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# ECOSYSTEM- AND TAXON-SPECIFIC DYNAMIC AND ENERGETICS PROPERTIES OF LARVAL FISH ASSEMBLAGES

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## ABSTRACT

Growth rates, mortality rates, and energetics properties of teleost larvae differ among species and among ecosystems. In this synthesis, the ingestion rates required to support mean growth of larvae were estimated and energy budgets were developed. Weight-specific growth coefficients (G), instantaneous mortality rates (Z), larval stage durations (D), gross growth efficiencies ($K_1$), and weight-specific oxygen uptake ($QO_2$) were obtained from published sources and categorized by marine and freshwater species. Rates and properties were subcategorized by marine ecosystems and by taxonomic group. The strong temperature dependencies of rates and properties for larvae were adjusted by analysis of covariance to allow mean values to be compared among ecosystems and taxa. After adjustment, relatively few significant differences were detected, indicating that, with important exceptions, teleost larvae have characteristic and predictable attributes. Marine fish larvae have higher Z, longer D and higher $QO_2$ than freshwater larvae, probably because marine larvae weigh less at hatch (47 $\mu$g versus 339 $\mu$g). Larvae of coral reef fishes had lower temperature-adjusted $\bar{G}$ than larvae from other marine ecosystems. Values of $K_1$ (mean = 0.301) differed little among ecosystems or taxonomic groups and were not related to temperature. Energy budgets, which integrate the effects of rates and properties, differed appreciably among ecosystems and taxa. Ingestion, metabolism, and assimilation were higher for marine than for freshwater larvae. Mean temperature-adjusted ingestion rates usually were 40 to 65% of body weight, although values as high as 97% (Scombroidei) were estimated. Larvae from cool ecosystems (10°C) required two to four times less ingested energy on a daily basis than larvae from warm systems (28°C) to grow at their respective mean rates. Assimilation efficiencies declined as temperature increased. Temperature-adjusted mean assimilation efficiencies ($\bar{A}$) were 0.65 for marine and 0.56 for freshwater teleost larvae; $\bar{A}$ ranged from 0.54 (shelf) to 0.75 (upwelling) for marine ecosystems, and from 0.47 (Salmoniformes) to 0.82 (Gadiformes) across taxonomic groups. Rates and relationships reported here, while not intended to predict species-specific responses, do provide information on deviations by individual species from predicted rates and can identify specific adaptations and life-history strategies. Results of the analyses will be useful to categorize, compare, and model ichthyoplankton assemblages in pelagic communities.

Most marine organisms have high fecundities and produce abundant progeny, which suffer high mortalities as they grow through early life toward recruitment. In teleost fishes, the recruitment process and its mechanisms are difficult to study because of the great potential for variability in growth and mortality rates in early life (Houde, 1987; Wootton, 1990), the problem of obtaining temporally and spatially representative samples, and the confounding effects of a dynamic, advective environment (Taggart and Leggett, 1987; McGurk, 1989; Taggart and Frank, 1990). Factors that may be categorized as either subtle or episodic affect the abundances of larval fish cohorts as they advance toward recruitment (Houde, 1989a). The causes of recruitment successes or failures often go unexplained, in part because mean rates and variability of response by larvae, as well as ecosystem and taxon-specific effects, are unknown.

The complexity of the recruitment process makes it unlikely that the process will be studied or understood in detail for many species. Thus, it is appealing to examine the problem in a general or conceptual framework. If levels of growth, mortality, and required ingestion of fish larvae are ecosystem-specific or taxon-specific, important issues could be addressed regarding life-history strategies, re-

cruitment dynamics, and early life bioenergetics. It also would be possible to consider fish larvae as components of ecosystems and to develop models that explicitly included fish early life stages.

