TRACKING DISSOLVED OXYGEN LEVEL THROUGH AN ORGANIC RAINBOW TROUT FARM AT CUERICÍ, COSTA RICA

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Abstract: Dissolved oxygen (DO) is essential to aquatic life and frequently limiting. We evaluated the relative importance of environmental factors on DO by measuring changes in DO through an organic rainbow trout aquaculture system at Cuerici, Costa Rica. We predicted that dissolved oxygen would decrease with increased temperature and respiration, and increase with photosynthetic activity, but we could not predict the relative importance of these forces. We found that photosynthetic index (a composite measure of algal abundance and sunlight), and not temperature or respiration, was the best predictor of DO level. Water temperature was quite stable throughout the aquaculture system at about 12°C, and was unrelated to dissolved oxygen. Surprisingly, the biomass of trout within pools, which reached as much as 6.4 kg of trout per m^3, also had no detectable effect on dissolved oxygen levels.

Keywords: rainbow trout farm, dissolved oxygen, water temperature, photosynthesis, respiration

INTRODUCTION

Oxygen is one of the most important elements for life on earth. Due to its poor solubility in water, oxygen is an especially important limiting factor in aquatic ecosystems. As humans increase in number, it becomes increasingly important for us to understand how our activities influence biologically important environmental features such as dissolved oxygen (DO) in aquatic ecosystems.

We conducted a study of dissolved oxygen within the aquacultural system of an organic rainbow trout farm at Cuericí Biological Station, Costa Rica. Our objective was to assess the relative importance in this system of the various physical and biological factors that are known to influence dissolved oxygen. We hypothesized that DO level would change throughout the trout farm due to changes in one or more of these factors including temperature, photosynthesis, respiration, water flow and surface area to volume ratio of trout pools.

These factors, and their interaction(s), can affect DO of streams and ponds in ways that are generally well understood. Algal photosynthesis tends to increases DO because O_2 is a chemical product of photosynthesis. Water temperature affects DO level because warmer water has the physical property of holding less oxygen at saturation than cooler water. Warmer water should also tend to decrease DO because increasing temperature increases the respiration rate (i.e., O_2 use) of fish, microbes, and other organisms living in the water. Increases in trout biomass relative to the size of pools is expected to decrease DO because more trout biomass means more O_2 depletion (both from the trout directly and from the microbes that are decomposers of trout feces). Increased water flow and surface area to volume ratio increases DO by increasing atmospheric oxygen input via increased aeration and diffusion area.

METHODS

We collected water quality and temperature measurements at 22 sites (numbered from upstream to downstream) along the trout farm at Cuericí Biological Station, Costa Rica (Figure 1). We measured DO, pH, water temperature and air temperature at each site at 1830 on 31 Jan and at 1030 and 1430 on 1 Feb 2008. We also rated algal content on an ordinal scale of 1 to 5 (lowest to highest) scale and categorized sunlight exposure as 1, 2, or 3 (shade, partial sun, or sun, respectively). We multiplied these two values to calculate a photosynthetic index for each site. For each tank or pond, we also measured water surface area, water volume, and estimated fish biomass. We interpreted fish biomass as a proxy for oxygen depletion by respiration from fish and associated microbes.

To determine which factor(s) best predicted DO, we evaluated all possible linear regression models involving one or more of the six putative drivers of DO: site number (upstream to downstream), water temperature, photosynthetic index, flow: volume, surface: volume, and biomass: volume. Models were compared with respect to Akaike's Information Criteria (AIC).

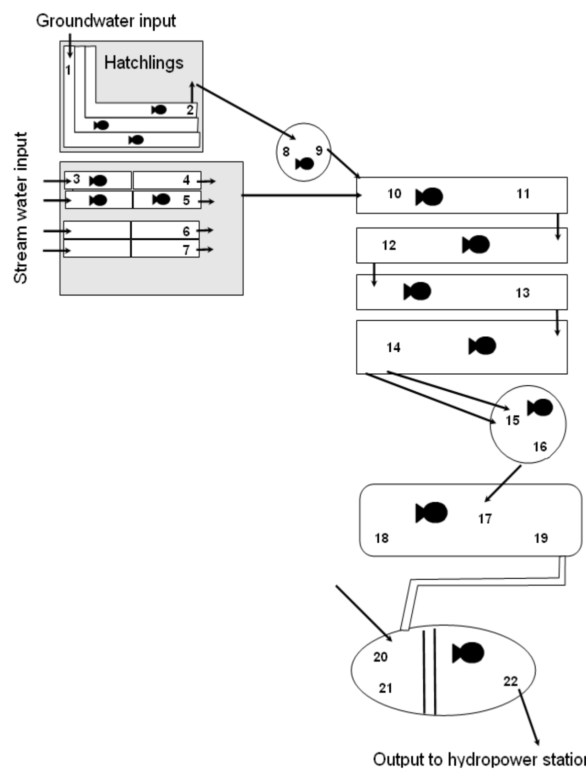

Figure 1. Map of rainbow trout farm at Cuericí Biological Station, Costa Rica. We chose 22 sampling sites at the input and output of each tank or pond, beginning upstream (1) and ending downstream (22) of the system.

RESULTS

The rainbow trout farm contains 12 fish pools of various sizes (volume: 3.5 - 478 m^3, surface area: 8.8 – 395 m^2). Trout are grouped by size, beginning with hatchlings upstream (up to 3 months age). Fish are moved downstream as they grow so fish size increases from upstream to downstream.

Average trout mass ranged from 1.26 g (hatchlings), to 433 g (adults), to 2167 g (breeders). Number of fish ranged from ca. 45,000 in the hatchery (sites 1-7) , ca. 400 in troughs (sites 10-14), ca. 200 in breeder pools (sites 8-9, 15-16, 20-21), and ca. 25,000 in lakes (sites 17-19, 22). Two pools in the hatchery contained no fish (sites 6 and 7).

