

**EFFECT OF TEMPERATURE ON THE INTERACTIONS BETWEEN
METABOLISM AND SWIMMING PERFORMANCE IN SEA BASS
(*DICENTRARCHUS LABRAX*).**

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Introduction

Temperature has been implicated as an important factor in regulating the seasonal movements (migrations) of numerous fish species. The proposed investigation aims at elucidating the ways in which the environment sets the limits (scope) within which internal bioenergetic processes, particularly those related to swimming, take place. For that purpose, existing models of the relationship between metabolism and temperature were refined and put at use in order to examine the seasonal and latitudinal effects on sea bass' swimming performance.

Materials and methods

Juvenile sea bass *Dicentrarchus labrax* of both sexes were 22.65 ± 0.10 cm total length and weighed 147.16 ± 2.68 g. They were thermoacclimated (1 month) and swam at 7, 11, 14, 18, 22, 26, and 30 °C in a Brett-type swimming respirometer. Experimental run consisted of a 30-min period at each designate speed up to the maximum sustainable speed. Speed increment was 0.1 m sec^{-1} . At each speed fish MO_2 was calculated. All MO_2 data were standardised to a 100g individual using a weigh exponent of 0.23.

The maximum swimming speed (U_{\max}) that fish was able to maintain was determined by direct observation. At this point, MO_2 usually levelled off or decreased slightly. For each temperature trial, an exponential regression equation was fitted by least squares to the MO_2 versus swimming speed (U) data

set. Eq.1: $MO_2 = a + bU^c$, where a , b and c are constants. The standard metabolic rate (SMR) was determined by extrapolating the MO_2 versus swimming speed relationship to zero swimming speed. The metabolic rate associated with U_{max} determined the active metabolic rate (AMR). After transforming eq.1, the optimal swimming speed (U_{opt}) was calculated. Eq. 2: $U_{opt} = (a/(c-1)b)^{1/c}$ (Videler, 1993).

At each experimental temperature, the net cost of transport (COT_{net}) was calculated as follow. SMR was first subtracted from every MO_2 values which were then converted to $J\ km^{-1}\ kg^{-1}$ using an oxycalorifique equivalent (3.24 cal mgO_2 ; Beamish, 1978) and converting cal to J (4.18 J cal^{-1}). A relationship between COT_{net} and swimming speed was plotted and an exponential regression was fitted using eq. 1.

In order to combine the effects of temperature and swimming speed on metabolic rate, the following modelling procedure was applied. Using the regression equations established at each temperature, the temperature-dependence of parameters a , b and c was examined in order to draft a three-dimension model. Eq. 3: $MO_2 = f(T) + f'(T)U^{f''(T)}$.

Results

Sea bass maximum sustainable swimming speed (U_{max}), active metabolic rate (AMR) and standard metabolic rate (SMR) increased significantly with acclimation temperature (ANOVA, $P < 0.0001$; Table 1). At each acclimation temperature a relationship between oxygen consumption and swimming speed was fitted by the least squares using eq. 1 (Table 2).

Table 1. Influence of acclimation temperature (T) on sea bass sustainable swimming speed (U_{max}), standard metabolic rate (SMR), active metabolic rate (AMR) and optimal swimming speed (U_{opt}). In each column, numbers sharing a superscripted letter are statistically similar ($P < 0.05$).

T (°C)	n	$U_{max} \pm se$ ($cm.sec^{-1}$)	$SMR \pm se$ ($mgO_2.h^{-1}.kg^{-1}$)	$AMR \pm se$ ($mgO_2.h^{-1}.kg^{-1}$)	U_{opt} ($cm.sec^{-1}$)
7	5	0.67 ± 0.012 ^a	43.1 ± 8.99 ^a	197.3 ± 16.59 ^a	0.32
11	8	0.77 ± 0.027 ^{ab}	43.88 ± 6.49 ^a	224.41 ± 43.24 ^a	0.37
14	10	0.84 ± 0.015 ^{bc}	92.5 ± 13.28 ^b	288.9 ± 49.26 ^{ab}	0.52
18	9	0.88 ± 0.019 ^c	93.71 ± 9.16 ^b	337.86 ± 26.69 ^{ab}	0.58
22	10	0.90 ± 0.019 ^c	116.56 ± 11.29 ^{bc}	407.92 ± 43.07 ^b	0.51
26	8	1.08 ± 0.041 ^d	139.08 ± 7.35 ^c	552.69 ± 39.22 ^c	0.58
30	7	1.12 ± 0.035 ^d	147.21 ± 19.94 ^c	609.58 ± 38.48 ^c	0.61

Table 2. Equations and r^2 values for regressions for the plots of oxygen consumption versus swimming speed: $MO_2 = a + bU^c$.

