the 24 hour period within the the rectangle.

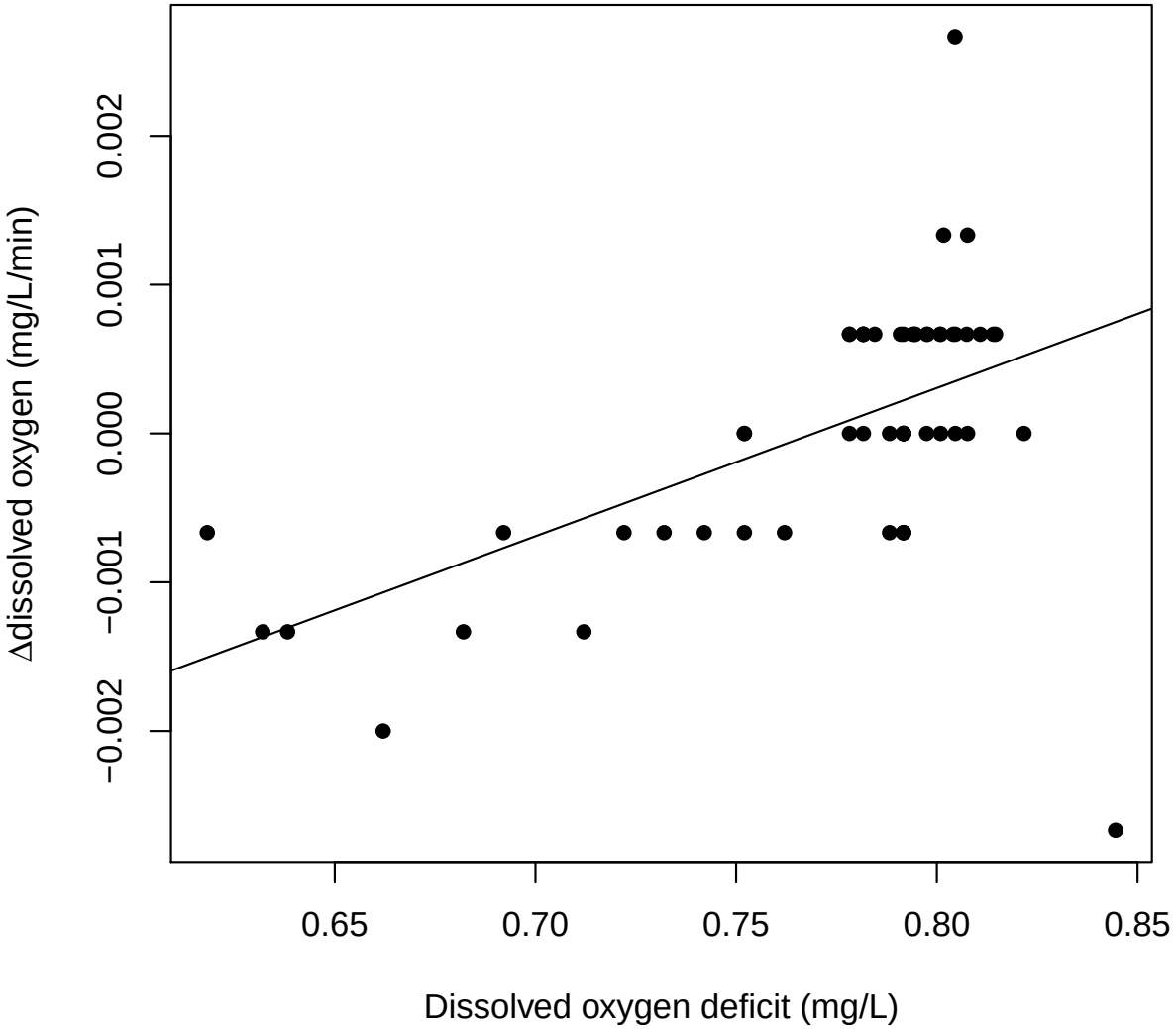

Figure 14: Results from the night time regression of the change in dissolved oxygen concentration vs. dissolved oxygen deficit on the North Fork Beaver Cr above Peterson Cr (LASAR station 34764). Regression equation is: y=-0.0077+0.01x; adjusted r^2=0.29; p=9.3e-06.

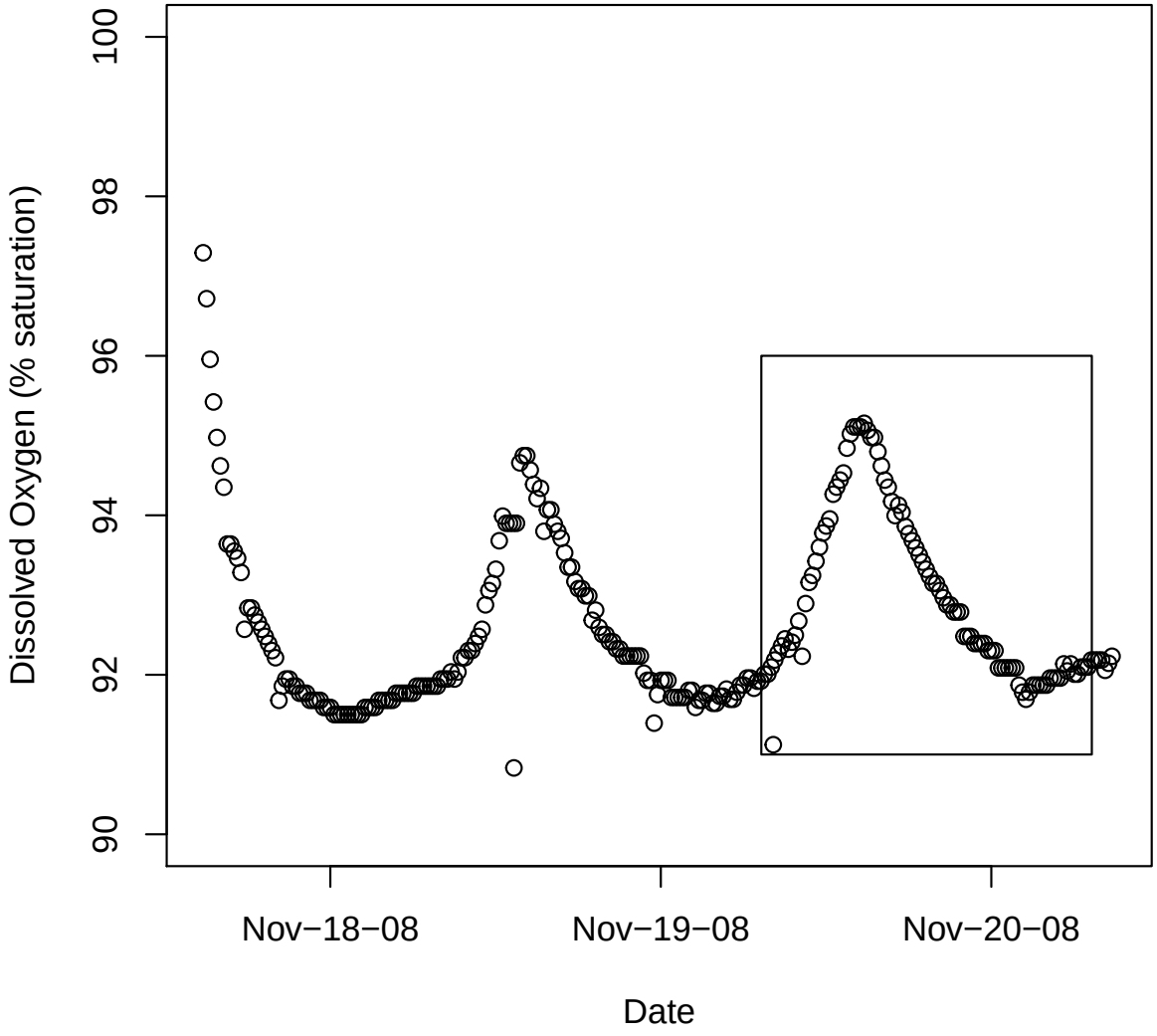

Figure 15: Diel dissolved oxygen (DO) dynamics on the North Fork Beaver Creek at Ona Grange river mile 4.8 (LASAR station 33644). Reaeration, gross primary production (GPP), and ecosystem respiration (ER) were estimated for the 24 hour period within the the rectangle.

