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Oxygen consumption of midwater fishes and crustaceans from the eastern Gulf of Mexico

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Abstract

Oxygen consumption was measured as a function of temperature, oxygen partial-pressure (P_{O_2}) and species depth of occurrence for twenty-three species of midwater fishes and crustaceans collected from the eastern Gulf of Mexico from June 1981 to July 1985. Q_{10}s (7° to 20 °C) of 3.90 and 3.24 were recorded for myctophid and non-myctophid fish groups, respectively, while values of 2.22, 2.19, 2.19 and 2.54 were calculated for sergestid, penaeid, carid and euphausiid crustacean groups, respectively. Q_{10}s were consistent for species within each group. All of the species tested regulated their oxygen consumption to P_{O_2} levels normally encountered within the eastern Gulf. Values of critical partial pressure (P_c) ranged from 20 to 40 mm Hg and increased slightly with increasing temperature and respiration rate. Declining respiration with increasing minimum depth of occurrence was primarily a function of temperature alone. Changes in size, dry weight and water content contributed only a small fraction to the observed decrease. This finding contrasts with studies from the eastern Pacific Ocean, where temperature is a minor contributor to changes in respiration rate with depth.

Introduction

With the exception of three studies on Atlantic fauna (Napora 1964, Teal and Carey 1967, Teal 1971), data on the metabolism of mesopelagic species are restricted to temperate eastern Pacific species (Pearcy and Small 1968, Childress 1971a, b, 1975, 1977a, Smith and Hessler 1974, Quetin and Childress 1976, Belman and Gordon 1979, Childress and Somero 1979, Torres et al. 1979, Smith and Laver 1981, Mickel and Childress 1982, Hiller-Adams and Childress 1983). Hydrographic conditions in tropical-subtropical areas, particularly the temperature and dissolved oxygen profiles, are quite different. Temperature in the upper 1 000 m ranges from 4° to 17 °C in the eastern Pacific (Scripps Institution of Oceanography 1965, GEOSECS 1981) compared to 5° to 29 °C in the eastern Gulf of Mexico (Hopkins 1982). Dissolved oxygen levels within the 100 m mixed layer are near air-saturation for both areas; however, below that the profiles differ significantly. In the eastern Pacific, oxygen levels drop sharply to as low as 0.2 ml l^{-1}, forming a severe and extensive minimum layer (Childress 1975, GEOSECS 1981), while levels in the eastern Gulf remain fairly high (minimum = 2.8 ml l^{-1}) throughout the water column (Hopkins unpublished data).

Studies from the eastern Pacific encompassing a variety of species (Childress 1971a, b, 1975, Smith and Hessler 1974, Gordon et al. 1976, Torres et al. 1979) have shown that oxygen consumption decreases with increasing minimum depth of occurrence (MDO: that depth below which 90% of the population lives, Childress 1971b). The reasons for the decline are not completely understood. Whether or not the same causative factors are present in other oceanic systems is also unknown. Childress (1977b) noted that distinctive temperature regimes probably result in dissimilar depths of occurrence among congeners from different locations. It follows that, in addition to directly affecting metabolic rates, a varied temperature profile could indirectly influence the oxygen consumption-MDO relationship. Other factors such as differences in the depth and severity of the oxygen minimum layer and the degree of vertical migration in the communities of the eastern Gulf of Mexico and the eastern Pacific could also have resulted in differences in the adaptive characteristics of the species present.

Information from geographically separate and hydrographically distinctive areas is needed to fully understand the open-ocean environment and the animals that reside there. This paper presents data on the oxygen consumption of epi- and mesopelagic micronekton from a tropical-subtropical system and the effects of temperature and external P_{O_2}.

Materials and methods

Animals were collected on eight cruises from June 1981 to July 1985 from a fifteen mile radius around 27°N, 86°W. Nets used in sampling were 1.8 × 1.8 m or 1.8 × 3.6 m Tucker-type trawls fitted with a thermally protecting cod-end bucket (Childress et al. 1978) towed at a speed of approximately two knots. Tows were conducted during both day and nighttime hours over various depths within the upper 1 000 m.

Upon net retrieval, the entire catch was transferred immediately to a bucket of chilled seawater. To help prevent thermal shock, specimens from deep trawls were put in 5° to 10 °C water while shallower catches were placed in warmer, 15° to 20 °C water. Whenever possible, animals were tested immediately (i.e., within 30 min). If not, they were kept in aerated seawater and maintained in the dark at 5° to 10 °C for 2 to 72 h. In all instances only the most active individuals were selected for use.

Oxygen-consumption rates were determined by allowing an individual to deplete the oxygen in a sealed, water-jacketed chamber filled with filtered seawater (0.45 μm pore-size). Chamber sizes varied with size of the individual. The time required varied from 4 to 20 h, depending on the size of the animal and its level of activity throughout the run. Experimental temperatures were maintained within 0.1 C° by means of a refrigerated water bath. Most runs were conducted during nighttime hours. Metabolic variation due to diel behavioral differences was incorporated into the overall variability of a species' rate. The oxygen partial-pressure in the chambers was monitored continuously by Clark-type polarographic oxygen electrodes (Clark 1956). To insure mixing of the water, stir bars turning at minimum speed were used in each chamber and separated from the main portion of the respirometer by a perforated false bottom to minimize disturbance of the animal. Electrodes were calibrated at each experimental temperature before each run using air- and nitrogen-saturated seawater. Streptomycin and neomycin (50 mg l^{-1} each) were added to the water to minimize bacterial growth. To measure the possible contribution of bacterial respiration, controls were conducted after selected runs. After the completion of selected runs, the animal was removed, its volume replaced with fresh filtered water, the chamber resealed, and oxygen consumption was monitored for a further 4 to 6 h. In all cases, microbial respiration was negligible (< 5%) in comparison to the total respiration rate of the animal.

