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Research Article

Water flow requirements related to oxygen consumption in juveniles of *Oplegnathus insignis*

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ABSTRACT. In this study the oxygen consumption rate in four groups of *Oplegnathus insignis* was examined under three different water temperatures 13, 18 and 23ºC. Average weight of each group of fish was 9.5, 198, 333 and 525 g respectively. Oxygen consumption was measured in a respirometer of 18.8 L capacity and results show that at the same water temperature occurs an inverse relationship between body weight and oxygen consumption whereas for same body weight (W in kg) the respiration rate varies proportionally with temperature rise (T in ºC). The generalized equation of oxygen consumption (Ro) in routine metabolism was determined as: Ro (mg O_2 kg^{-1} h^{-1}) = [85.229 + (10.03 T)]-(221.344 W). The information it is analized with regard to establishing quantitative relationships that allow a more precise specification of the water flow requirements and renewal rates in open flow systems without oxygenation, considering aspects such as body weight, respiratory rate, temperature and stocking density.

Keywords: *Oplegnathus insignis*, oxygen consumption, water flow, water exchange, Chile.

Requerimientos de flujo de agua en función del consumo de oxígeno en juveniles de *Oplegnathus insignis*

RESUMEN. Se determinó la tasa de consumo de oxígeno de *Oplegnathus insignis* en cuatro grupos de peces bajo tres temperaturas diferentes: 13, 18 y 23ºC. El peso promedio de cada grupo de peces fue de 9,5, 198, 333 y 523 g respectivamente. El consumo de oxígeno se determinó en un respirómetro de 18,8 L de capacidad y los resultados muestran que a una misma temperatura ocurre una relación inversa entre el peso corporal (W en kg) y el consumo de oxígeno, mientras que para un mismo peso corporal la tasa respiratoria varía proporcionalmente con el ascenso de temperatura (T en ºC). La ecuación generalizada que representa el consumo de oxígeno (Ro) en metabolismo de rutina se determinó como: Ro (mg O_2 kg^{-1} h^{-1}) = [85.229 + (10.03 T)]-(221.344 W). Se analizó la información en relación a establecer las relaciones cuantitativas que permitan una especificación más exacta de los requerimientos de flujo de agua y tasas de renovación en sistemas de flujo abierto y sin oxigenación, considerando aspectos tales como peso corporal, tasa respiratoria, temperatura y densidad de cultivo.

Palabras clave: *Oplegnathus insignis*, consumo de oxígeno, flujo de agua, renovación de agua, Chile.

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INTRODUCTION

Among the native fishes of Chile, *Oplegnathus insignis* (Kner, 1867), commonly known as "San Pedro" is a species that exhibits interesting attributes to be considered as a potential candidate for aquaculture. *O. insignis* is a rockfish whose geographical distribution extends from northern Chile

(Antofagasta) to Galapagos Islands (Ecuador) (Chirichigno, 1998), revealing a natural affinity for living in relatively warmer waters. Preliminary studies on the growth of *O. insignis*, at different temperatures, show that this fish grows better at higher temperatures (Segovia, unpublished data). So for aquaculture purposes and to ensure better growth its rearing should be at temperatures above 19ºC. Attempts to develop a culture technology of *O. insignis* have given promising results regarding the production of larvae and juveniles. However, it is necessary to include improvements in culture technique to establish appropriate conditions for its on-growing in land based tanks.

Preliminary observations have shown that *O. insignis* is very sensitive to the reduction of oxygen in water; therefore it is important to pay attention to the requirements of flow of water relative to oxygen dissolved in the water and oxygen consumption by fish. There are no previous reports on the dynamics of oxygen consumption for *O. insignis*. The water exchange is an important aspect in land based culture systems. The flow of water needed depends on factors such as species, stocking density, respiratory rate and physiological state of animals. Colt (1991) indicates that in open flow systems and water reuse, estimating the flow of water required can be calculated from mass balance and is commonly assumed that the dissolved oxygen is the most limiting factor in these systems.