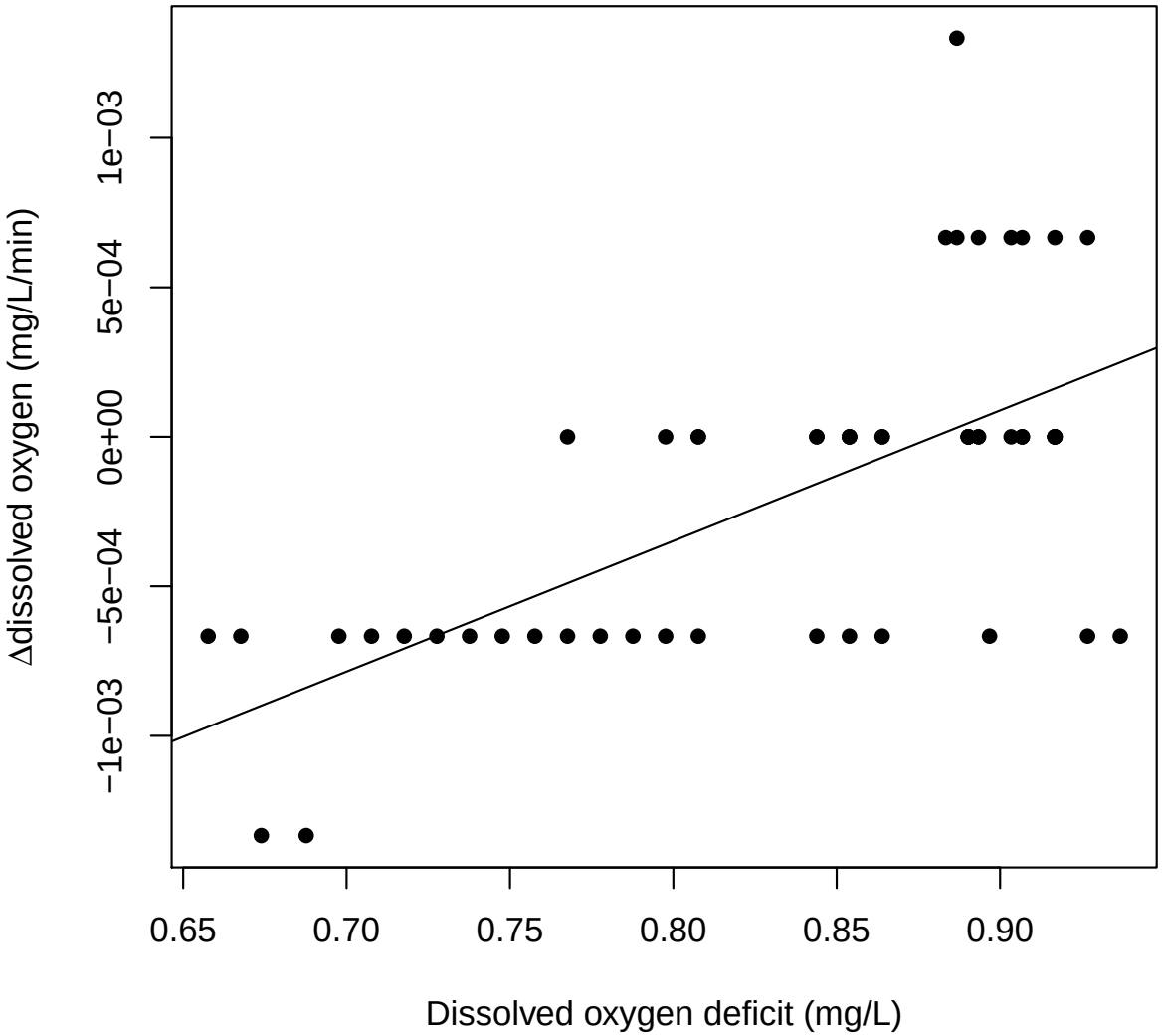

Figure 16: Results from the night time regression of the change in dissolved oxygen concentration vs. dissolved oxygen deficit on the North Fork Beaver Creek at Ona Grange river mile 4.8 (LASAR station 33644). Regression equation is: y=-0.0038+0.0044x; adjusted r^2=0.42; p=2.6e-08.

below the spawning criteria during each of the night time periods measured (to 7 mg O_2 L^{-1} and 66%; Figure 17). Peak DO concentrations occurred during midday and were recorded as 10.6 mg O_2 L^{-1} and 103% (Figure 17). Temperatures ranged from 12.1 to 14.4°C during the monitoring period. Discharge at the time of monitoring was not recorded.

We estimated reaeration, gross primary production, and ecosystem respiration rates for the 24 hour period encompassing sunrise to sunrise on 25- 26 June 2008. Sunrise for both days was 05:32 while sunset was 21:05. Basal rates of reaeration and ecosystem respiration determined from the night-time regression were 5.6 d^{-1} and -17.2 mg O_2 L^{-1} d^{-1}, respectively (Figure 18).

We calculated daily rates of GPP and ER as 8.79 and -17.3 mg O_2 L^{-1} d^{-1}, respectively, translating into a P/R of 0.51 and a NDM of -8.53 mg O_2 L^{-1} d^{-1}. These results suggest that the reach upstream represented by the monitoring station (20 km) was heterotrophic, driven by decomposition of organic matter.

Station 34001: South Beaver Creek Below Oliver Creek (Mid Coast) Data collected from 2008-06-24 11:05:00 to 2008-06-26 13:00:00 suggest that dissolved oxygen concentrations fell below the spawning criteria during each of the night time periods measured (to 9.1 mg O_2 L^{-1} and 83%; Figure 19). Peak DO concentrations occurred during midday and were recorded as 10.5 mg O_2 L^{-1} and 100% (Figure 19). Temperatures ranged from 11.2 to 14.6°C during the monitoring period. Discharge at the time of monitoring was not recorded.

We estimated reaeration, gross primary production, and ecosystem respiration rates for the 24 hour period encompassing sunrise to sunrise on 25-26 june 2008. Sunrise for both days was 05:33 while sunset was 21:05. Basal rates of reaeration and ecosystem respiration determined from the night-time regression were 2 d^{-1} and -0.544 mg O_2 L^{-1} d^{-1}, respectively (Figure 20).

We calculated daily rates of GPP and ER as 14.8 and -9.84 mg O_2 L^{-1} d^{-1}, respectively, translating into a P/R of 1.5 and a NDM of 4.91 mg O_2 L^{-1} d^{-1}. These results suggest that the reach upstream represented by the monitoring station (60 km) was heterotrophic, driven by decomposition of organic matter.