Data were recorded using either a potentiometric strip-chart recorder or a digital data-logger system. Oxygen consumption rates for a particular P_{O_2} were determined by measuring the decline in oxygen concentration over a 30 min interval around that P_{O_2}. For data acquired with the chart recorder, rates were read directly as the slope of the curve. For data acquired with the data-logger, rates were calculated as the means of values measured over the 30 min period around a given P_{O_2}. The average respiration rate was calculated as the mean of individual rates recorded at P_{O_2}s over a flattened portion of the rate vs P_{O_2} curve (usually occurring between 30 and 90 mm Hg). Average wet weight-specific respiration rate ($\dot{V}_{O_2}$) values are considered to be estimates of routine respiration, as the rates were obtained over an intermediate P_{O_2} range subsequent to the initial excitatory period but still above the critical oxygen partial pressure for the animal (P_c = that P_{O_2} below which O_2 consumption is no longer independent of external P_{O_2}; Prosser 1973, and is analogous to the 30 to 70 mm Hg rates of Childress 1975). The maximum rate reflects the highest measured oxygen consumption, and was commonly recorded within the first two hours of the run. Similarly, the minimum rate is the lowest measured oxygen consumption at a P_{O_2} above the P_c.

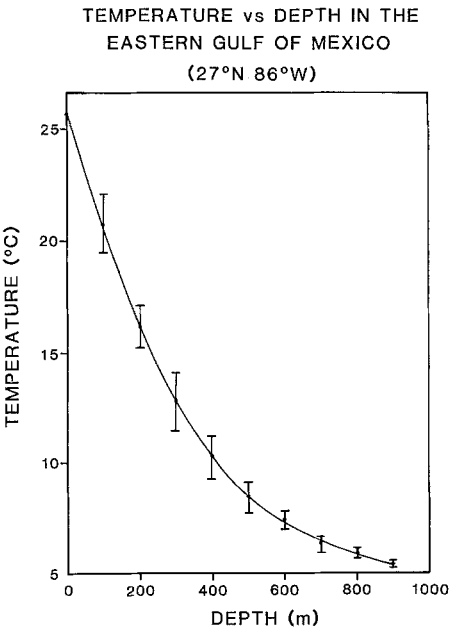

Fig. 1. Temperature vs depth in eastern Gulf of Mexico measured over eight cruises (June 1981–July 1985; combined data)

All animals in the study underwent some degree of physical trauma during collection and testing; therefore, the respiration rates reported here should be regarded as estimates of routine metabolism.

Results

Twenty-three species of fishes and crustaceans, representing ten families, were examined at five experimental temperatures (Tables 1 and 2). For purposes of analysis and discussion, all species are categorized into six groups: myctophid fishes, non-myctophid fishes, euphausiids, sergestids, penaeids, and carids. The data set is characteristic of the indigenous micronekton community in the eastern Gulf of Mexico (Hopkins et al. 1981). Temperatures for the sampling area ranged from 5° to 29 °C within the upper 1 000 m (Fig. 1). Seasonal variations in temperature over the eight cruises were less than 3 C°.

Table 1. Midwater fishes. Wet weights, depth distribution, weight-specific respiration rates ($\dot{V}_{O_2}$), Q_{10}s and critical partial pressures (P_c). $\dot{V}_{O_2}$, minimum and maximum rates are expressed as μl O_2 mg^{-1} wet wt h^{-1}. Temperatures are experimental temperatures. Conversion (conv.) factors for dry wt (DW) and ash-free dry wt (AFDW) should be multiplied by wet wt rate ($\dot{V}_{O_2}$) to convert to dry and ash-free dry weight-specific form. MDO: minimum depth of occurrence; ND: no data

Species (ref.)	(*n*)	$\bar{x}$ wet wt (range) (g)	% H_2O	AFDW as % DW	Depth distrib. (m) day	Depth distrib. (m) night	MDO (m)	*T* (°C)	No. of runs	$\dot{V}_{O_2}$ (σ)	min. rate (σ)	max. rate (σ)	DW conv.	AFDW conv.	Q_{10} (T_1–T_2)	P_c (mm Hg)
Myctophidae																
Diaphus mollis (B)	(2)	0.168 (0.112–0.223)	47.6	78.6	400–500	80– 200	90	20	2	0.292 (0.125)	0.416 (0.125)	0.167 (0.125)	1.91	2.43	ND	ND
Lampanyctus nobilis (E)	(2)	3.670 (1.186–6.155)	78.9	80.9	550–600	100– 600	120	7	2	0.043 (0.001)	0.016 (0.010)	0.108 (0.005)	4.74	5.86	ND	ND
Lepidophanes guentheri (F)	(3)	1.292 (0.937–1.696)	74.5	76.9	500–800	80–1 000	105	7	1	0.049 (0.028)	0.011	0.116	4.05	4.94	3.27 (7–20)	ND
								14	1	0.084 (0.003)	0.081	0.087	3.98	5.09	2.16 (7–14)	ND
								20	1	0.229 (0.001)	0.228	0.231	4.24	5.26	5.32 (14–20)	ND
Myctophum affine (G)	(4)	1.900 (0.315–2.863)	71.1	76.9	500–600	0– 600	0	7	2	0.051 (0.013)	0.019 (0.009)	0.147 (0.011)	3.19	3.81	ND	ND
								14	2	0.198 (0.004)	0.156 (0.038)	0.375 (0.093)	3.73	5.19	6.94 (7–14)	ND
Anoplogasteridae																
Anoplogaster cornuta (I)	(2)	17.368 (7.817–26.920)	90.1	72.7	ND	ND	600	7	1	0.032 (0.003)	0.028	0.071	8.85	12.88	ND	ND
								20	1	0.155 (0.084)	0.056	0.262	11.69	15.26	3.37 (7–20)	45–50
Ceratiidae																
Cryptopsaras couesi (I)	(2)	2.676 (1.836–3.516)	89.3	75.6	ND	ND	800	20	2	0.122 (0.000)	0.106 (0.001)	0.195 (0.021)	9.32	12.33	ND	40
Gonostomatidae																
Gonostoma elongatum (M)	(7)	10.192 (4.906–19.720)	88.2	72.6	450–800	80– 900	140	7	4	0.039 (0.015)	0.029 (0.008)	0.050 (0.023)	8.45	11.66	ND	ND
								14	3	0.071 (0.023)	0.060 (0.019)	0.077 (0.026)	8.46	11.64	2.35 (7–14)	ND
Sternoptychidae																
Argyropelecus aculeatus (Q)	(2)	2.609 (1.739–3.478)	80.0	76.5	160–900	130– 900	165	20	2	0.161 (0.010)	0.111 (0.017)	0.203 (0.030)	5.01	6.55	ND	ND