The water flow rate (Q) should be sufficient to control dissolved oxygen levels and remove toxic metabolites in a tank volume (V). In many cases the data reported on the amount of water to be added to a culture system are often confused because different water supply methods result in different quantities of water replaced. Terms such as water renewal rate, water exchange rate (Q/V), hydraulic retention time (V/Q) and other are commonly used to quantitatively refer the water added to a culture system. Some of the most important calculated terms are:

Residence time = *V/Qt* the time required for all of the water in the tank to be "replaced" by either recycled or new water.

Turn over (per hour) = (*Qt x 60)/ V* the number of system volumes "replaced" per hour

Replacement time = *V/(Qf)* time to "replace" all of the tank volume with new water

Replacement volume = (*Qf x 1440)/ V* the fraction of volume replaced daily with new water.

Water exchange rate can be expressed as number of replacement per hour or as percentage (%) of total tank volume by time unit. Water amount is often expressed as volumetric flow rate and is directly related with carrying capacity in culture system. Huguenin & Colt (1989) demonstrated a simple mathematical formulation for quantifying water flow and carrying capacity in open flow systems. However for open flow system without addition of oxygen is necessary to consider the point made by Kraul *et al*. (1985) in the sense that in a continuous flow system and under the assumption that the tanks are completely mixed systems, the ratio of flow rate and volume of the tank (Q/V) does not reflect the actual replacement of water per unit of time. The actual water renewal rate is lower than Q/V because not only old, but a mixture of old and new water will go out of tank.

The development of a culture technology involves primarily known the eco-physiological requirements of the species and from this knowledge to establish the optimum environmental conditions that favor its development and growth under conditions of high population density. A first step is to determine the oxygen requirements for different body sizes and temperatures. Thus the purpose of this study is to contribute to the development of a culture technology for *O. insignis* providing technical information on respiratory dynamics and their relation to water flow requirements.

MATERIALS AND METHODS

The oxygen consumption experiments were carried out on fish produced in the hatchery of the Universidad Arturo Prat in Iquique, Chile. The oxygen consumption rate under routine metabolism was measured using a respirometer (Fig. 1). The system consisted of a respirometry chamber 18.8 L where fish were stocked. The readings of the variations of dissolved oxygen in the water were taken with YSI multiparameter probe 85 (Yellow Spring Instruments, Ohio, USA) calibrated for measurements at 35 ppt salinity.

Oxygen consumption was measured in four groups of juveniles fish: (1) 9.5 g average weight (n = 215 fish, range: 8.4 to 12.5 g), (2) 198 g average weight (n = 16 fish, range: 181.3 to 208.5 g), (3) 333 g average weight (n = 12 fish, range: 305 to 348 g; and (4) 523 g average weight (n = 8 fish, range: 472 to 556 g). For each of the groups of fish consumption oxygen was measured under three different temperatures: 13, 18 and 23°C.

Measurements were performed in triplicate. Before each measurement fish were kept under starving conditions for 48 h to avoid possible contamination