A.2.3 *Alsea River*

Station 34227: Alsea River at Salmonberry Road Data collected from 2008-09-22 13:46:00 to 2008-09-25 11:31:00 suggest that dissolved oxygen concentrations fell below the spawning criteria during each of the night time periods measured (to 8.6 mg O_2 L^{-1} and 80%; Figure 21). Peak DO concentrations occurred during midday and were recorded as 11.9 mg O_2 L^{-1} and 120% (Figure 21). Temperatures ranged from 12.4 to 16.8°C during the monitoring period. Discharge at the time of monitoring was not recorded.

We estimated reaeration, gross primary production, and ecosystem respiration rates for the 24 hour period encompassing sunrise to sunrise on 25-26 september 2008. Sunrise for both days was 07:04 while sunset was 19:07. Basal rates of reaeration and ecosystem respiration determined from the night-time regression were 7.39 d^{-1} and -4.95 mg O_2 L^{-1} d^{-1}, respectively (Figure 22).

We calculated daily rates of GPP and ER as 7.52 and -4.98 mg O_2 L^{-1} d^{-1}, respectively, translating into a P/R of 1.5 and a NDM of 2.54 mg O_2 L^{-1} d^{-1}. These results suggest that the reach upstream represented by the monitoring station (30 km) was autotrophic, driven by internal organic matter production by algae and/or other aquatic plants.

Station 10585: Alsea River at Five Rivers Bridge Data collected from 2008-09-22 14:16:00 to 2008-09-25 11:01:00 suggest that dissolved oxygen concentrations fell below the spawning criteria during each of the night time periods measured (to 9.1 mg O_2 L^{-1} and 87%; Figure 23). Peak DO concentrations occurred during midday and were recorded as 10.8 mg O_2 L^{-1} and 108% (Figure 23). Temperatures ranged from 13.1 to 15.9°C during the monitoring period. Discharge at the time of monitoring was not recorded.

We estimated reaeration, gross primary production, and ecosystem respiration rates for the 24 hour period encompassing sunrise to sunrise on 25-26 september 2008. Sunrise for both days was 07:04 while sunset was 19:07. Basal rates of reaeration and ecosystem respiration determined from the night-time regression were 4.78 d^{-1} and -6.43 mg O_2 L^{-1} d^{-1}, respectively (Figure 24).

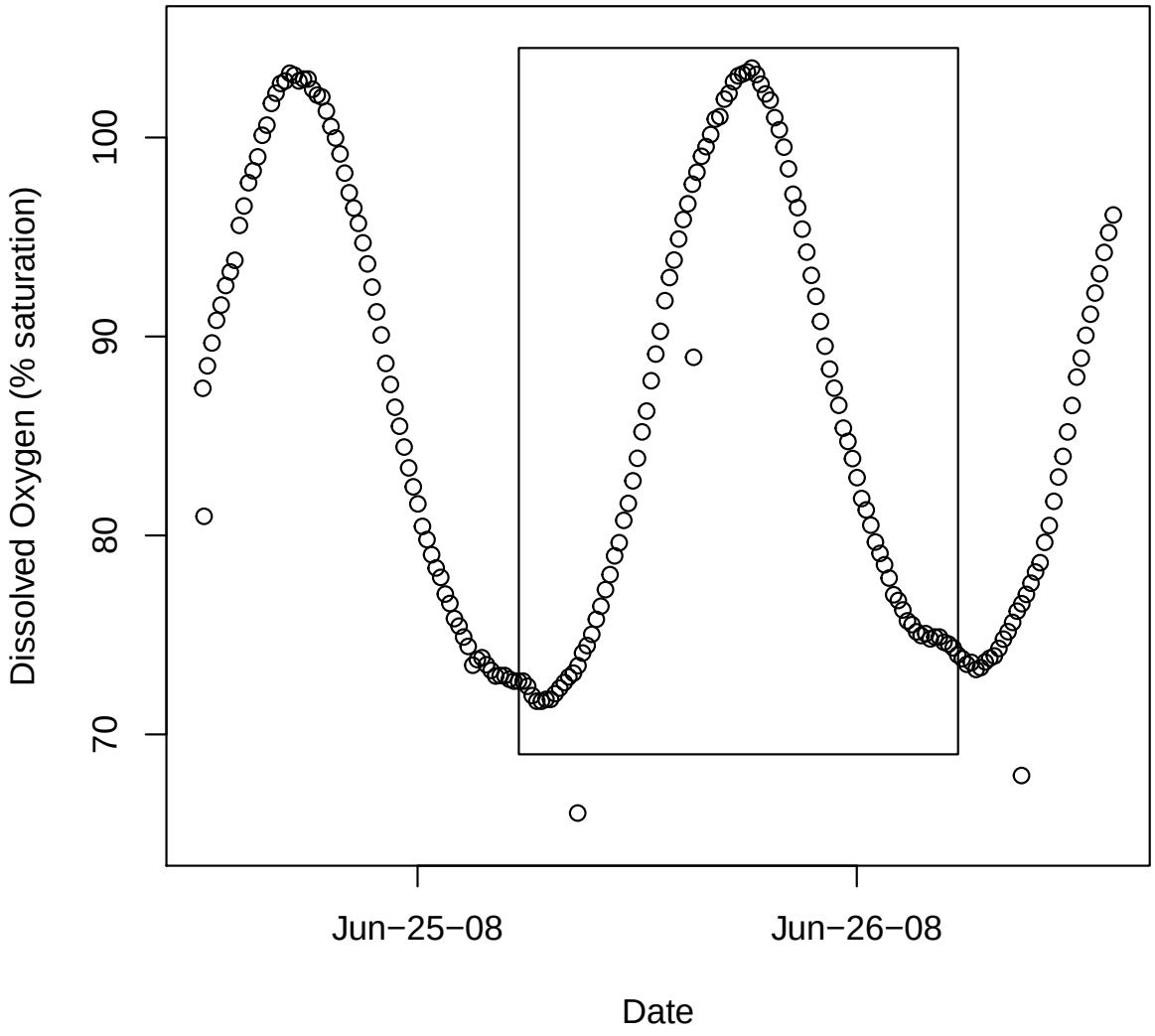

Figure 17: Diel dissolved oxygen (DO) dynamics on the South Beaver Creek at 1st S Beaver Cr Rd Bridge RM 0.9 (Mid Coast) (LASAR station 33996). Reaeration, gross primary production (GPP), and ecosystem respiration (ER) were estimated for the 24 hour period within the the rectangle.

