Oxyclimatic Classification System and Its Use in Determining Production Cycles for Tropical Aquaculture Systems

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ABSTRACT

In parts of the world with large fluctuations in annual temperature many aquaculture management decisions, including stocking and harvesting dates, need to be based on climatology. However, this need not be the case for many tropical areas which have relatively constant annual temperature regimes. Consequently in these areas stocking and harvesting dates can be set so that maximum nutrient loading will occur during periods that favor maximum oxygen production.

Evaluation of the factors that influence dissolved oxygen content of tropical pond waters indicate that while oxygen production in the photic zone is mainly dependent on light conditions, wind and pond orientation to the prevailing winds are highly beneficial in increasing dissolved oxygen concentrations in underlying waters. The coupling of the nutrient loading cycles with the climatological parameters of Lajas, Puerto Rico indicates that maximum nutrient loading of ponds should take place during the end of June and early July. This recommendation is based on the effects that plankton abundance, solar radiation, hours of daylight, wind intensity (speed) and water temperature have on dissolved oxygen budgets. A relatively simple oxyclimatic classification system, involving wind-run, solar radiation and oxygen requirements, is presented and its application in rating sites for aquaculture introduction and the appropriate periods for maximum nutrient loading is discussed.

INTRODUCTION

Since aquaculture often involves the production of organisms in nutrient-enriched waters, the limitations imposed by the abiotic environment must be identified and analyzed if the biological and operations factors of production are to be successfully implemented. Water temperature is an environmental factor that often serves as a critical constraint to aquaculture. Not only does the annual temperature regime dictate "species acceptability" but it also establishes optimum stocking and harvesting dates. Tropical areas, are generally characterized by small annual temperature ranges, and, as such, production cycles can be implemented that would permit nutrient loading to take place when environmental factors are most favorable for the maximization of the evolution of oxygen; which has long been recognized as the critical factor for aquatic life that have aerobic respiration.

The important environmental parameters for oxygen production in fish ponds are light intensity and duration, water temperature, and water movement (mixing); while the principle (non-environmental) factor that will influence the production of oxygen in ponds is plankton abundance. Ideally, optimum plankton abundance will coincide with optimum oxygen production occurring during periods of greatest oxygen demand; *i.e.* at the final stages of a production cycle.

This paper describes a relatively simple model that can predict oxygen concentrations at varying depths in earthen ponds used for semi-intensive tilapia culture, as a function of wind-induced water movement and mixing, oxygen demand of the sediment and water column, and light intensity. The model could be applied in determining production cycles that would enhance the possibility of maintaining "acceptable" water quality and for rating sites for aquaculture introduction.

STUDY AREA

Puerto Rico is the smallest (8,000 km^2) and the eastern most island of the Greater Antilles. It is roughly rectangular (180 km x 70 km) shape, with its long side oriented east-west.

Puerto Rico has six distinct ecological life zones comprising such contrasting subtypes as tropical rain forest to semi-desert (Ewel and Whitmore, 1973). This wide variety of climates can be explained by geographical differences in precipitation; the main reasons for which are the range of small mountains running east-west along the center of the island and the trade winds that arrive from the east and northeast throughout the year. The southwest part of the island,which is located on the leeward side of the central mountain range, is semiarid due to a rain shadow effect in combination with high evaporation rates caused by high temperature and year round winds.

The ponds used in this study are located at 18°3' N latitude and 67°3' W longitude. They are located 9 km inshore from the southwest coast at an elevation of approximately 28 m above sea level.

METHODS

The climatological data, with the exception of wind velocities, were taken from a weather station located approximately 0.2 km from the study site. Wind velocities from the station were adjusted and used in the study after determining the difference in wind velocities between an anemometer placed 60 cm above the ground at the study area and one at the climatological station. Solar radiation values were measured directly at the station. Because long term radiation values are not available, they were estimated from data employing the equation developed by Lopez and Soderstrom (1983).

The wind-driven circulation patterns were developed by measuring dissolved oxygen (DO) and temperature profiles in ponds that had approximately the same fish biomass, sediment and community respiration rates and chemical oxygen demands. DO and temperature profiles were measured with a polarographic DO meter. Wind velocities were measured continuously at the study area from 0730 to 1630 hrs and estimated from 1630 to 0730 hrs by correcting the climatological station value by the above mentioned method.

Light and dark bottles prepared from 300-ml biochemical oxygen demand (BOD) bottles were filled with pond water and incubated for 2 to 4 h between 0800 and 1200 hours at the surface and at depths of 0.5, 1, 1.5, 2, 3, 4 and 5 Secchi disc values when possible. Concentrations of DO in the bottles were measured by the modified Winkler method before and after incubation, while DO values were measured at the same depths every two hours between 0800 and 1600 hours with a polarographic DO meter. Chemical oxygen demand of the water was measured using the modified method of Boyd (1979a) while that of the muds was measured using the method of Nelson and Sommers (1982).