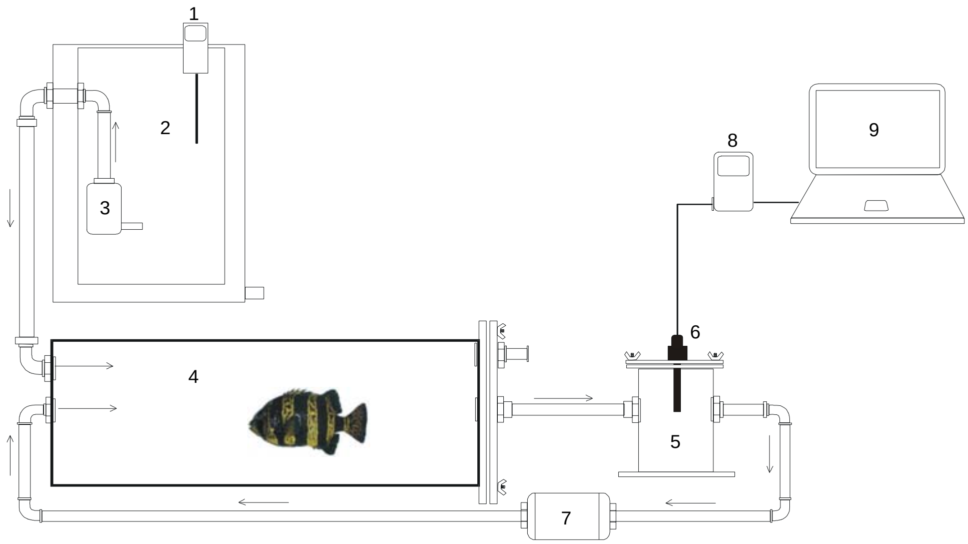

Figure 1. Schematic diagram of respirometer system used in present study. 1: temperature sensor, 2: water temperature controlling tank, 3: water supply pump, 4: respirometer chamber, 5: measurement chamber, 6: oxygen temperature sensor, 7: recirculation pump, 8: oxygen-meter, 9: computer.

Figura 1. Diagrama esquemático del respirómetro usado en el presente estudio. 1: sensor de temperatura, 2: estanque de termo-regulación de agua, 3: bomba de alimentación, 4: respirómetro, 5: cámara de medición, 6: sensor de medición de oxigeno y temperatura, 7: bomba de recirculación, 8: oxigenómetro, 9: computador.

and oxidation of organic matter. Before starting each trial fish were acclimated previously within the respiration chamber for a period of 2 h. Each experiment lasted about 90 min until oxygen saturation reached about 75%.

Specific oxygen consumption in mg of O_2 by body weight unit (kg) by time unit (hour) was estimated from following mathematical expression:

$$Ro = \frac{\Delta O_2}{\Delta t \cdot \delta} \quad (1)$$

where:

Ro = specific oxygen consumption (mg O_2 kg^{-1} h^{-1})

ΔO_2 = measured variation of oxygen concen-tration in respirometer (mg O_2 L^{-1})

Δt = time interval between measurements (h)

δ = fish stocking density inside respirometer (kg L^{-1})

The relationship between metabolic rate and temperature (Q_{10}) was computed from averaged oxygen consumption data for each experimental temperature using the following equation:

$$Q_{10} = \left[Ro_2/Ro_1\right]^{(10/(T_2-T_1))} \quad (2)$$

where:

Q_{10} = increment ratio in oxygen consumption by interval of temperature rise.

T_2 = higher temperature

T_1 = lower temperature

Ro_2 = oxygen consumption at temperature T_2

Ro_1 = oxygen consumption at temperature T_1

Using a simple spreadsheet was possible to simulate the water requirement from respiration rates determined experimentally. Theorical water flow in relation to respiratory rate was calculated from following equation:

$$Q = \frac{R_o\,B}{C_i - C_f} \quad (3)$$

where:

Q = water requirement (L min^{-1}) by m^3 of rearing volume

R_o = specific consumption of oxygen by fish (mg O_2 kg^{-1} min^{-1})

B = fish stocking density (kg m^{-3})

C_i = oxygen concentration in water inlet (mg O_2 L^{-1})

C_f = oxygen concentration in water outlet (mg O_2 L^{-1})

Ro values used were those from the generalized equation describing the oxygen consumption for different body weights and temperatures which were determined in this study as:

$$Ro = [85{,}229 + (10{,}03T)] - [221{,}344\ W] \quad (4)$$

where:

Ro: oxygen consumption expressed in mg O_2 kg^{-1} min^{-1}

T: temperature in Celsius degrees.

W: body weight expressed in kilograms.

The equation proposed by Kraul *et al.* (1985) was used as correction for computing the fraction of new water actually replaced in the system. Equation can be expressed as:

$$F = 1 - e^{-TQ/V}\ 100\% \qquad (5)$$

where:

F: fraction of new water replaced by unit of volume (1 m^3) expressed as percentage

T: time (60 min).

Q: water flow in L min^{-1}.

V: unit of rearing volume (1000 L = 1 m^3).

For the simulation input data considered were 250 g body weight, at 19°C temperature and three typical stocking densities (8, 10 and 12 kg m^{-3}).

RESULTS

The oxygen consumption results presented in Figure 2 show that for a same temperature occurs an inverse relationship between body weight (W) and oxygen consumption, whereas for the same body weight oxygen consumption varies directly with the temperature increase.