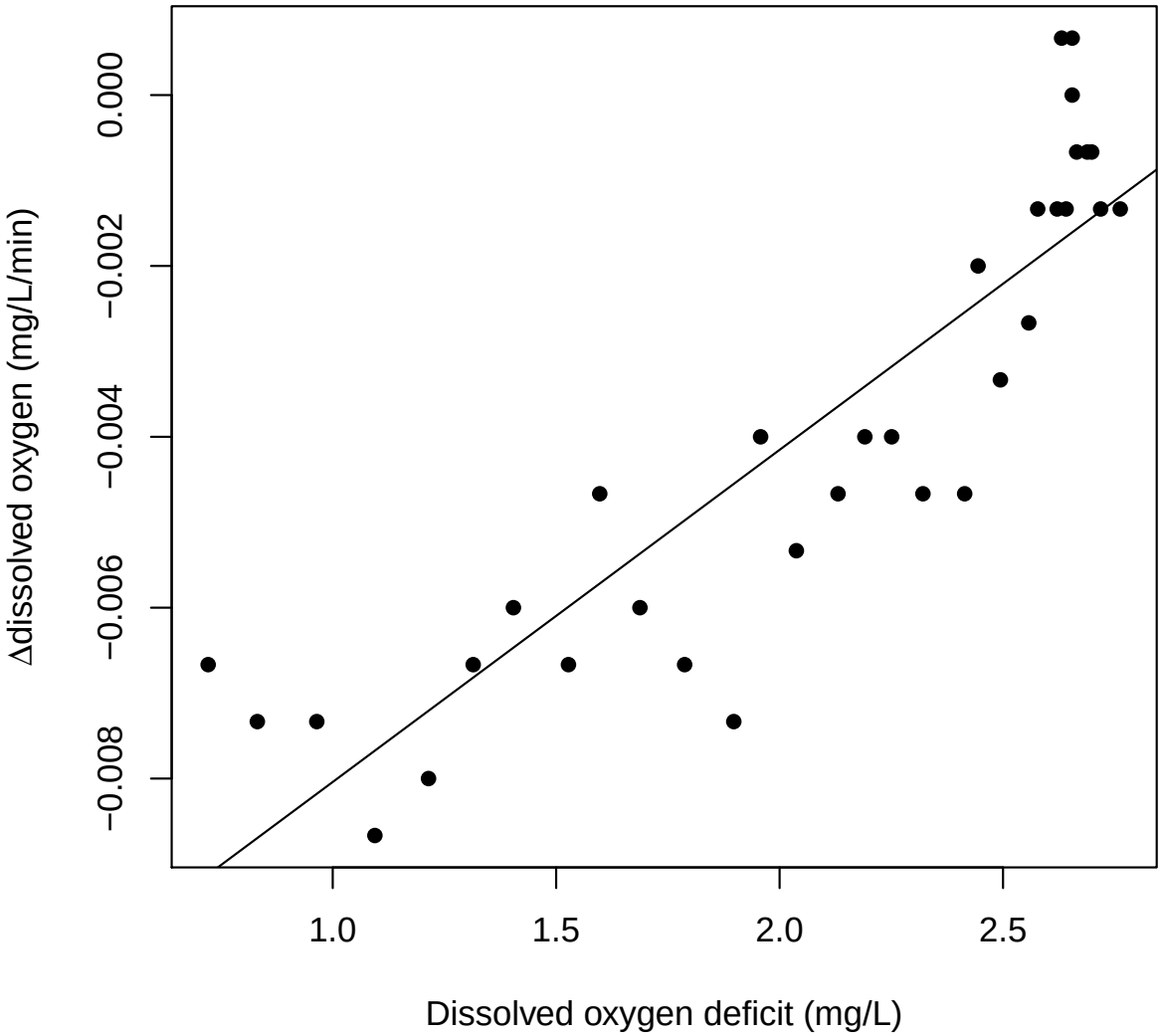

Figure 18: Results from the night time regression of the change in dissolved oxygen concentration vs. dissolved oxygen deficit on the South Beaver Creek at 1st S Beaver Cr Rd Bridge RM 0.9 (Mid Coast) (LASAR station 33996). Regression equation is: y=-0.012+0.0039x; adjusted r^2=0.78; p=6.5e-12.

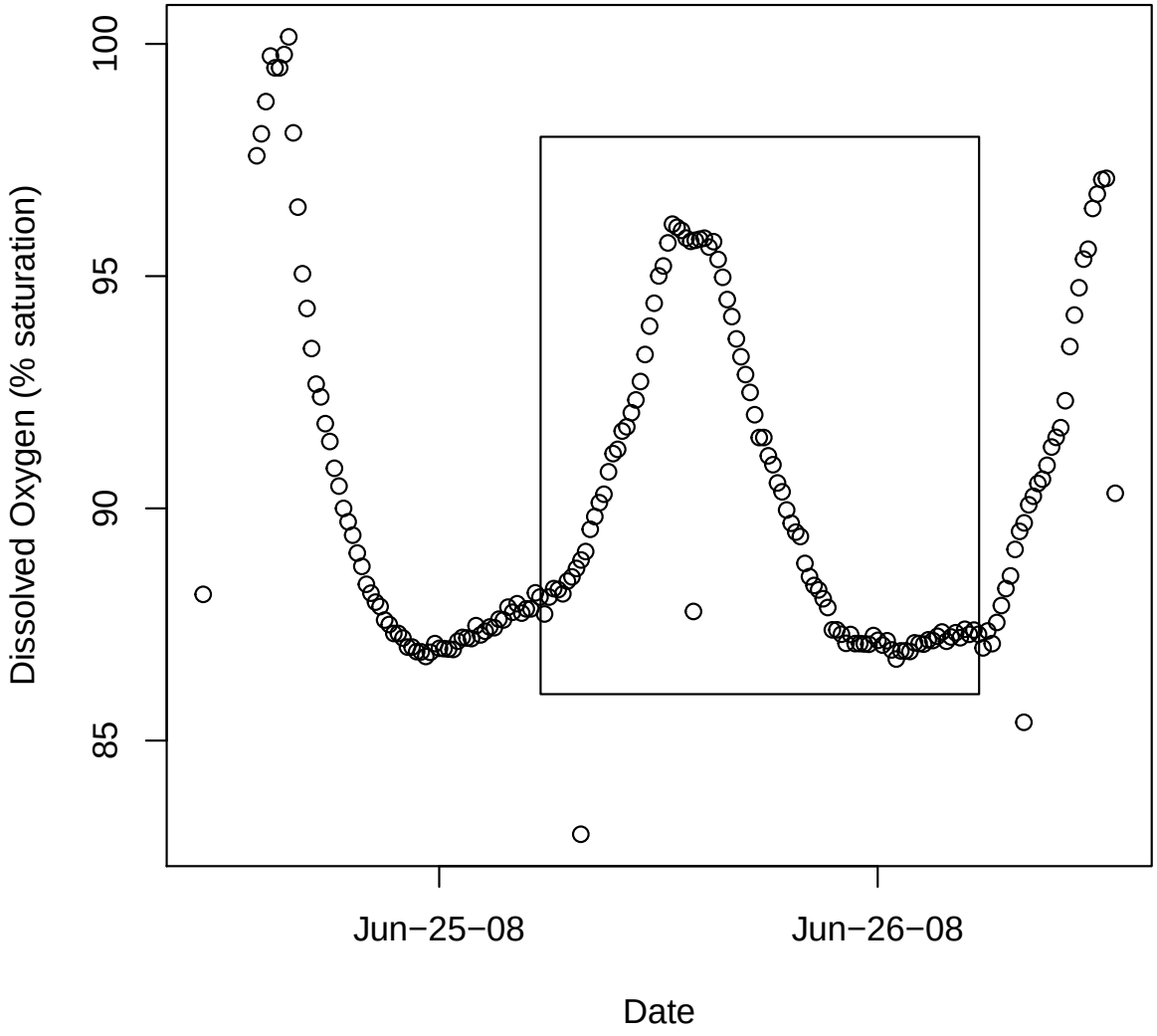

Figure 19: Diel dissolved oxygen (DO) dynamics on the South Beaver Creek Below Oliver Creek (Mid Coast) (LASAR station 34001). Reaeration, gross primary production (GPP), and ecosystem respiration (ER) were estimated for the 24 hour period within the the rectangle.