RESULTS

The winds that flow across Puerto Rico are probably its most constant climatological feature. They flow almost without exception from the east, with a strong southeast (SE) component. These strong SE winds usually begin in midmorning and increase in velocity until around noon when they begin to abate. A slightly more southerly wind begins in midafternoon and increases in velocity until late afternoon or early evening. The winds that blow from 0800 to 16 00hrs account for approximately three-quarters of the diel pattern (Table 1).

The difference between the length of the longest and shortest day is only 17%. The longest day is approximately 13.2 h long while the shortest is about 11 h (late June/early July) and (mid-December) (Table 1). The difference between mean monthly solar radiation values for the highest and lowest monthly values is about 29%; with a maximum monthly average of 507 langleys (ly) for April and a minimum monthly average of 360 ly in December. During the course of the year the angle of incidence of the solar radiation striking 18°N latitude, with respect to the azimuth, varies from 5°N to 41° S.

A record of morning and afternoon seasonal water temperatures at the surface and at 1 m deep show an absence of large temperature gradients due to mixing by high winds (Table 1). Temperature differences as large as 4.5°C have been observed in a larger reservoir pond during October through January, the months with the least amount of wind, but these differences occurred over a depth of 2.2 m. The greatest difference in surface temperatures during the seven year period reported here was 8.8°C between February and August. Late afternoon temperatures never dropped below 25°C during the same period.

The data that formed the basis for the rating criteria were selected based on the similar chemical and biological nature of the ponds (Table 2).

Table 1. Atmospheric and hydrological conditions at Lajas ponds - seasonal changes.

	Water temperature										Wind * Radiation
	Surface		Bottom		Sunlight[1]		Wind Run	Rainfall	pH		
Month	AM	PM	AM	PM	(1 y/d)	(h/d)	(km/9h)	(cm)	AM	PM	(1,000)
January	25.1	27.5	23.8	25.1	399-394	11.7	46	4.8	7.8	8.3	18.4
February	24.7	27.2	23.1	24.8	421-456	11.8	50	3.7	7.8	8.4	21.0
March	25.8	28.1	24.6	27.4	491-530	12.3	56	4.4	7.6	8.8	27.4
April	26.6	29.0	25.2	28.2	507-463	12.8	53	7.6	7.8	8.5	26.9
May	27.3	29.5	25.8	28.2	473-552	13.0	34	10.0	8.1	8.5	16.1
June	27.9	30.8	26.9	29.8	503-564	13.2	61	6.0	7.9	8.5	30.7
July	28.7	31.3	27.6	29.9	475-532	12.9	58	9.0	8.0	8.8	27.6
August	28.9	31.4	28.3	29.8	488-489	12.9	56	13.8	7.8	8.6	27.3
September	29.1	30.5	28.5	29.7	462-518	12.5	54	17.2	7.6	8.6	25.0
October	28.3	29.8	27.4	29.1	438-452	11.8	51	14.7	7.4	8.7	22.3
November	27.5	29.7	26.0	27.1	371-423	11.4	43	12.6	7.6	8.6	16.0
December	25.8	28.0	23.3	25.6	360-339	11.0	41	7.1	7.5	8.3	14.7

[1] For Sunlight data the first value is the average of the period 1978-1988 when values are available, the second value is an estimated value using the equation of Lopez and Soderstom (1983).

Table 2. Pond water characteristics.

Parameter	Value
Sediment Respiration	2.8-3.4 g/m^2/d
Chemical Oxygen Demand	31.2-40.8 g/m^3/d
Secchi Disc visibility	9-20 cm
Tilapia biomass	7,500-10,000 kg/ha

Diurnal fluctuations in DO concentrations at the pond surface was strongly regulated by the intensity of solar radiation (Figure 1), while the difference in DO values that were measured between the surface and a depth of 90 cm were primarily a function of the wind velocity (Figure 2). A high correlation was found for the change of DO that occurs at 90 cm between 0730 and 1630 h and the total daily solar radiation and the wind run for that period (Figure 3).

DISCUSSION

The climatological conditions were presented to define the geophysical characteristics of the study area. Even though these features confirm the premise that the area can support the growth of tropical aquatic species year-round they also demonstrate that growing seasons can be developed that can maximize the benefit these abiotic and physical conditions have on pond ecology and growth.

DO is important for aquatic animals since it is required for respiration and the lack of it will limit production and in some cases result in death. The primary abiotic factors that will determine DO values are the intensity of solar radiation (light intensity and duration), water temperature, and wind induced mixing. Since the temperature and light duration profiles demonstrate slight variations over the calendar year these factors can be ignored in trying to develop production cycles that will enhance water quality stability (Table 1). However, intensity of solar radiation and wind velocity have been shown to be highly correlated with changes in DO values (Figures 1, 2, and 3) and should be considered in determining production cycles.