Table 2. Midwater crustaceans. Wet weights, depth distribution, weight-specific respiration rates ($\dot{V}_{O_2}$), Q_{10}s and critical partial pressures (P_c). $\dot{V}_{O_2}$, minimum and maximum rates are expressed as $\mu l\ O_2\ mg^{-1}$ wet wt h^{-1}. Temperatures are experimental temperatures. Conversion (conv.) factors for dry wt (DW) and ash-free dry wt (AFDW) should be multiplied by wet wt rate ($\dot{V}_{O_2}$) to convert to dry and ash-free dry weight-specific form

Species (ref.)	(*n*)	$\bar{x}$ wet wt (range) (g)	% H_2O	AFDW as % DW	Depth distrib. (m) day	Depth distrib. (m) night	MDO (m)	*T* (°C)	No. of runs	$\dot{V}_{O_2}$ (σ)	min. rate (σ)	max. rate (σ)	DW conv.	AFDW conv.	Q_{10} (T_1–T_2)	P_c (mm Hg)
Euphausiidae																
Thysanopoda monocantha (S)	(7)	0.174 (0.137–0.222)	73.5	85.7	400–>800	100–700	200	7	5	0.086 (0.019)	0.064 (0.019)	0.151 (0.063)	4.06	4.73	ND	ND
								14	2	0.196 (0.008)	0.122 (0.053)	0.296 (0.062)	3.06	3.57	3.24 (7.14)	ND
Sergestidae																
Sergestes armatus (V)	(3)	0.029 (0.054–0.318)	72.3	84.9	300–600	0–600	150	7	2	0.085 (0.005)	0.034 (0.014)	0.466 (0.033)	3.53	4.09	ND	ND
								14	1	0.217 (0.036)	0.168	0.379	3.77	4.59	3.81 (7–14)	25–30
Sergestes corniculum (W)	(3)	0.284 (0.047–0.419)	69.4	89.3	40–850	0–500	125	7	2	0.090 (0.067)	0.081 (0.070)	0.146 (0.078)	3.24	3.58	ND	ND
								20	1	0.170 (0.043)	0.129	0.300	3.18	3.84	1.63 (7–20)	35
Sergia grandis (Y)	(3)	0.713 (0.629–0.764)	76.2	81.9	600–800	300–600	400	14	1	0.159 (0.036)	0.108	0.317	3.57	4.49	2.14 (14–20)	30–35
								17	1	0.165 (0.022)	0.139	0.217	5.18	6.31	1.13 (14–17)	ND
								20	1	0.251 (0.030)	0.206	0.289	3.87	4.61	4.05 (17–20)	45–50
Sergia robustus (Z)	(9)	1.635 (0.519–2.937)	75.0	82.1	300–1 000	100–900	225	7	1	0.094 (0.007)	0.081	0.103	4.65	5.62	2.22 (7–17)	ND
								12	1	(0.094) (0.014)	0.082	0.187	3.94	4.65	ND	ND
								14	5	0.174 (0.032)	0.111 (0.006)	0.292 (0.037)	3.70	4.57	2.41 (7.14)	30
								17	1	0.209 (0.022)	0.176	0.234	4.20	5.03	1.84 (14–17)	25–30
								20	1	0.351 (0.047)	0.308	0.533	4.72	5.70	5.63 (17–20)	ND
Sergia splendens (a)	(12)	0.286 (0.116–0.412)	70.6	85.4	120–1 000	0–1 000	195	7	6	0.086 (0.027)	0.071 (0.028)	0.111 (0.020)	3.52	4.15	2.61 (7–20)	ND
								14	1	0.187 (0.022)	0.165	0.301	3.27	3.99	3.03 (7–14)	ND
								20	5	0.300 (0.056)	0.194 (0.057)	0.541 (0.111)	3.94	4.56	2.20 (14–20)	35
Sergia talismani (b)	(4)	0.202 (0.114–0.332)	74.7	84.6	500–1 000	0–200	125	7	1	0.141 (0.093)	0.046	0.574	4.05	4.81	ND	ND
								20	3	0.263 (0.028)	0.185 (0.040)	0.654 (0.206)	3.93	4.63	1.62 (7–20)	35
Penaeidae																
Funchalia villosa (d)	(11)	2.086 (0.478–2.634)	72.9	86.6	150–1 000	0–900	70	7	5	0.061 (0.024)	0.040 (0.023)	0.106 (0.057)	3.56	4.08	ND	20–25

Table 2. (continued)

								20	6	0.217 (0.051)	0.177 (0.060)	0.362 (0.118)	3.80	4.37	2.65 (7–20)	30–35
Gennadas capensis (f)	(2)	0.265 (0.194–0.336)	67.5	ND	300–950	275–950	410	7	2	0.098 (0.001)	0.071 (0.022)	0.218 (0.096)	3.08	ND	ND	ND
Gennadas scutatus (g)	(2)	0.512 (0.123–0.180)	75.2	83.8	275–700	75–925	135	14	1	0.146 (0.063)	0.083	0.232	3.67	4.69	ND	ND
								20	1	0.215 (0.017)	0.199	0.763	4.39	4.92	1.91 (14–20)	30–35
Gennadas valens (h)	(20)	0.534 (0.238–0.819)	75.5	85.7	250–800	100–425	290	7	7	0.092 (0.018)	0.067 (0.023)	0.190 (0.092)	4.31	5.11	2.12 (7–20)	
								14	5	0.137 (0.026)	0.100 (0.026)	0.205 (0.084)	3.76	4.46	1.77 (7–14)	25–30
								20	8	0.244 (0.054)	0.190 (0.059)	0.464 (0.147)	4.08	4.63	2.62 (14–20)	30–35
Oplophoridae																
Acanthephyra purpurea (j)	(12)	1.391 (0.481–2.584)	73.6	79.6	400–1 000	200–550	325	7	10	0.085 (0.014)	0.067 (0.016)	0.152 (0.117)	3.89	4.76	ND	25–30
								14	1	0.199 (0.061)	0.120	0.359	2.79	ND	3.37 (7–14)	30–35
Oplophorus gracilirostris (m)	(9)	2.010 (0.112–3.130)	69.5	81.0	350–600	90–450	100	7	4	0.095 (0.041)	0.072 (0.049)	0.198 (0.108)	3.41	4.21	ND	25
								20	5	0.303 (0.083)	0.238 (0.068)	0.498 (0.132)	3.18	3.92	2.44 (7–20)	30
Systellaspis debilis (n)	(25)	1.118 (0.158–1.888)	71.6	84.8	100–1 000	100–900	150	7	12	0.077 (0.014)	0.056 (0.020)	0.164 (0.098)	3.07	3.48	1.79 (7–20)	25
								14	3	0.156 (0.035)	0.100 (0.028)	0.250 (0.079)	3.22	3.97	2.74 (7–14)	30
								20	10	0.164 (0.037)	0.128 (0.038)	0.297 (0.096)	3.83	4.61	1.09 (14–20)	35–40
Pandalidae																
Parapandalus richardi (r)	(5)	0.284 (0.054–0.380)	70.8	82.7	100–600	80–350	150	7	3	0.094 (0.62)	0.064 (0.038)	0.139 (0.074)	3.56	4.29	2.61 (7–17)	ND
								14	1	0.136 (0.033)	0.089	0.177	2.56	3.10	1.69 (7–14)	ND
								17	1	0.245 (0.010)	0.234	0.257	4.01	4.98	7.11 (14–17)	25–30