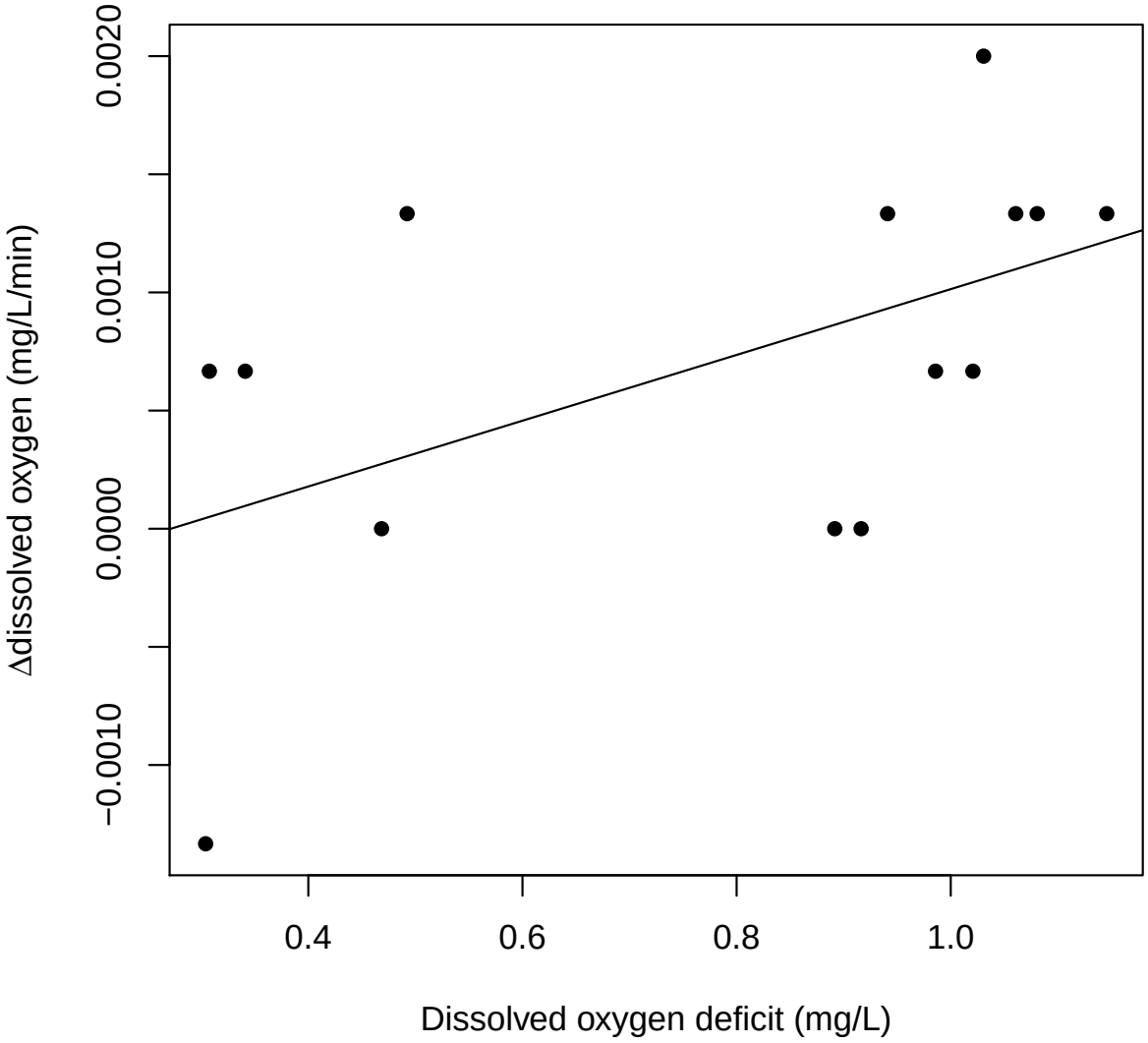

Figure 20: Results from the night time regression of the change in dissolved oxygen concentration vs. dissolved oxygen deficit on the South Beaver Creek Below Oliver Creek (Mid Coast) (LASAR station 34001). Regression equation is: y=-0.00038+0.0014x; adjusted r^2=0.22; p=0.052. The number of points in the regression have been reduced to exclude outliers.

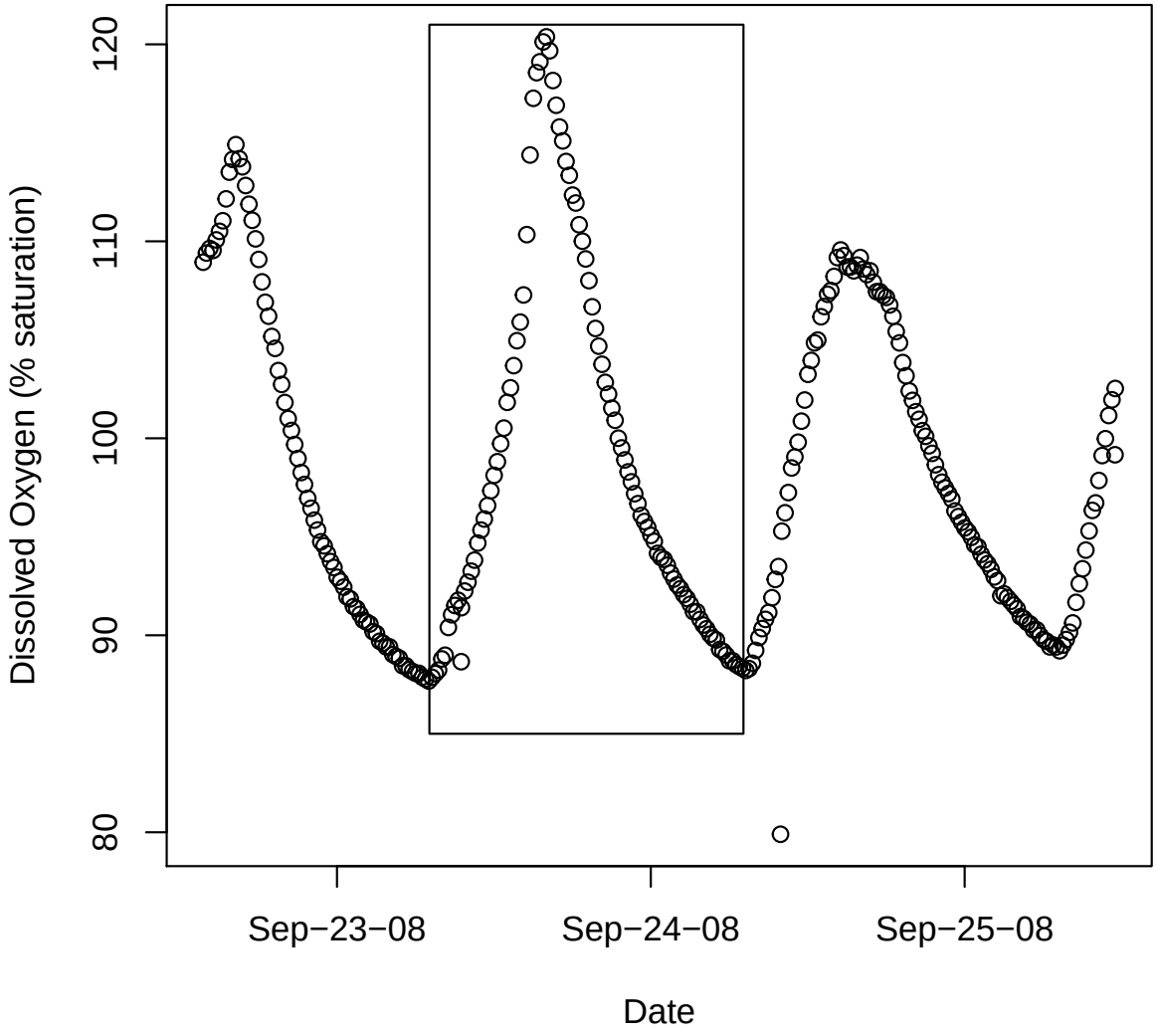

Figure 21: Diel dissolved oxygen (DO) dynamics on the Alsea River at Salmonberry Road (LASAR station 34227). Reaeration, gross primary production (GPP), and ecosystem respiration (ER) were estimated for the 24 hour period within the the rectangle.