The generalized equation that describes the oxygen consumption (mg O_2 kg^{-1} min^{-1}) for different body weight and temperatures in *Oplegnathus insignis* can be written as:

Ro = [85.229 + (10.03 T)]-[221.344 W] (R^2 = 0.96; SD: ±13.21; $P > 0.05$)

Variations in oxygen consumption in function of temperature increments (Q_{10}) are presented in Table 1.

A simple simulation of the required water flow (Q) relative to experimentally measured respiratory rates are shown in Table 2, taking into account a range of concentrations from 2 to 8 mg L^{-1}. Also are presented numerical values on actual replacement fraction (F) and hydraulics retention time (T) for each calculated flow rate.

Estimations of water flow (Q), replacement fraction (F%) and hydraulic retention time (T) are inversely proportional to the difference in dissolved oxygen concentration. For stocking densities (8, 10 and 12 kg m^{-3}) the deficit calculated ranged from 41.4 to 80.2%, 33.2 to 75.9% and 26.6 to 71.8% respectively.

Figure 3 show a simulated curve of water requirements and water replacement deficit for a specific density (10 kg m^{-3}) at different concentrations of dissolved oxygen in water. As the availability of dissolved oxygen in water increases, the water flow requirement per unit volume decreases but the amount of water for replacement also diminishes proportionally which produces an increase in the deficit.

DISCUSSION

There are no previous reports on the respiratory dynamics of *Oplegnathus insignis*. The oxygen consumption rates determined in this study for *O. insignis* were similar to published values for other marine fish species. (Kim *et al.*, 1995; Oh *et al.*, 2007). Oh *et al.* (2006) found that the rate of oxygen consumption in juvenile *O. fasciatus* increases with

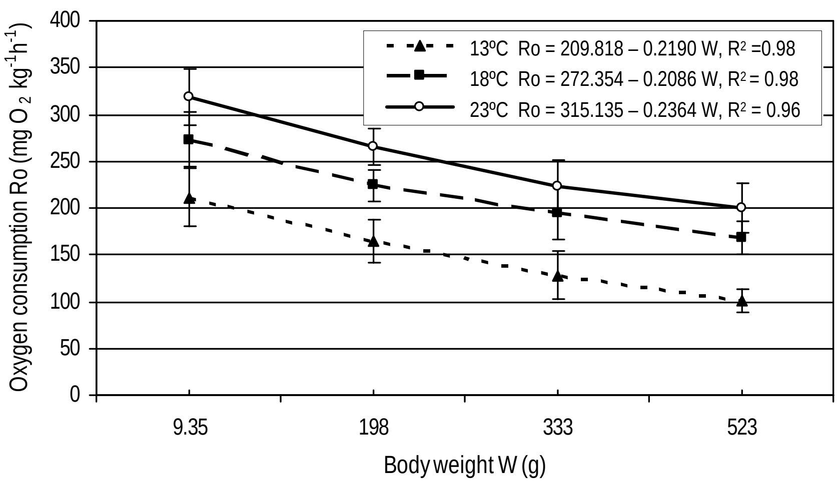

Figure 2. Oxygen consumption of *Oplegnathus insignis* (mg O_2 kg^{-1} min^{-1}).

Figura 2. Consumo de oxigeno promedio de *Oplegnathus insignis* (mg O_2 kg^{-1} min^{-1}).

Table 1. (Q_{10}) values of *Oplegnathus insignis* for different temperatures ranges and body weight.

Tabla 1. Valores (Q_{10}) en la tasa respiratoria de *Oplegnathus insignis* para diferentes pesos corporales.

Weight (g)	Temperature interval (ºC)		
	13-18	18-23	13-23
9.5	1.68	1.35	1.50
198	1.85	1.40	1.61
333	2.32	1.30	1.74
523	2.78	1.41	1.98

increasing temperature and lengthening the light period, and therefore they recommend monitoring changes in water quality such as reduced oxygen conditions high temperature and long dayligth photoperiod that trigger increased activity in the fish.