Regulation of oxygen consumption

P_c values were recorded for 2 fish and 14 crustacean species (Tables 1 and 2). All values recorded were lower than the lowest P_{O_2}s in the eastern Gulf of Mexico [65 mm Hg (=2.8 ml l^{-1}) at a depth of approximately 500 m, T. L. Hopkins unpublished data].

P_cs at two different temperatures were obtained for *Sergia grandis, Funchalia villosa, Gennadas valens, Acanthephyra purpurea, Oplophorus gracilirostris* and *Systellaspis debilis.* In all cases the P_c increased with increasing temperature and $\dot{V}_{O_2}$ (Fig. 2).

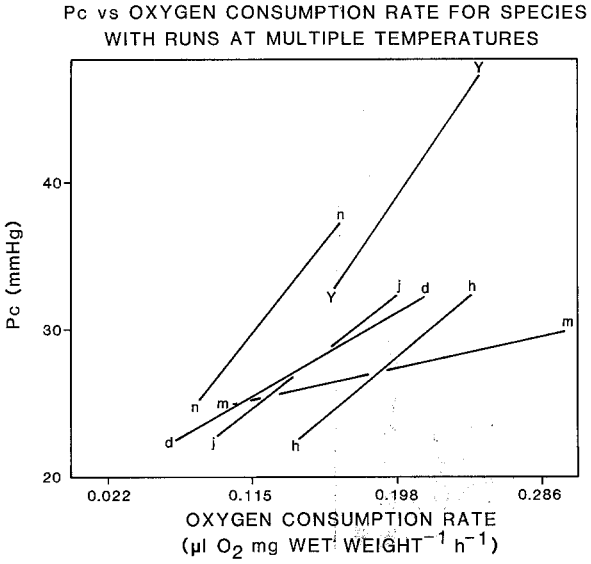

Fig. 2. Critical partial-pressure vs oxygen consumption rate for crustaceans at multiple temperatures. Letters are reference symbols for *Sergia grandis* (Y, 14° to 20 °C), *Funchalia villosa* (d, 7° to 20 °C), *Gennadas valens* (h, 14° to 20 °C), *Acanthephyra purpurea* (j, 7° to 14 °C), *Oplophorus gracilirostris* (m, 7° to 20 °C) and *Systellapsis debilis* (n, 7° to 20 °C)

Oxygen consumption as a function of temperature

Respiration rate as a function of temperature is plotted in Figs. 3 and 4. Q_{10}s over the 7° to 20 °C range are given for each group. Values for the fishes were 3.90 and 3.24 for the myctophid and non-myctophid groups, respectively (Figs. 3b, c), with a combined Q_{10} of 3.22 (Fig. 3a). Values for the crustaceans ranged from 2.19 to 2.54 (Figs. 4b–4e), with an overall Q_{10} of 2.20 (Fig. 4a). Individual Q_{10}s for 4 fish and 14 crustacean species (Tables 1 and 2) were consistent with values calculated for the groups as a whole.

Q_{10} values over multiple temperature ranges were obtained for one myctophid and five decapod species. The myctophid *Lepidophanes guentheri* displayed a large increase in Q_{10} (2.16 at 14 °C, 5.32 at 20 °C; Table 1). *Sergia splendens* and *Gennadas valens* displayed small changes in Q_{10} at higher temperatures. *S. splendens,* showed a slight decrease in Q_{10} from 3.03 to 2.20 (Table 2), possibly implying some thermal compensation at higher temperatures. *G. valens* had an increased Q_{10} at the higher temperature (1.77 at 14 °C compared to 2.62 at 20 °C). The remaining four species exhibited large changes in Q_{10}. *Systellaspis debilis* showed a considerable drop in Q_{10} (2.74 to 1.09), implying a substantial increase in thermal compensation. *Sergia robustus* displayed a variety of responses. At the upper temperatures of its range there was a small compensatory reaction and a concomitant drop in Q_{10} from 2.41 to 1.84. At temperatures outside the normal range of the species the thermal effect became exaggerated and the Q_{10} increased sharply to 5.63 (20 °C). A similar response was shown by *Sergia grandis,* with a Q_{10} increase at higher temperatures from 1.13 to 4.05.

Oxygen consumption as a function of depth of occurrence

Values for minimum depth of occurrence and day-night depth distributions are listed in Tables 1 and 2. With the