Recently, some conceptualized approaches to understand factors that affect levels of growth and mortality in early life have been proposed. The roles of body size, of ontogenetic shifts in susceptibility to mortality, and the interdependence of growth and mortality rates, have helped to relate events in early life to overall life history strategies (Werner and Gilliam, 1984; Peterson and Wroblewski, 1984; McGurk, 1986, 1987; Miller et al., 1988; Beyer, 1989; Pepin, 1991). Growth and mortality have been found to depend upon body size, food availability, and temperature. There are strong, apparently predictable, relationships between temperature and vital rates of marine fish larvae (Houde, 1989b; Morse, 1989). Thus, the bioenergetics and ingestion requirements of larvae developing under warm or cool temperatures differ markedly, and spawning strategies of fishes may vary latitudinally as a consequence of temperature-related constraints in early life. Evolved, taxon-specific growth potential in early life also may be latitudinally regulated (Conover, 1990; Conover and Present, 1990), adding complexity to probable relationships. Taxon-specific feeding behavior and potential are morphologically determined (Hunter, 1981) and may affect growth and mortality rates, as well as energetics properties, of teleost larvae.

In this paper we examine growth and mortality rates, stage durations, metabolic rates, and growth efficiencies of fish larvae from marine and freshwater ecosystems. Within the marine category, comparisons were made among taxa from estuarine, shelf, oceanic, upwelling, and coral reef systems. Taxon-specific comparisons were made at the levels of order and suborder. Primary objectives were to determine ingestion requirements and develop energy budgets of larvae from the designated ecosystem and taxonomic categories. An overall goal was to learn whether food requirements of fish larvae are basically similar across taxa and ecosystems, regulated strongly by the physiological constraints imposed by temperature, or whether there are characteristic and adaptive differences within ecosystems or taxa that shape the recruitment process and other aspects of teleost life histories.

## METHODS

Values of instantaneous mortality rates and instantaneous (weight-specific) growth rates, weight-specific oxygen uptakes, and gross growth efficiencies of teleost larvae were obtained from published literature or, if not explicitly given, were calculated when appropriate data were provided. Except for mortality rates, which came only from studies on unmanipulated wild populations, data were from both laboratory and field experiments. The data base (Appendix A) is restricted to the larval stage from hatching to metamorphosis and is expanded significantly beyond that compiled by Houde (1989b) to explore relationships between vital rates, energetics, and temperature for marine fish larvae. The analysis undertaken was not without risk because the data are of variable quality, and were collected and analyzed for different purposes. Despite these concerns, the approach is believed to be worthwhile, especially as an attempt to find generalities in teleost life histories that will be useful to understand population and community dynamics at ecosystem or broad taxonomic levels.

When weight-specific rates were not given, we converted growth rates for length to growth rates for weight using length-weight relationships. For some taxa, especially coral reef species, it was necessary to apply length-weight relationships from larvae of morphologically similar species (usually Sparidae). In cases where temperatures were not reported (e.g., coral reef species) we determined approximate temperatures from atlases of seasonal sea surface temperatures that corresponded to the areas of interest.

When rates and values were not estimated and reported explicitly in a publication, but suitable raw data were provided, we sometimes calculated rates, efficiencies, and energetics values. Except for the coral reef fishes, data points are for individual species. The coral reef larvae were treated at the genus level because, while larvae of many coral reef species have been measured and aged (e.g., Brothers et

al., 1983; Victor, 1986, 1987; Thresher and Brothers, 1989; Wellington and Victor, 1989), usually only a few individuals of any single species were analyzed.

Larvae were assigned to marine or freshwater categories. The marine larvae were subcategorized as estuarine, shelf, oceanic, upwelling, or coral reef species. Taxa were examined at the ordinal or subordinal level of classification (Appendix A). Some freshwater fishes with atypically large larvae (e.g., Salmonidae, Acipenseridae, Ictaluridae) were not included in our analyses.

The following data were used: $W_0$, Dry weight at hatch ($\mu$g); $W_{met}$, Dry weight at metamorphosis ($\mu$g); G, Weight-specific growth coefficient ($\cdot d^{-1}$); Z, Instantaneous mortality coefficient ($\cdot d^{-1}$); D, Larval stage duration (d). Days to grow from weight at hatch ($W_o$) to estimated weight at metamorphosis ($W_{met}$); $QO_2$, Weight-specific oxygen uptake ($\mu l\ O_2 \cdot mg^{-1} \cdot h^{-1}$); I, Weight-specific daily food ingestion ($\cdot d^{-1}$), expressed as a fraction of body weight; and $K_1$, Gross growth efficiency, defined as the ratio of G/I.