The Q_{10} values calculated between 13 and 18ºC were higher than Q_{10} values from 18 to 23ºC, indicating that the rate of increase in metabolism was greater at lower temperatures. The overall Q_{10} calculated over the entire range (13-23ºC), is within the range commonly reported for marine fish. Jobling (1982) indicates that when temperature rises fish increase oxygen consumption and this response can remains for various hours. Acute changes in temperature represent a realistic situation in aquaculture facilities, where the temperature acts as a stressor, particularly due to the very pronounced temperature cycles during the day in culture tanks or thermal shocks due to the accidental water exchange. Under these conditions, the concentration of dissolved oxygen can become limiting. For example, in a sudden temperature change, increasing from 20 to 30°C, the dissolved oxygen concentration is reduced by 16% while the metabolic rate is increased at least threefold.

The fish production that a given volume of water can support depends on the amount of dissolved oxygen in the water, the oxygen consumption rate of the fish, and the efficiency with which fish can extract oxygen from the water (Soderberg, 1982) and the waterflow requirement is biologically and economically important in land-based systems since it is one of the limiting factors for fish production (Fivelstad, 1988). In intensive aquaculture fish are reared at high density. Such a system requires water treatment to remove metabolic wastes and to reduce the risk of oxygen depletion. The hydraulic retention time in a tank will depend on the specific time necessary to remove the products of excretion. In commercial aquaculture it is a common practice to install oxygenation devices on land-based fish farms to increase fish carrying capacity (Colt & Watten, 1988). Despite some merits of using hyperoxic conditions in intensive fish farming, the use of oxygen saturation operation should be cautious to avoid unnecessary operation cost for using pure oxygen (Dong *et al*., 2011).

From the standpoint of designing an aquaculture system an adequate flow of water must ensure the supply of oxygen for fish respiration (Soderberg, 1982), removal of metabolic products and solid (Klapsis & Burley, 1984; Cripps & Poxton, 1993) to promote swimming behavior (Ross *et al*., 1995; Odeh *et al*., 2004), and even to aid in the removal of external parasites (Bodensteiner *et al*., 2011). Considering, for example, those data for a density of 10 kg m^{-3} can be observed a deficit of total renewal of water with an approximate range from 33 to 76% at flow rates of 18.4 and 4.6 L min^{-1} m^{-3} respectively (Fig. 3). It can also be deduced that higher concentrations of oxygen available allow a more extended hydraulic retention time for each cubic meter of rearing volume. For the present case these values are 0.9 and 3.6 h respectively for the flow rates listed above as example. These values may be lower if we consider the correction. In practice, the deficit of water replacement may be higher due to increased oxygen consumption caused by factors such as swimming and feeding activity and eventually the fluctuations (rises) temperature. An increase in water temperature within the thermal limits brings together a increase in feeding activity (if the food is not limited) and therefore an increase in the daily rhythm of oxygen consumption due to food and not by a temperature effect on the metabolism. Therefore usually the oxygen consumption rate is typically expressed in relation to food (g O_2/g food) (Timmons *et al*., 2001).

The application of the correction developed by Kraul *et al*. (1985) has been reported by Schram *et al*. (2009) where they found that increasing the flow rate in the culture of juvenile turbot (*Scophthalmus maximus*) are reached higher growth rates when the flow rate rises to 4.7 tank volumes/h.

Indeed, an increased supply of water should be compatible with the availability of a pumping system that allows adjustment of the water requirements according to the reality of each fish farm and water quality conditions. Thus, the correction factor can be used in numerical models to simulate water quality conditions at varying water flow rates and also to establish design flows in the sizing of a fish farm facility according to projected production plans. The input variables may be the metabolic activity dependent of the weight and temperature, feeding rate, excretion rate, or the stocking density to list a few examples.

Table 2. Theorical water flow rates Q (L min^{-1} m^{3}) in relation to actual replacement fractions F(%) and hydraulic retention time (T) for different stocking densities and available oxygen concentrations.

Tabla 2. Tasas de flujo de agua teóricas Q (L min^{-1} m^{3}) en relación a la fracción real de reemplazo F(%) y tiempo de retención hidráulica (T) para distintas densidades y concentraciones de oxígeno disponibles.