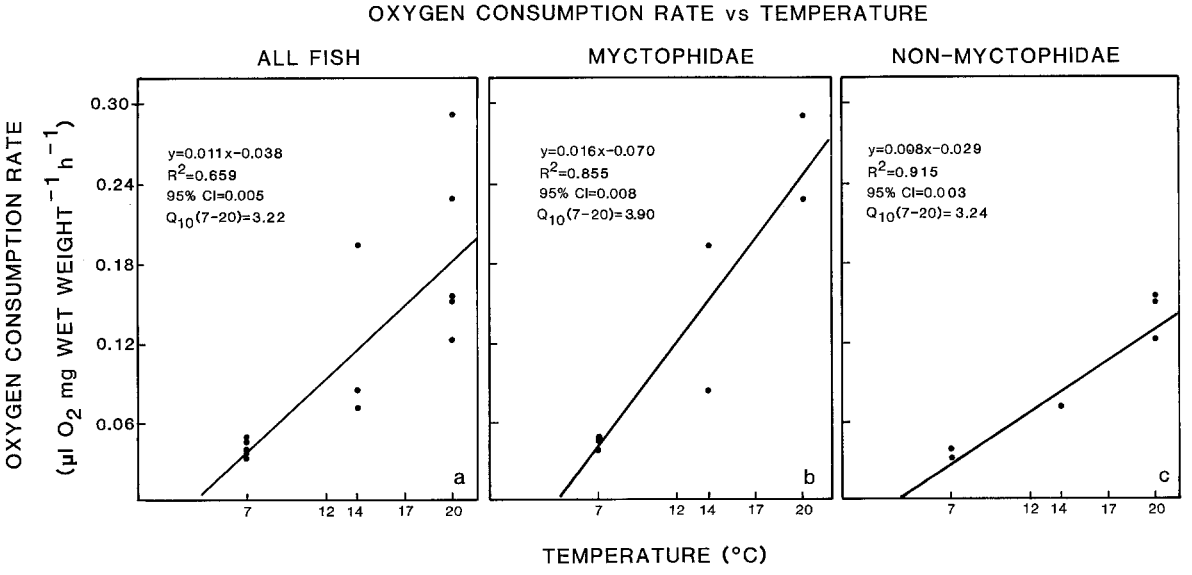

Fig. 3. Oxygen consumption rate vs temperature for all fishes, all myctophids, all non-myctophids

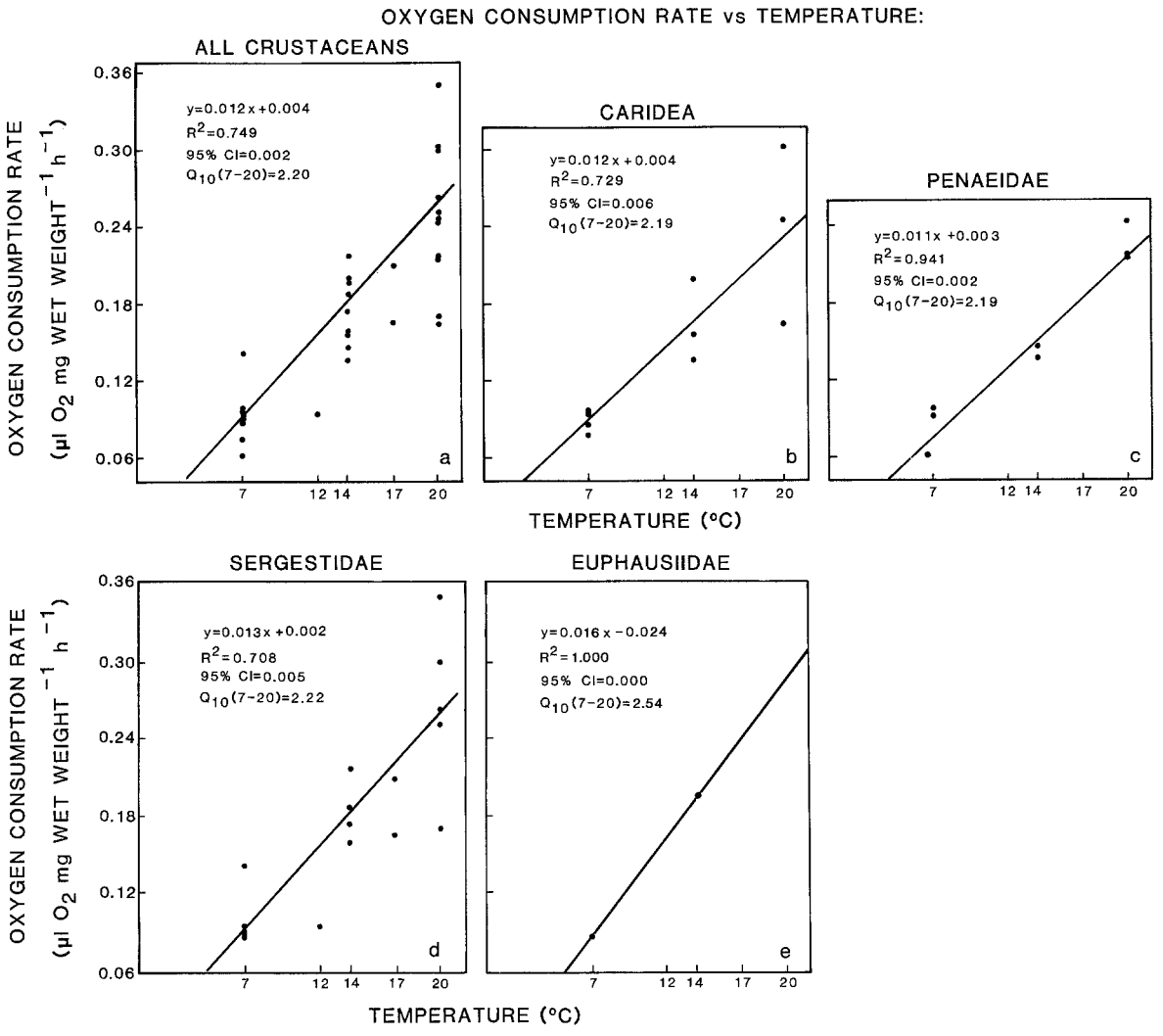

Fig. 4. Oxygen consumption rate vs temperature for all crustaceans, all carids, all penaeids, all sergestids, and all euphausiids

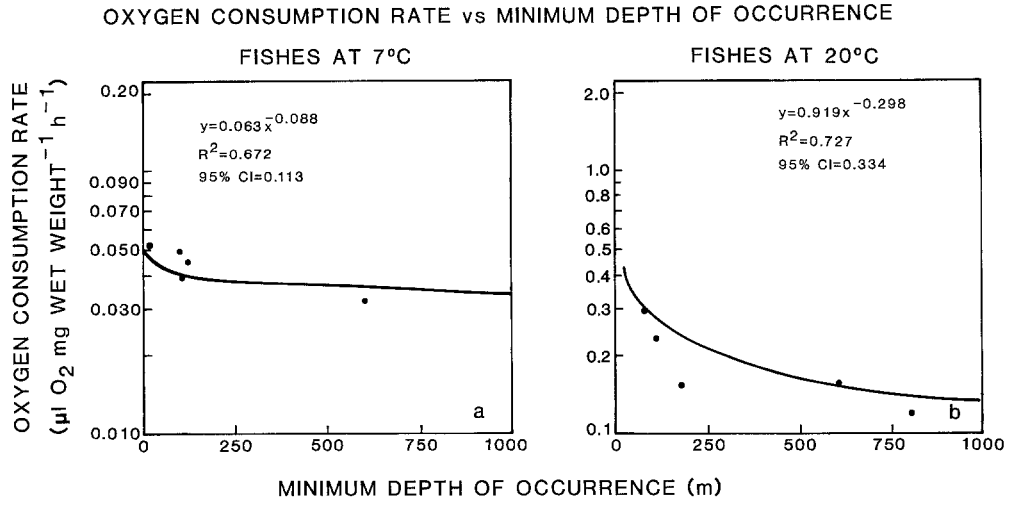

Fig. 5. Oxygen consumption rate vs minimum depth of occurrence for all fishes at 7° and 20 °C

