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Oxygen consumption and ventilatory frequency responses to gradual hypoxia in common dentex (*Dentex dentex*): Basis for suitable oxygen level estimations

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Abstract

This study established different oxygen level categories (optimal, sub-optimal, dangerous and lethal) for *Dentex dentex* according to ventilatory frequency (V_f) and oxygen consumption (MO_2) in response to gradually decreasing dissolved oxygen levels for different fish masses (117–745 g) and water temperatures (13.9–28.1 °C). Initial and maximum ventilatory frequency (V_{f0} and V_{fmax}, respectively) and oxygen saturation at which ventilatory frequency was altered (S_{Vf}) ranged from 31.3 to 71.3 beats/min, 58.0 to 129.7 beats/min and 48.1 to 81.7%, respectively. *D. dentex* maintained a constant MO_2 rate, until a critical oxygen saturation (S_{crit}) was reached. The S_{crit} and lethal oxygen saturation (LS50) ranged from 26.5 to 40.6% and 12.3 to 18.9%, respectively. V_{f0}, V_{fmax}, S_{crit} and LS50 were correlated positively and significantly with temperature, but only V_{fmax} was correlated with body mass, pointing to a higher V_f response in small than large fish. In the range of fish masses and temperatures tested, our findings suggest an optimal dissolved oxygen saturation of above 70–75% (constant V_f and MO_2), a sub-optimal value of between 70 and 35% (altered V_f but not MO_2), with anything below 35% being dangerous (altered V_f and MO_2). We conclude that suitable oxygen levels for *D. dentex* are similar with respect to other species of interest in aquaculture.

Keywords: Oxygen; Hypoxia; Ventilatory frequency; Temperature; Body mass; *Dentex dentex*

1. Introduction

Common dentex (*Dentex dentex*) is a sparid fish which has been proposed as being highly suitable for intensive culture in Mediterranean coastal waters. This species is greatly appreciated by consumers and shows excellent possibilities for reproduction in captivity (Glamuzina et al., 1989). Furthermore, this fish shows higher growth rates and tolerance to lipids in the diet than other cultured species, such as *Sparus aurata* or *Dicentrachus labrax* (Efthimiou et al., 1994; Rueda and Martínez, 2001; Company et al., 1999). A negative note is the fact that both larvae and juveniles are highly aggressive and sensitive to handling and pathological processes (Efthimiou et al., 1994). Current investigations are focused on feeding and nutrient utilisation with commercial diets (Skalli et al., 2004).

In this study, a description of the respiratory behaviour of *D. dentex* is presented, since knowledge

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of its oxygen consumption and ventilatory frequency responses in situations of gradual hypoxia will provide information on suitable dissolved oxygen levels for its culture. Generally, fish respond to a decrease in the levels of dissolved oxygen by simultaneously increasing both ventilatory frequency and ventilation volume rate (Randall, 1982). The cost for ventilation has been estimated in the region of 3–10% of the resting oxygen consumption at normoxia (Farrell and Steffensen, 1987; Rantin et al., 1992). However, this cost may increase to 50% in situations of hypoxia (Hughes and Saunders, 1970), so any increase in ventilation will reduce the energy available for other metabolic processes such as growth (Jones, 1971). Furthermore, if oxygen levels continue decreasing the animals will not be able to obtain their oxygen requirements (critical oxygen level) and their vital functions will be affected. Above this critical level, most fish species – the so-called regulators" – maintain a constant oxygen consumption rate, regardless of the concentration of dissolved oxygen, while those fish whose oxygen consumption is directly related with oxygen concentration are denominated "conformers" (Shelton, 1970). Thus, the optimal oxygen level could be defined as the oxygen concentration at which ventilatory frequency and oxygen consumption are not modified. On the other hand, temperature and body mass may both modify oxygen consumption and ventilatory frequency responses to hypoxia. In the first place, higher temperatures provoke higher oxygen consumption (Jobling, 1982), a decrease in oxygen solubility (Weiss, 1970) and a reduced affinity of haemoglobin for oxygen (Grigg, 1969). As regards body mass, smaller animals show higher mass-specific oxygen consumption than larger ones (Jobling, 1982; Grottum and Sigholt, 1998), so it can be supposed that fish will require higher oxygen levels as temperature rises and body mass decreases. Hence, the main objective of this study is to pay special attention to parameters, such as the oxygen saturation at which ventilatory frequency is modified, to identify critical and lethal oxygen saturation levels, and to assess the influence of temperature and fish mass. These data will be taken into account for estimating different oxygen level categories (optimal, sub-optimal, dangerous and lethal).

2. Material and methods

2.1. Animals: maintenance and feeding

Specimens of common dentex (*D. dentex*) caught by local fishermen in San Pedro del Pinatar (Murcia, SE Spain) were transported to the laboratory in aerated water. The animals (100–800 g) were housed in 1600-l circular tanks with an open flow-through system using seawater. It has previously been demonstrated that these types of tank are more suitable than raceways or rectangular tanks for *D. dentex* culture (García García and Cerezo, 2003a). The temperature and photoperiod were seasonal between July 2001 and January 2002 period (37° 50′N, 0° 46′W); salinity was 37‰ and oxygen saturation was kept above 70%. Fish were fed ad libitum every day with bogue (*Boops boops*) which are accepted by the animals.

2.2. Experimental design

When the fish were completely acclimated and showed a regular daily feeding rate they were transferred to the experimental aquaria (volume = 200 l; $[O_2] > 90\%$; salinity = 38‰; pH = 8.1; $(NO_2)^- < 0.5$ mg/l; $NH_3 < 0.01$ mg/l). These aquaria formed part of a closed system with biological filtration, an ultraviolet lamp, and a thermostat to maintain the experimental temperatures. Three of the walls of the aquaria were covered by an opaque perspex sheet to keep the fish calm. Eight experiments were carried out with variable fish masses (117 to 745 g) and temperatures (13.9–28.1 °C; see Table 1). In each experiment, three replicates of three to six individuals were placed in separate 200-l aquaria. The fish were completely acclimated over a minimum period of 2 weeks prior to the experiments and were starved 36 h before measurements were made. The duration of the experiments ranged from 5 to 14 h, depending on the water temperature and fish biomass.

2.3. Measurement of oxygen consumption and ventilatory frequency

Oxygen consumption was measured simultaneously in the replicate aquaria by closed respirometry from the drop in oxygen concentration at 30-min intervals according to the following formula:

$$MO_2 = \frac{([O_2]_{t1} - [O_2]_{t2}) * V}{(B * t)},$$

where MO_2 is the individual oxygen consumption expressed as mgO_2/kg/h; $[O_2]_{t1} - [O_2]_{t2}$ is the difference in oxygen concentrations (mgO_2/l) over measurement time; V is the volume of the aquarium in litres; B is fish biomass in kilogram adjusted as a function of alive number of fish, and t is the length of time (hours) during which oxygen consumption was measured.