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Ecosystem Indicators of Water Quality Part II. Oxygen Production and Oxygen Demand

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Abstract Seasonal transitions from oxygen production to oxygen demand at coastal aquaculture sites in southwestern New Brunswick (SWNB) can be defined in terms of the production-respiration (P/R) ratio. During the summer, when P/R is greater than 1, an autotrophic ecosystem is in place, and dissolved oxygen (DO) in surface waters remains above thresholds for optimal fish growth. During the fall and winter, when P/R is less than 1, a heterotrophic system is in effect, and DO can decrease to below threshold. Photochemical decomposition may act as a seasonal link, contributing to the onset of net oxygen demand by facilitating the breakdown of terrestrial and marine organic carbon in the fall. The overall carbon load is not a useful index of the bioreactive material that creates oxygen demand. Instead, bacterial number and chlorophyll concentration (expressed in terms of a bacteria:chlorophyll ratio) may be better indicators of the seasonal regulation of oxygen dynamics by the ecosystem. Low DO is the cumulative effect of sustained oxygen demand; a seasonal change in P/R from greater to less than 1 is an early warning of this demand. The application of both indices (P/R and DO) in tandem can be used to develop ecosystem-sensitive plans for the management of water quality at aquaculture sites.

Keywords Aquaculture · Oxygen production and demand · P/R ratio · Oxygen dynamics · Water quality

1 Introduction

The rapid growth of coastal finfish culture has forced the aquaculture industry to face a number of problems related to water quality. For example, caged salmon production in the surface waters of the southwestern New Brunswick (SWNB) coastal region has increased by a factor of about 40 between 1983 and 2003 [1]. Given that aquaculture will continue to expand in SWNB as the culture of other species is perfected, there is an ongoing requirement for clear indices of water quality - not only as affected in the near field by caged fish, but also as affected in the far field by the seasonal changes encountered in this temperate coastal ecosystem. As it continues to grow, the aquaculture industry in SWNB will deal with many of the issues faced by finfish aquaculture as a whole. This means that lessons learned about environmental quality within the region may be applicable worldwide.

One of the main environmental factors associated with inshore aquaculture is the oxygen demand generated by respiration in water, sediment and fish. At both aquaculture and non-cultured sites in SWNB, the results from mass balance calculations [2] indicate that the majority of respiration is located in the water column. In addition, these results suggest that salmon aquaculture wastes may be distributed over wide areas, and that accurate estimates of the time and space scales of waste discharge are required to determine impacts of the discharge. Hargrave [3] has also suggested that if salmon respiration is greater than 20% of total oxygen demand at a particular cage site, caution should be exercised to ensure that dissolved oxygen (DO) does not become critically depleted in the water column.

There is an annual inshore and offshore cycle of ambient oxygen in SWNB surface waters [4], as high (saturated/supersaturated) DO in the summer gives way to lower (undersaturated) DO during late summer/early fall when respiration tends to dominate the surface water ecosystem [5]. Page et al. [4] have shown that caged fish can amplify this seasonal low in DO, but only during the second year of growth. During the first year of fish grow-out, DO is not reduced below a subsaturation threshold of 6.75 mg O_2 L^{-1}. During the second year, DO is reduced further (by larger fish and their higher respiration rates) to less than threshold. The potential for this amplification of a seasonally-low DO to be maintained over the length of time required to cause stress in caged fish then becomes dependant on ambient DO, current speed and their combined effect on the delivery of oxygen from outside of a cage.

Even though it is reasonable to assume that oxygen demand by respiration in the water column will be a prime regulator of the ambient DO available for optimal fish growth, the production of oxygen by the phytoplankton is equally important. In addition, the transition from oxygen production during summer months to oxygen demand in the late summer/early fall [5]