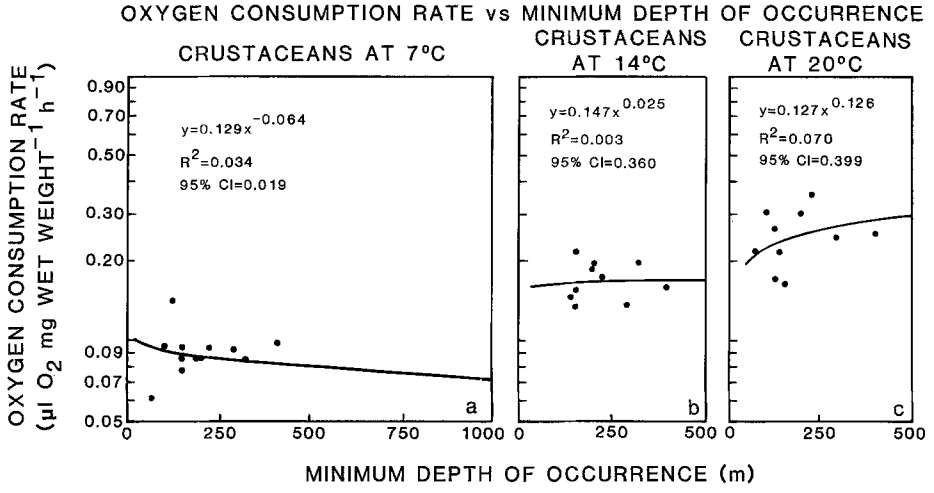

Fig. 6. Oxygen consumption rate vs minimum depth of occurrence for all crustaceans at 7°, 14° and 20 °C

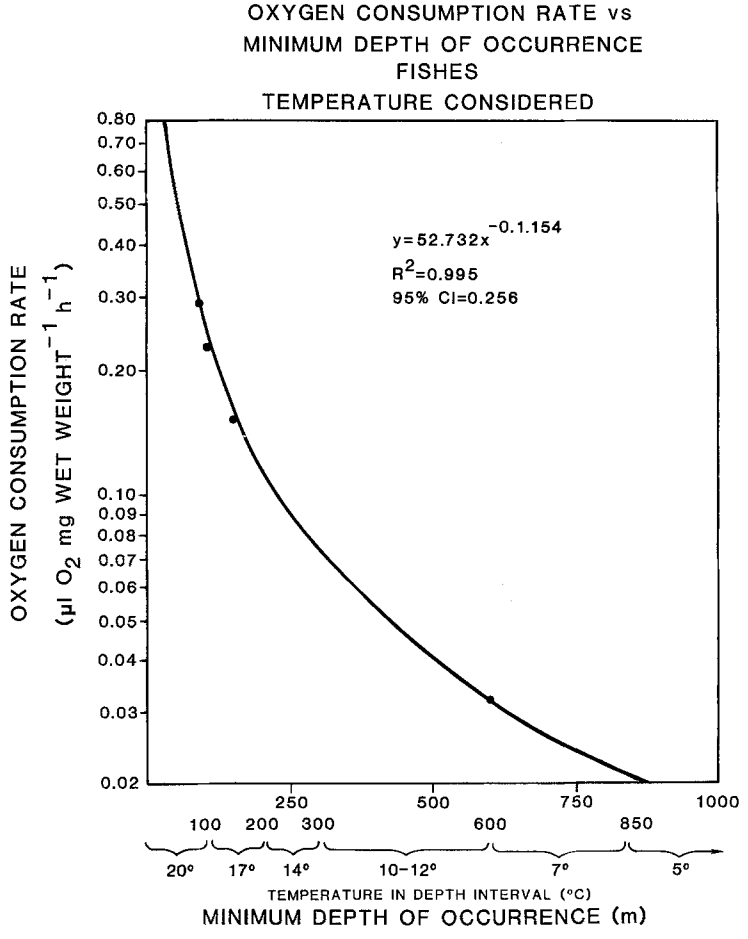

Fig. 7. Oxygen consumption rate vs minimum depth of occurrence for all fishes as a function of temperature changes with depth

exception of *Anoplogaster cornuta* and *Cryptopsaras couesi,* all the depth information was generated at the same station in the eastern Gulf of Mexico as this study (Hopkins et al. 1981, Gartner and Hopkins unpublished data).

Plots of $\dot{V}_{O_2}$ versus MDO were constructed using oxygen consumption rates determined at 7° and 20 °C for the fishes and at 7°, 14° and 20 °C for the crustaceans (Figs. 5 and 6). Regression curves of the form $y = ax^b$ are shown in each graph. No effect of depth of occurrence on metabolism was apparent at any single temperature for the crustaceans, while the fish showed a moderately decreasing oxygen consumption only at the higher temperature. When $\dot{V}_{O_2}$ was plotted against MDO taking into account the changes in environmental temperature with depth (Figs. 7 and 8), both groups showed a significant decline in rate with depth.