Available oxygen mg L^{-1}	Fish stocking density								
	8 kg m^{-3}			10 kg m^{-3}			12 kg m^{-3}		
	Q (L min^{-1} m^{3})	F (%)	T (h)	Q (L min^{-1} m^{3})	F (%)	T (h)	Q (L min^{-1} m^{3})	F (%)	T (h)
2,0	14,7	58,6	1,1	18,4	66,8	0,9	22,0	73,4	0,8
2,5	11,8	50,6	1,4	14,7	58,6	1,1	17,6	65,3	0,9
3,0	9,8	44,5	1,7	12,2	52,0	1,4	14,7	58,6	1,1
3,5	8,4	39,6	2,0	10,5	46,7	1,6	12,6	53,0	1,3
4,0	7,3	35,7	2,3	9,2	42,4	1,8	11,0	48,4	1,5
4,5	6,5	32,4	2,6	8,2	38,7	2,0	9,8	44,5	1,7
5,0	5,9	29,7	2,8	7,3	35,7	2,3	8,8	41,1	1,9
5,5	5,3	27,4	3,1	6,7	33,0	2,5	8,0	38,2	2,1
6,0	4,9	25,5	3,4	6,1	30,7	2,7	7,3	35,7	2,3
6,5	4,5	23,8	3,7	5,7	28,8	2,9	6,8	33,4	2,5
7,0	4,2	22,3	4,0	5,2	27,0	3,2	6,3	31,5	2,6
7,5	3,9	21,0	4,3	4,9	25,5	3,4	5,9	29,7	2,8
8,0	3,7	19,8	4,5	4,6	24,1	3,6	5,5	28,2	3,0

T was calculated as T = V/Q

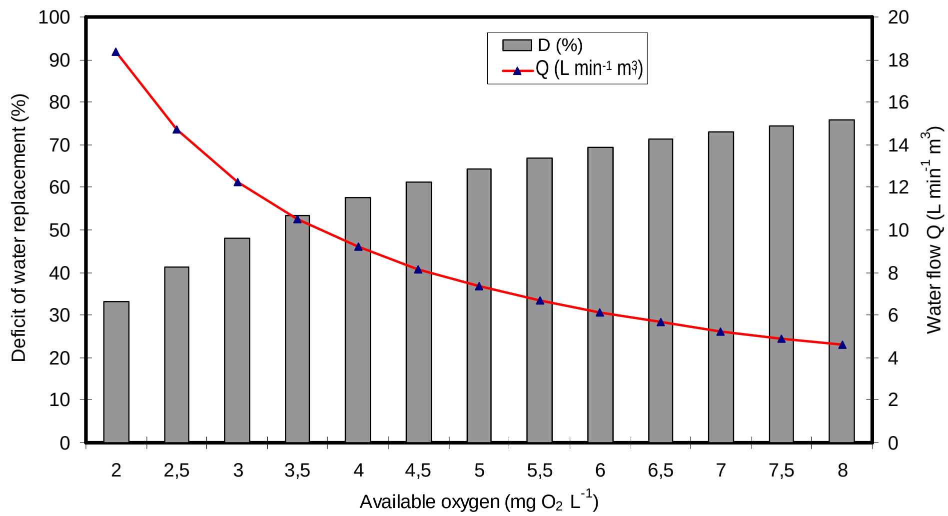

Figure 3. Deficit of amount of replaced water and theorical requirement of water flow per unit volume (1 m^3) at different levels of oxygen available in water. Graph was made considering fish of 250 g body weight, at 19ºC temperature and 10 kg m^{-3} stocking density.

Figura 3. Déficit de reemplazo de agua y requerimiento teórico de agua por volumen unitario (1 m^3) a diferentes niveles de oxígeno disponible en el agua. Gráfico fue elaborado considerando peces de 250 g de peso, a 19ºC de temperatura y a una densidad de 10 kg m^{-3}.

In conclusion, the setting water flow rates should consider those hydraulic deviations occurring in open flow systems and it is advisable to incorporate the necessary corrections to ensure an adequate flow of water to culture systems with and without addition of oxygen. Finally the results of this study can be the basis for the development of a culture technology for *O. insignis* which at present is in an incipient stage of development.

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