T (°C)	<i>a</i>	<i>b</i>	<i>c</i>	r^2
7	39.41	380.74	2.08	0.702
11	50.88	388.77	2.23	0.692
14	107.47	399.07	3.24	0.689
18	88.33	267.3	1.95	0.623
22	108.91	385.43	2.57	0.720
26	139.04	358.67	2.74	0.858
30	155.17	382.51	2.26	0.859

At each temperature the optimal swimming speed was calculated using eq. 2. We found that U_{opt} was increased twofold over the temperature range 7 – 30 °C *i.e.*, from 0.32 to 0.61 cm sec⁻¹. A relationship between U_{opt} and temperature (T) was fitted using a linear regression $U_{opt} = 0.0116T + 0.2866$ ($r^2 = 0.75$). When the seven temperature trials were compared, a strong relationship between the extent of sea bass' aerobic performance and their sustainable swimming speed was observed $U_{max} = 0.001AMR + 0.5051$, $r^2 = 0.9656$.

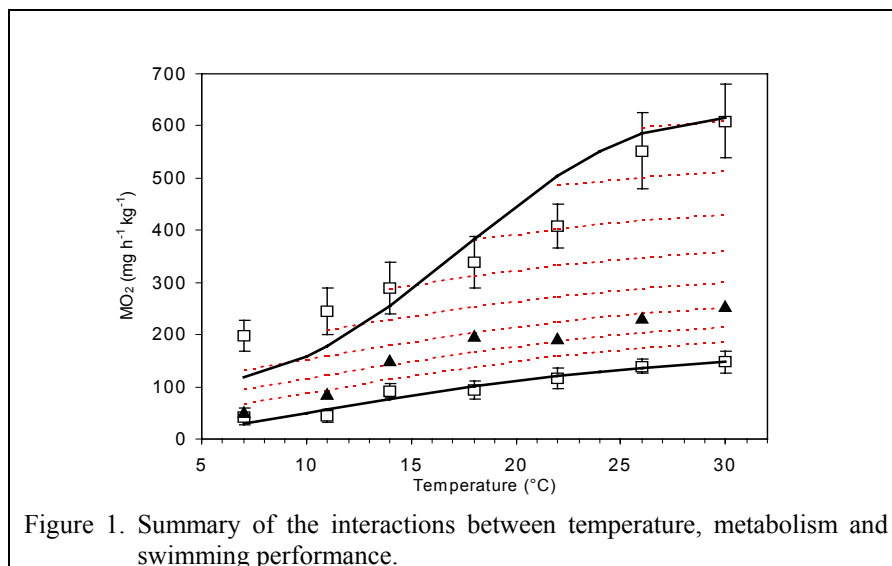
The relationship between swimming speed and net cost of transport (COT_{net}) was not influenced by acclimation temperature.

In order to investigate the effect of acclimation temperature on the relationship between aerobic metabolism and swimming performance we designed the following model

$$MO_2 = 168.6(1-EXP(-0.0077T^{1.65})) + 366.07U^{2.44}.$$

The level of good fit between observed MO_2 and modelled MO_2 was examined using a linear regression $y = 0.9307x + 24.267$, $r^2 = 0.82$.

The various models and experimental data that describe the interactions between temperature and sea bass' metabolism and swimming performance are summarised in Fig. 1.



Open symbols are AMR and $SMR \pm 95\%$ confidence interval. Solid lines represent the consolidated models $AMR = f(T)$ and $SMR = f(T)$ which were fitted using the equations reported in Claireaux and Lagardère (1999) and after combining the two data sets. Dotted lines are ‘isospeed’ curves that were drawn using eq. 4. The point where one given ‘isospeed’ curve meets the $AMR = f(T)$ relationship indicates U_{max} at the considered temperature. Close symbols indicate the metabolic rate at U_{opt} for the considered temperature. On average, the cost of swimming at U_{opt} represented $27.26 \pm 2.79\%$ of sea bass’ metabolic scope.

Discussion

During the last decades, the lack of integration between our knowledge of fish physiology and the environmental variables has been repeatedly identified as the main obstruction to the development of efficient procedures for the management of living resources. In the case of sea bass, the deficiency of basic information is striking, particularly when it comes to defining environmental tolerances and physiological optima (Pickett and Pawson, 1994). Moreover, although the links between environmental constraints on physiological performances and behaviour have been identified, their ecological significance and implication for sustainable management of exploited resources are still to be adequately established. Clearly, these hindrances must be removed if an ecosystem approach to bass fishery management is to be promoted.

The ability to move is a fundamental property by which we define animal life. Although rarely proven, logic dictates that swimming performance somehow factors into the Darwinian fitness of fish. In the present study we designed an integrated tool to investigate the controlling and directive influences of seasonal temperature changes on swimming and metabolic performances. This tool should also allow us to examine the link between global climate change and the recent extension of the bass range into the North Sea.

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