Percent water content with depth did not change in the crustaceans (Fig. 9b) and only slightly increased in the

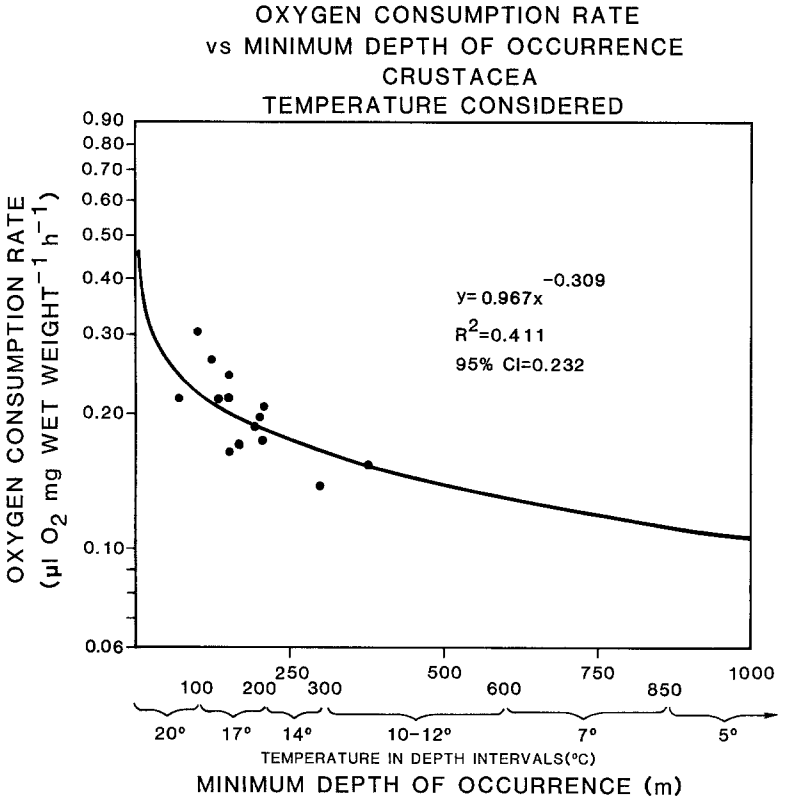

Fig. 8. Oxygen consumption rate vs minimum depth of occurrence for all crustaceans as a function of temperature changes with depth

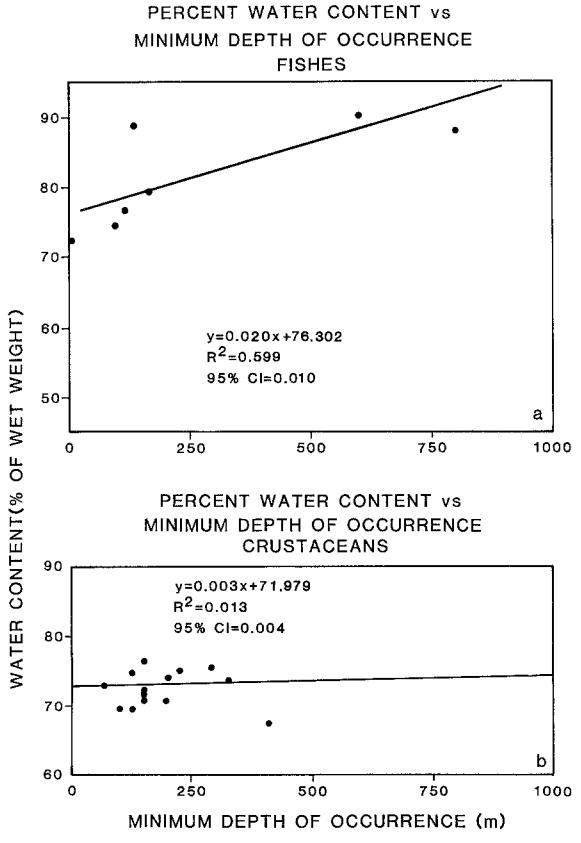

Fig. 9. Percent water content vs minimum depth of occurrence for all fishes and all crustaceans

fishes (Fig. 9a). It should have little effect on any depth-related changes in wet weight-specific respiration rate.

Discussion

This study indicates that temperature is a major factor controlling the respiration of the midwater community in the eastern Gulf of Mexico. Dissolved oxygen never becomes physiologically limiting, as all the species are able to regulate their oxygen consumption at the ambient P_{O_2} levels found throughout their vertical range. The fact that individual P_c values were considerably lower than the lowest P_{O_2} present in the Gulf may reflect regulatory extremes based upon minima encountered elsewhere within the species' geographic distribution. None of the species are restricted to the Gulf of Mexico.

Data from other investigators on identical species are limited (Table 3). Respiratory rates for *Acanthephyra purpurea* and *Systellaspis debilis* (as reported by Teal 1971) agree well, while our rates for *Parapandalus richardi* are somewhat lower than those of Teal (1971). Rates for *S. debilis* from Napora (1964) are considerably higher than ours. As noted by Teal (1971), such difference most probably results from different experimental methods. Our rate for *Thysanopoda monocantha* is similar to that of Teal and Carey (1967). Our rate for *Anoplogaster cornuta* is slightly higher than that of Childress (1975), but agrees well with

rates from Gordon et al. (1976) and Torres et al. (1979) from individuals collected in the eastern Pacific.

Comparison with eastern Pacific congeners (Table 4) shows that our respiration data range from similar to 2–3 times higher. Some of the differences may be attributable to individual variability; the remainder can be explained by differences in temperature regimes, species, depth of occurrence between the two areas (Childress 1975), and as disparities in lifestyles among species.

The effects of temperature on metabolism revealed varying trends among fishes and crustaceans. All the myctophids examined are vertical migrators to epipelagic waters at night. Their elevated Q_{10} (3.90) may reflect significant changes in respiration between daytime and nighttime depths.

Q_{10}s for the Crustacea were consistent, particularly among the three decapod groups. Mean values of 2.22, 2.19 and 2.19 for the Sergestidae, Caridea and Penaeidae, respectively, imply comparable metabolic responses to changing temperatures even though a variety of depth distributions and vertical migrations are exhibited by the species involved. Each group contains both epi- and mesopelagic representatives, with migration patterns ranging from strong to weak or non-existent. Q_{10}s measured in individual species (*Sergia robustus, Sergia splendens, Funchalia villosa, Gennadas valens, Oplophorus gracilirostris* and *Systellaspis debilis*) also were similar. All of these are epipelagic or upper- mesopelagic (MDO from 70 to 290) and undergo significant diel migrations. The lower Q_{10}s at higher temperatures exhibited by *Sergia robustus* and *Systellaspis debilis* suggest thermal compensation at the higher temperatures of their depth ranges. Sharp changes in Q_{10} values in general, however, coincided well with the depth distributions for the majority of species, indicating a close association between thermal effect and the extremes of a species' vertical range.