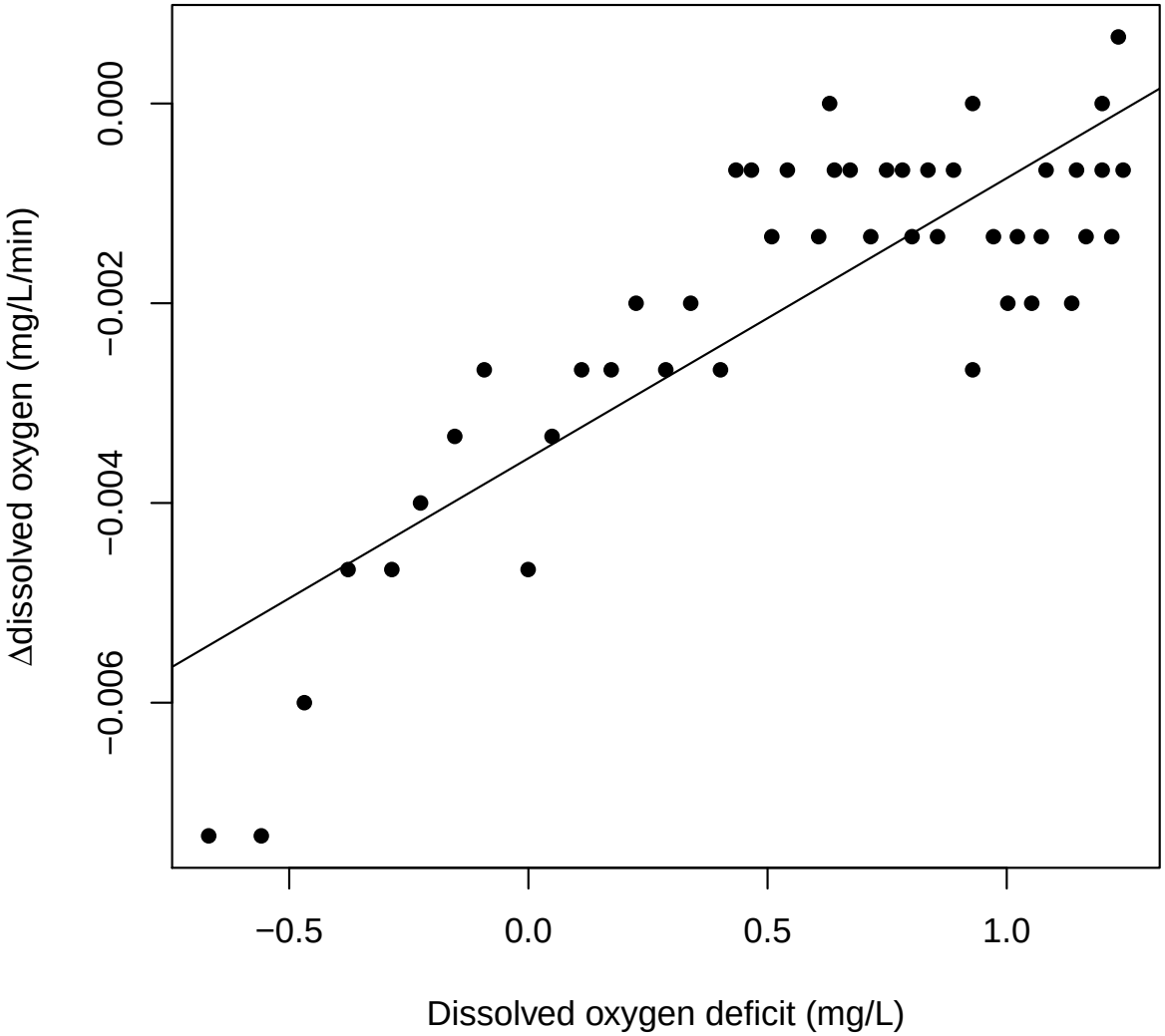

Figure 22: Results from the night time regression of the change in dissolved oxygen concentration vs. dissolved oxygen deficit on the Alsea River at Salmonberry Road (LASAR station 34227). Regression equation is: y=-0.0036+0.0028x; adjusted r^2=0.7; p=2e-13.

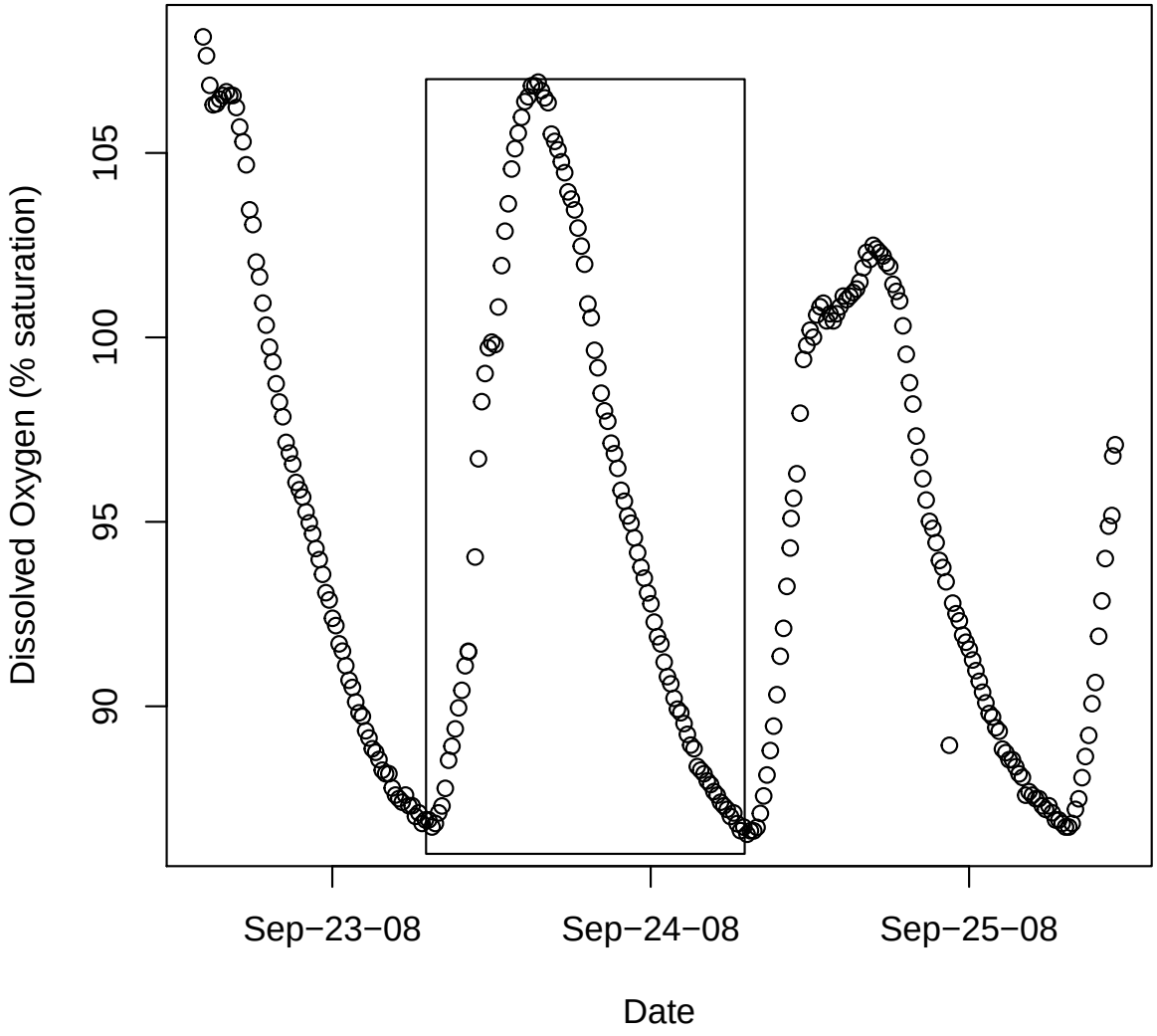

Figure 23: Diel dissolved oxygen (DO) dynamics on the Alsea River at Five Rivers Bridge (LASAR station 10585). Reaeration, gross primary production (GPP), and ecosystem respiration (ER) were estimated for the 24 hour period within the the rectangle.