Mean flow rate ranged from 0.53 - 4.6 L/s with an average flow rate of 3.34 L/s. Water pH varied between sites ($F = 23.00$, df = 22, $P < 0.0001$), but did not significantly increase or decrease through the trout farm ($F= 2.10$ df = 1, 42 $P = 0.016$ $r^2=0.05$) or in relation to fish abundance ($F = 1.81$, df = 1, 64, $P = 0.18$ $r^2 = 0.03$). Because pH only ranged from 6.5 to 7.0 (mean ± SD 6.8 ± 0.12), we doubt that this variation was biologically meaningful.

The average concentration of dissolved oxygen varied among sampling locations (range = 5.23 - 8.67 mg/liter; $F = 8.85$, df = 21, 42 , $P < 0.0001$) and sampling times (repeated measures ANOVA, $F = 46.84$, df = 2, 42, $P < 0.0001$). Because there was no interaction between site and time (based on visual assessment of the data since the data structure precluded a formal test), we averaged DO across time for the remainder of the analysis. Surprisingly, DO level was also higher at 1830 than at 1030 and 1430.

Contrary to our prediction, DO level did not decrease with increasing temperature ($F = 2.29$, df = 1, 20, $P = 0.15$, $r^2 = 0.07$). The ratio of fish biomass: pool volume was also unrelated to DO ($F = 0.22$, df = 1, 20, $P = 0.65$, $r^2 = 0.01$).

Of all possible linear models involving any combination of the six theoretical drivers of DO that we measured (site number, water temperature, photosynthetic index, flow:volume, surface:volume, and/or biomass:volume), a model that included photosynthetic index alone emerged as the best model (Table 1, $\Delta AIC > 10.3$ compared to any alternative model). Across the range of photosynthetic indices in our study system, average dissolved oxygen increased from 5.23 to 8.67 mg / liter (Figure 2. $F = 15.68$, df = 1, 20, $P = 0.0008$, $r^2 = 0.44$). None of other independent variables were significantly related to DO in simple linear regressions. For example, fish biomass relative to tank or pool water volume (biomass: volume) was unrelated to DO ($r^2 = 0.01$, df = 1, 20, $P = 0.65$).

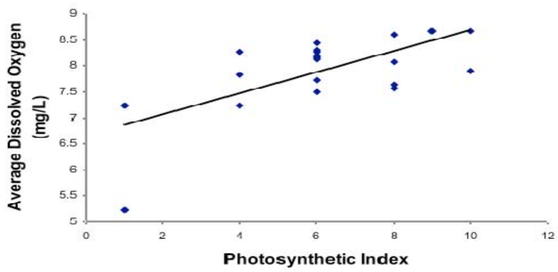

Figure 2. Relationship between photosynthetic index (1-low to 15-high) and average dissolved oxygen at Cuericí Biological Station, Costa Rica.

DISCUSSION

Photosynthetic index was the best predictor of DO. Apparently, of all variables tested, oxygen produced by photosynthesis had the largest effect on changes in DO levels. While photosynthetic index was the best statistical predictor of DO, other factors such as temperature, algal mass: volume, and water depth can also influence the rate of photosynthesis. So the full causal pathways could involve other variables.

If photosynthesis is an important driver, it is expected that there would be diurnal cycles in DO associated with diurnal cycles in photosynthetically active radiation. Indeed, the highest DO that we measured was at 18:30 on the first night, which might have reflected the accumulation of DO over the day from photosynthesis. However, the dissolved oxygen meter malfunctioned after the first reading, requiring that we change the membrane and re-calibrate the meter. Thus the higher DO measurements at 18:30 could have been an artifact. Future studies that include repeated day and night measurements could easily resolve the question of whether the pattern we reported is indeed driven by photosynthesis, rather than other factors positively correlated with photosynthesis.

It seemed surprising that there was no effect of fish biomass on DO. Some pools had no fish, while one (site 17, 18, 19) contained about 25 1000-g trout in 478 m^3 of water. Based on the general interspecies relationship, the expected respiration rate of a 1000 g poikilotherm at 12 °C is about 410 ml $O_2 \cdot kg^{-1} \cdot h^{-1}$ (Peters 1983), which seems like it could have measurably depleted DO within the pool, especially in combination with decomposition of trout feces. However, it seems that this respiration is modest relative to the constant input of oxygen from the inflow of water, photosynthesis within the tank, and/or diffusion of O_2 from air into sub-saturated water. In any case, it seems that this aquaculture system is presently not DO limited.

As human impact on the environment increases, it becomes increasingly important to understand the factors that influence DO level in aquatic ecosystems. Our study shows that, among other factors, photosynthesis of aquatic vegetation is important in determining DO level in aquatic systems.

LITERATURE CITED

Peters, R.H. 1983. The ecological implications of body size. Cambridge University Press, Cambridge, England.

Table 1. Models of individual variables affecting dissolved oxygen level in a rainbow trout farm at Cuericí Biological Station, Costa Rica.

Variables	**Biological Reason**	**R^2**	**AIC value**
Photosynthetic Index (PI)	Increased photosynthesis increases D.O..	0.44	-22.7
Water Temperature (T)	Decreased water temperature increases D.O	0.10	-12.4
Flow: Volume (F:V)	Increased water flow increases D.O.	0.08	-11.9
Surface area: Volume (SA:V)	Greater SA:V allows more atmospheric oxygen to enter	0.03	-10.8
Biomass: Volume (B:V)	Increased fish respiration and decomposition decreases D.O.	0.01	-10.3