An oxyclimatic rating system for the Lajas Valley based on solar radiation and wind run can be considered the first step in describing a rating methodology for aquaculture introduction that can predict yield and inputs required to substain predicted yields with minimal field work. Based on the results of DO variation, the oxyclimatic environment of Lajas is characterized by two periods during which the solar radiation and wind characteristics would favor a stable pond environment at times of high nutrient input. These periods occur from late February until mid-April, and from mid-June until mid-August. More precisely, the last week of June and the first two weeks of July would be the best period for introducing the largest quantities of nutrients while maintaining adequate DO

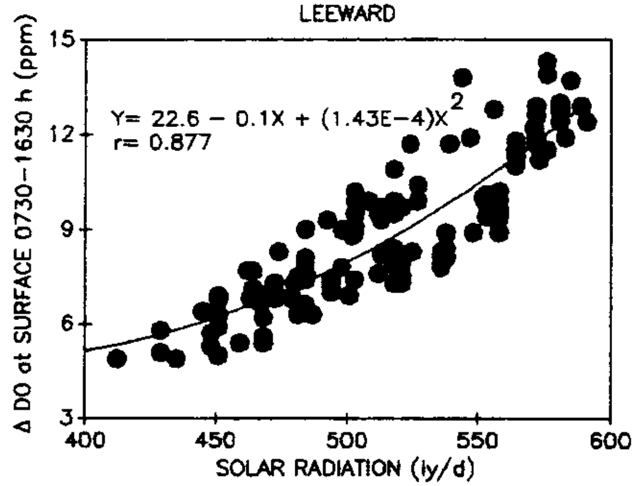

Figure 1. Change in DO at surface as a function of solar radiation

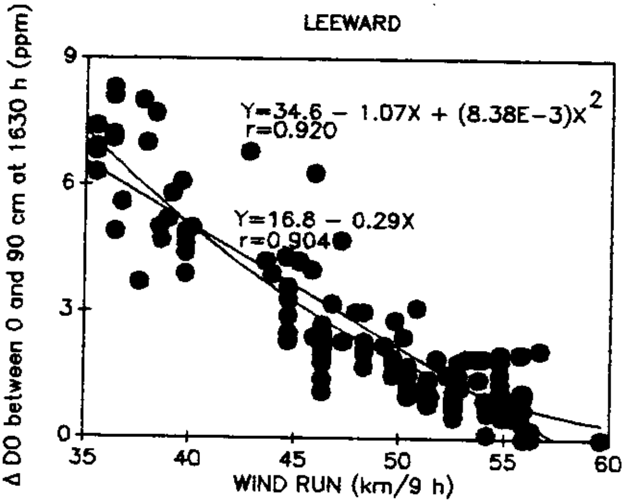

Figure 2. Difference in afternoon DO values between the surface and 90 cm as a function of wind.

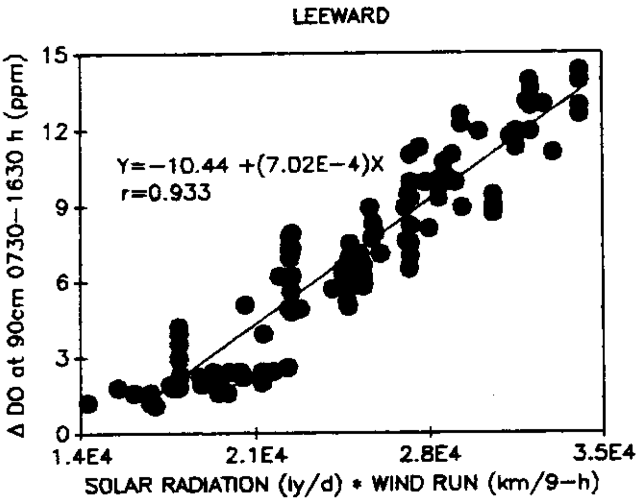

Figure 3. Change in DO at 90 cm as a function of wind and sun.

values.

Studies have placed the safe feeding rate for channel catfish in ponds within the range of 34 to 45 kg/ha/d (Swingle 1958; 1968; Shell, 1968) and when feeding approached 78 kg/ha/d early morning dissolved oxygen levels were routinely below 2 mg/l which resulted in reduced growth and increased mortalities (Boyd, 1979b). A feeding study conducted to determine maximum safe feeding rates for tilapia in the tropics demonstrated that DO remained above 2 mg/l even after the fish had been receiving around 65 kg/ha/d for three weeks. When the feeding rate approached 71 kg/ha/d, DO fell below 2 mg/l for the first time during the 26 week growing period which ended in the first week of March (Ayarza Real, 1988). Using rainfall data to estimate solar radiation would indicate a twenty percent decrease in expected radiation.

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