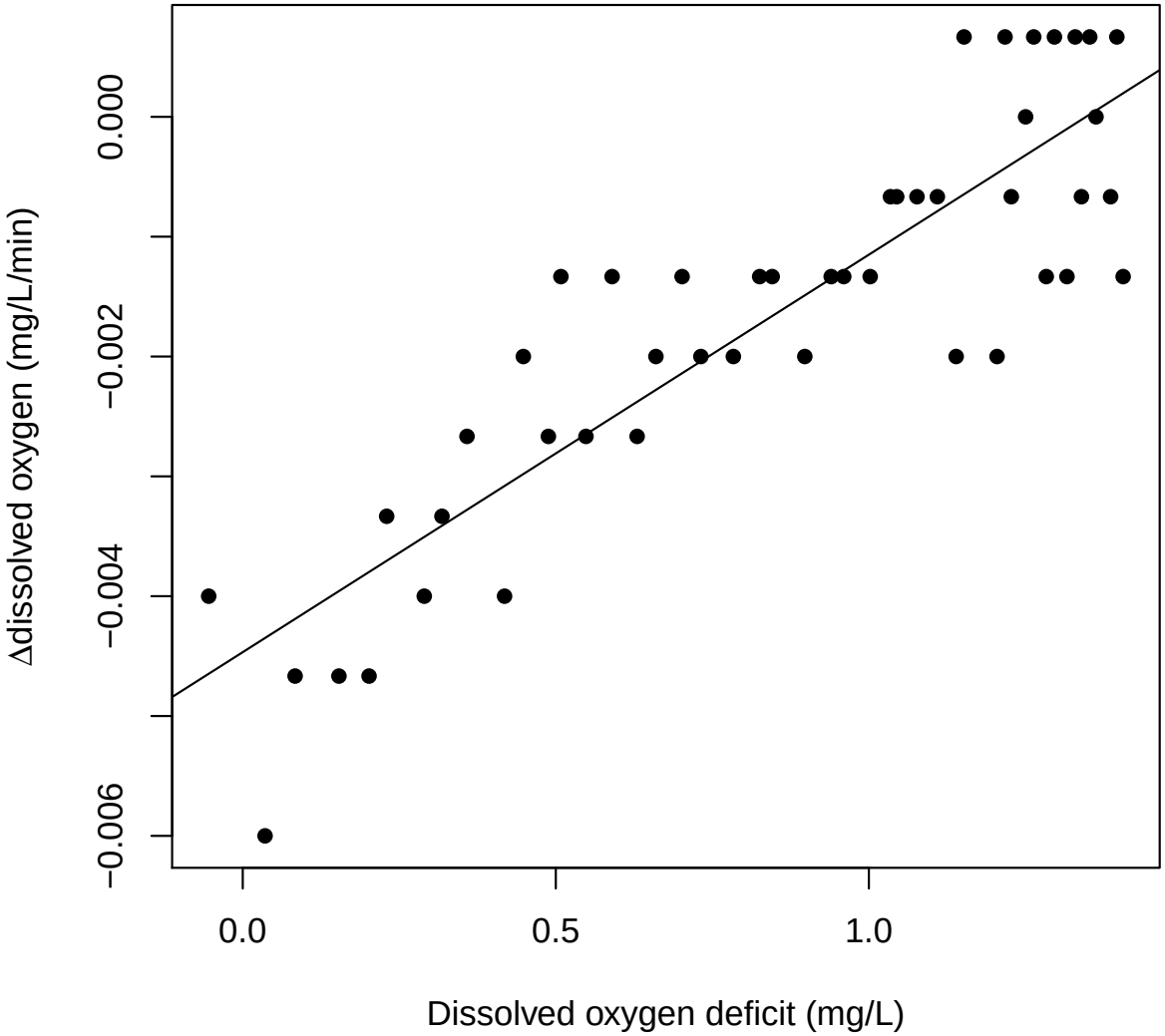

Figure 24: Results from the night time regression of the change in dissolved oxygen concentration vs. dissolved oxygen deficit on the Alsea River at Five Rivers Bridge (LASAR station 10585). Regression equation is: y=-0.0045+0.0033x; adjusted r^2=0.77; p=5.6e-16.

We calculated daily rates of GPP and ER as 4.5 and -6.4 mg O_2 L^{-1} d^{-1}, respectively, translating into a P/R of 0.7 and a NDM of -1.89 mg O_2 L^{-1} d^{-1}. These results suggest that the reach upstream represented by the monitoring station (30 km) was heterotrophic, driven by decomposition of organic matter.

Station 11263: Alsea River at Thissell Road (Mike Bauer Park) Data collected from 2008-09-22 14:31:00 to 2008-09-25 10:30:00 suggest that dissolved oxygen concentrations fell below the spawning criteria during each of the night time periods measured (to 9.1 mg O_2 L^{-1} and 90%; Figure 25). Peak DO concentrations occurred during midday and were recorded as 10.1 mg O_2 L^{-1} and 101% (Figure 25). Temperatures ranged from 14 to 16.3°C during the monitoring period. Discharge at the time of monitoring was not recorded.

We estimated reaeration, gross primary production, and ecosystem respiration rates for the 24 hour period encompassing sunrise to sunrise on 25-26 september 2008. Sunrise for both days was 07:04 while sunset was 19:09. Basal rates of reaeration and ecosystem respiration determined from the night-time regression were 3.21 d^{-1} and -3.33 mg O_2 L^{-1} d^{-1}, respectively (Figure 26).

We calculated daily rates of GPP and ER as 1.86 and -3.33 mg O_2 L^{-1} d^{-1}, respectively, translating into a P/R of 0.56 and a NDM of -1.47 mg O_2 L^{-1} d^{-1}. These results suggest that the reach upstream represented by the monitoring station (40 km) was heterotrophic, driven by decomposition of organic matter.