Perhaps the most significant result concerning the importance of temperature in the ecology of the Gulf is the role it plays in the oxygen consumption vs minimum depth-of-occurrence relationship. Our data suggest that temperature alone is responsible for most of the observed

Table 3. Comparison of respiration rates recorded in present study with those from other investigators on conspecific fishes and crustaceans

Species	Present study		Other studies		
	T (°C)	$\dot{V}_{O_2}$	T (°C)	$\dot{V}_{O_2}$ (σ)	Source
Anoplogaster cornuta	7	0.032 (0.003)	5.0	0.024 (0.009)	Torres et al. (1979)
			5.5	0.019	Childress (1975)
			7.0	0.032 (0.003)	Gordon et al. (1976)
Thysanopoda monacantha	14	0.196 (0.008)	10.0	0.190[a]	Teal and Carey (1967)
Parapandalus richardi	7	0.094 (0.062)	5.0	0.125[a]	Teal (1971)
	17	0.245 (0.010)	15.0	0.340[a]	
Acanthephyra purpurea	7	0.085 (0.014)	5.0	0.075[a]	
	14	0.199 (0.061)	15.0	0.160[a]	
Systellaspis debilis	7	0.077 (0.014)	5.0	0.060[a]	
	14	0.156 (0.035)	15.0	0.140[a]	
	20	0.164 (0.037)	20.0	0.220[a]	
			15.0	0.650[a]	Napora (1964)
			20.0	1.000[a]	

[a] Values available from graphs only

Table 4. Comparison of respiration rates with data from other investigators on congeneric fishes and crustaceans. –: no data

Present study			Other studies			
Species	T (°C)	$\dot{V}_{O_2}$ (σ)	Species	T (°C)	$\dot{V}_{O_2}$ (σ)	Source
Diaphus mollis	20	0.292 (0.125)	*D. theta*	5.0	0.107 (0.020)	Torres et al. (1979)
				7.0	0.208 (0.020)	
Lampanyctus nobilis	7	0.043 (0.001)	*L. ritteri*	5.0	0.041 (0.004)	
				10.0	0.059	
Sergestes armatus	7	0.085 (0.005)	*Sergia phorcus*	5.5	0.024 (0.003)	Childress (1975)
	14	0.217 (0.036)	*Sergestes similis*	10.0	0.288 (–)	Pearcy and Small (1968)
Gennadas valens	7	0.092 (0.018)	*G. propinquus*	5.5	0.027 (0.003)	Childress (1975)
Acanthephyra purpurea	7	0.085 (0.014)	*A. curtirostris*	5.5	0.036 (0.005)	
Systellaspis debilis	7	0.077 (0.014)	*S. cristata*	5.5	0.033 (0.002)	

decrease in respiration with depth. This is considerably different from the situation in the eastern Pacific, where temperature is only a minor factor (Childress 1975, Torres et al. 1979: 17 and 2%, respectively). Comparing this study with those of Childress (1975) and Torres et al. (1979), the primary studies addressing respiration and MDO in the eastern Pacific, our data are biased towards shallow-living species while theirs are biased towards deeper-living species. For fishes, 75% of our species displayed an MDO of less than 200 m while 60% of the species studied by Torres et al. (1979) had MDO's greater than 300 m and, of those, 73% had MDOs greater than 500 m. For crustaceans, 80% of our species had an MDO less than 300 m, 83% of these being found at 200 m or less. Of the crustaceans studied by Childress (1975), 63% lived deeper than 300 m, and 71% of those lived deeper than 500 m. Disparity in depth distributions is unavoidable because of the different migration patterns exhibited within the two communities. In the eastern Gulf, 62% of the fish and 63% of the decapods are extensive vertical migrators and ascend into shallow waters at night (Hopkins et al. 1981), while in the eastern Pacific only 32% of the fish and 13% of the crustaceans undertake major migrations (Pearcy et al. 1977). Our data set reflects the vertical distribution patterns exhibited by species in the Gulf of Mexico.

The distinct physical parameters of the two regions have resulted in differences in the relative importance of temperature. Temperature extremes in the upper 1 000 m range from 5° to 29 °C in the eastern Gulf, but between 4° and 17 °C in the eastern Pacific. The very nature of the wider thermal range would exert greater selective pressure in the Gulf. Conversely, the importance of dissolved oxygen is much higher in the eastern Pacific due to the expansive and severely low oxygen-minimum layer there, a condition that potentially places considerably greater constraints on respiration and activity levels.

Factors such as increasing size or increased water content with depth contributed only slightly to the decrease in respiration, the importance of both being slightly higher in the fish than the crustaceans. Mean dry weights for species living shallower than 200 m compared to those below 200 m were 0.575 and 0.989 g, respectively, for the fish and 0.199 and 0.238 g, respectively, for the crustaceans. Percent increase in water content from the surface to 1 000 m was 20.8 for the fish and only 4.0 for the crustaceans (from Fig. 9). Changes in protein content with depth occur in both fish and crustaceans (Childress and Nygaard 1973, 1974). More important than quantity, however, are changes in protein quality and levels of enzyme activity. Childress (1975) suggested that deeper-living animals, as a consequence of a less variable habitat, "would require much less enzymatic machinery to deal with environmental fluctuations than would shallower living ones". The hypothesis is substantiated in fishes by the findings of Childress and Somero (1979) and Torres et al. (1979). Decreases in protein-specific respiration with depth measured by Torres et al. (1979) were considerably greater than decreases in protein content, implying a change in the nature of muscle metabolism over and above changes in mere muscle mass. In conjunction, Childress and Somero (1979) found disproportionate declines in both glycolytic and citric acid cycle enzyme activity with depth relative to changes in contractile and structural protein concentrations. It should be noted, however, that the studies dealing with changes in enzyme activity and muscle mass involve species from the temperate eastern Pacific. Not only do a much greater percentage of the Gulf of Mexico species migrate but they also tend to travel further when they do migrate. Thus, vertical migration requires that species in the Gulf of Mexico retain a more developed musculature to perform these migrations. It is possible that the traditional arguments for absence of need for muscle in midwater animals do not apply here. In any event, while oxygen consumption rates in midwater species do decline with increased depth of occurrence, rate decreases in species in the Gulf of Mexico are attributable almost completely to temperature.

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