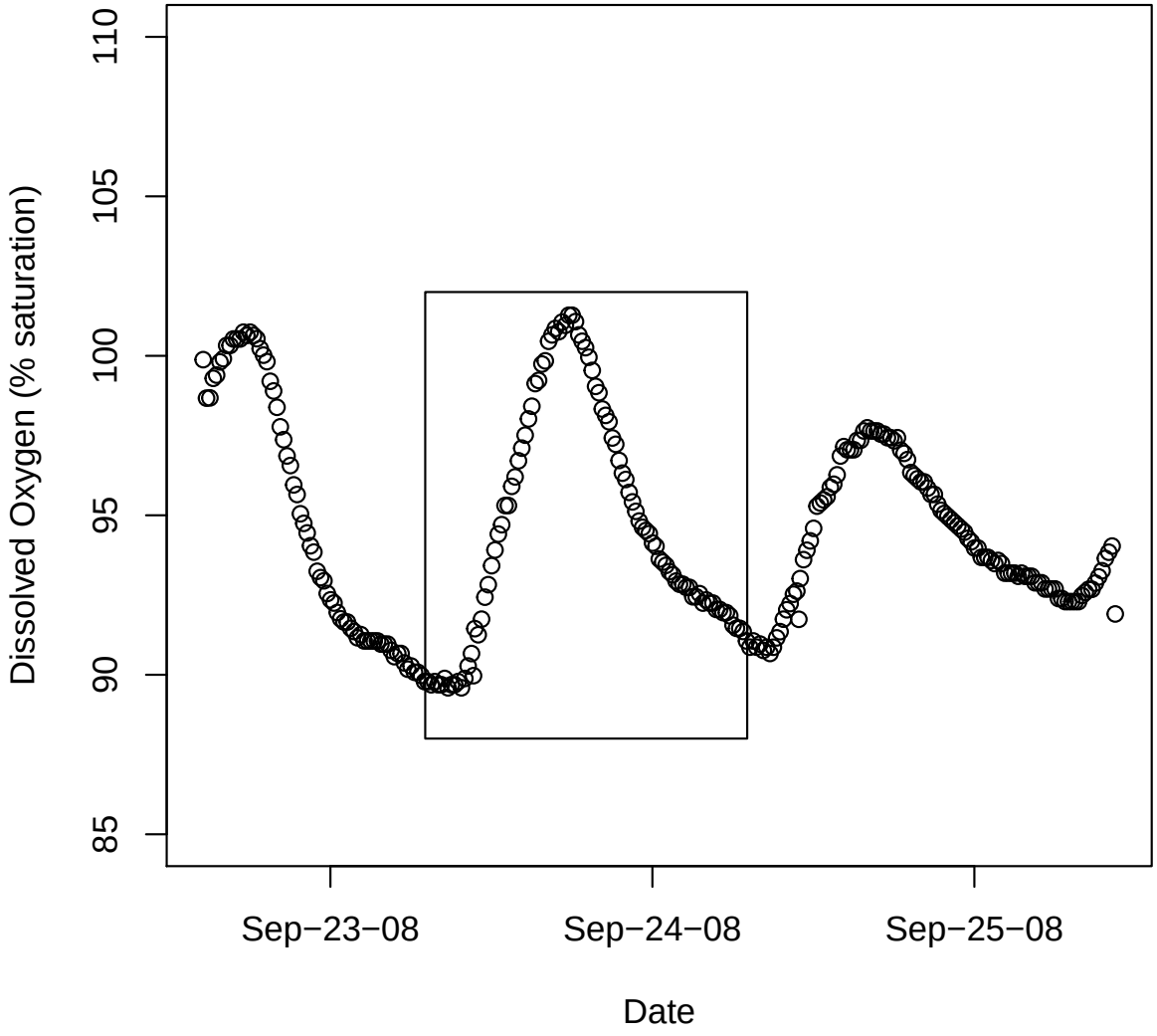

Figure 25: Diel dissolved oxygen (DO) dynamics on the Alsea River at Thissell Road (Mike Bauer Park) (LASAR station 11263). Reaeration, gross primary production (GPP), and ecosystem respiration (ER) were estimated for the 24 hour period within the the rectangle.

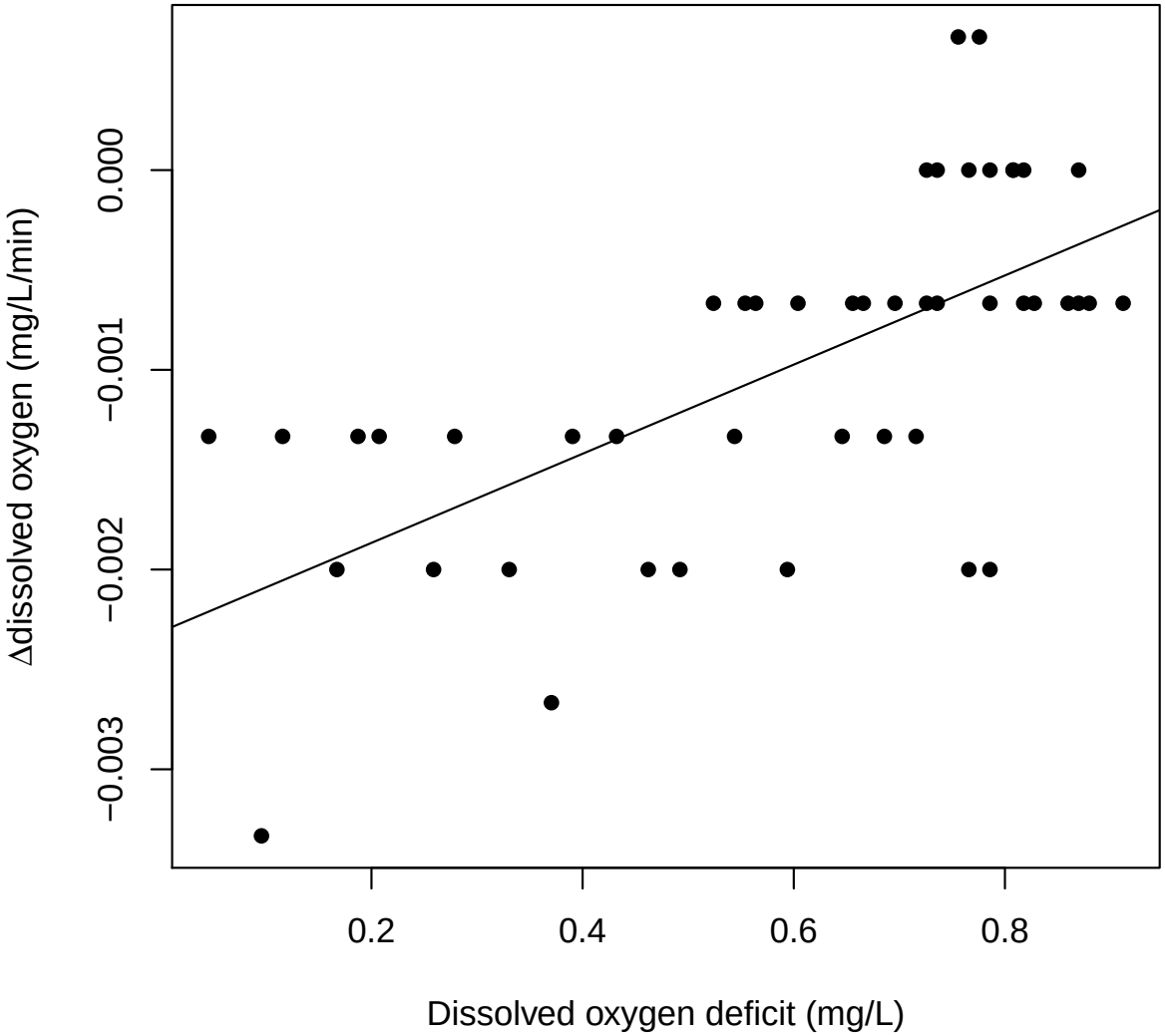

Figure 26: Results from the night time regression of the change in dissolved oxygen concentration vs. dissolved oxygen deficit on the Alsea River at Thissell Road (Mike Bauer Park) (LASAR station 11263). Regression equation is: y=-0.0023+0.0022x; adjusted r^2=0.4; p=1.2e-06.