Regression relationships between these variables and temperature were derived. When more than a single value of a variable was available, the median values were regressed on median temperature. Analysis of covariance, with temperature as the covariate, was used to determine if the regression relationships or mean values differed among ecosystems or among taxa. The adjusted means (temperature effects having been removed) were tested (ANCOVA) to determine which differed significantly ($\alpha = 0.10$) and, consequently, if larvae could be categorized by ecosystem or taxon. An $\alpha$ level of 0.10 was selected to increase the power of tests to discern possible differences among ecosystems or taxa, admittedly at an increased risk of concluding falsely that differences existed (Type I error).

Daily ingestion requirements (I) of fish larvae seldom are reported in published literature (but, see MacKenzie et al., 1990). However, if both G and $K_1$ are known, I can be estimated as $I_A = G/K_1$. We examined the relationship between I and temperature. A second approach to estimate I, which accounts for temperature effects and which is based upon the relationship $I_E = G/\bar{K}_1$, also was applied, where $\bar{K}_1$ is mean gross growth efficiency and G is the expected growth rate derived from the relationship between growth and temperature. Because G had been derived from the equation, $G = a + bT$ (where T is temperature °C), and $\bar{K}_1$, had been estimated, the expected relationship between daily ingestion rate and temperature was $I_E = (a + bT)/\bar{K}_1$. The $I_A$ and $I_E$ estimates are not completely independent, since both were derived from $\hat{G}$ and $\hat{K}_1$ values that were available. The $I_E$ estimator is a more general form because it uses the growth-temperature relationships to predict mean ingestion requirements for the ecosystem and taxon categories.

Energy budgets of teleost larvae were derived for all larvae, marine larvae, freshwater larvae, and for larvae classified by ecosystem-specific and taxon-specific categories. These budgets were developed from the mean values of ingestion, growth, and metabolism that were estimated for each of the categories. Budgets in $cal \cdot mg^{-1} \cdot d^{-1}$ were expressed as: $I = G + M + U + F$ where I = ingestion, G = growth, M = metabolism, U = urine, and F = feces. The assumed conversion from dry weight to calories was $0.005\ cal \cdot \mu g^{-1}$. An oxycalorific conversion coefficient of $0.00463\ cal \cdot \mu l^{-1}\ O_2$ was applied (Brett and Groves, 1979) to convert oxygen uptake ($QO_2$) to metabolism. Reported oxygen uptake values generally were stated to be, or we presumed them to be, resting or routine rates. To determine M, we assumed that the reported $QO_2$ prevailed during a 12-h dark period each day when feeding and activity were minimal, and that a doubled rate ($2 \cdot QO_2$) prevailed during a lighted 12-h period when larvae were active and feeding. Urine production accounts for a small proportion of ingestion and we assumed that $U = 0.07I$, the mean value for young, carnivorous fishes (Brett and Groves, 1979). Loss as feces was obtained by difference. Assimilation efficiency was calculated as $A = (I - F)/I$. The $Q_{10}$ values were calculated for G and M. Both temperature-specific and temperature-adjusted energy budgets were developed. The temperature-adjusted budgets, which allow direct comparisons of budget components among ecosystems and among taxonomic groups, were derived from the adjusted mean rates estimated in the analyses of covariance.

## Results

The regression relationships between larval G, D, Z, $QO_2$, and temperature were significant but quite variable (Figs. 1–4). The addition of more marine species (primarily coral reef and oceanic) and the addition of freshwater species to the data base of Houde (1989b) did not change fundamental relationships, but the variability about the regressions increased. A total of 118 species was included in our analyses (Appendix A). A summary of the mean values for vital rate and energetics parameters is included as Table 1.

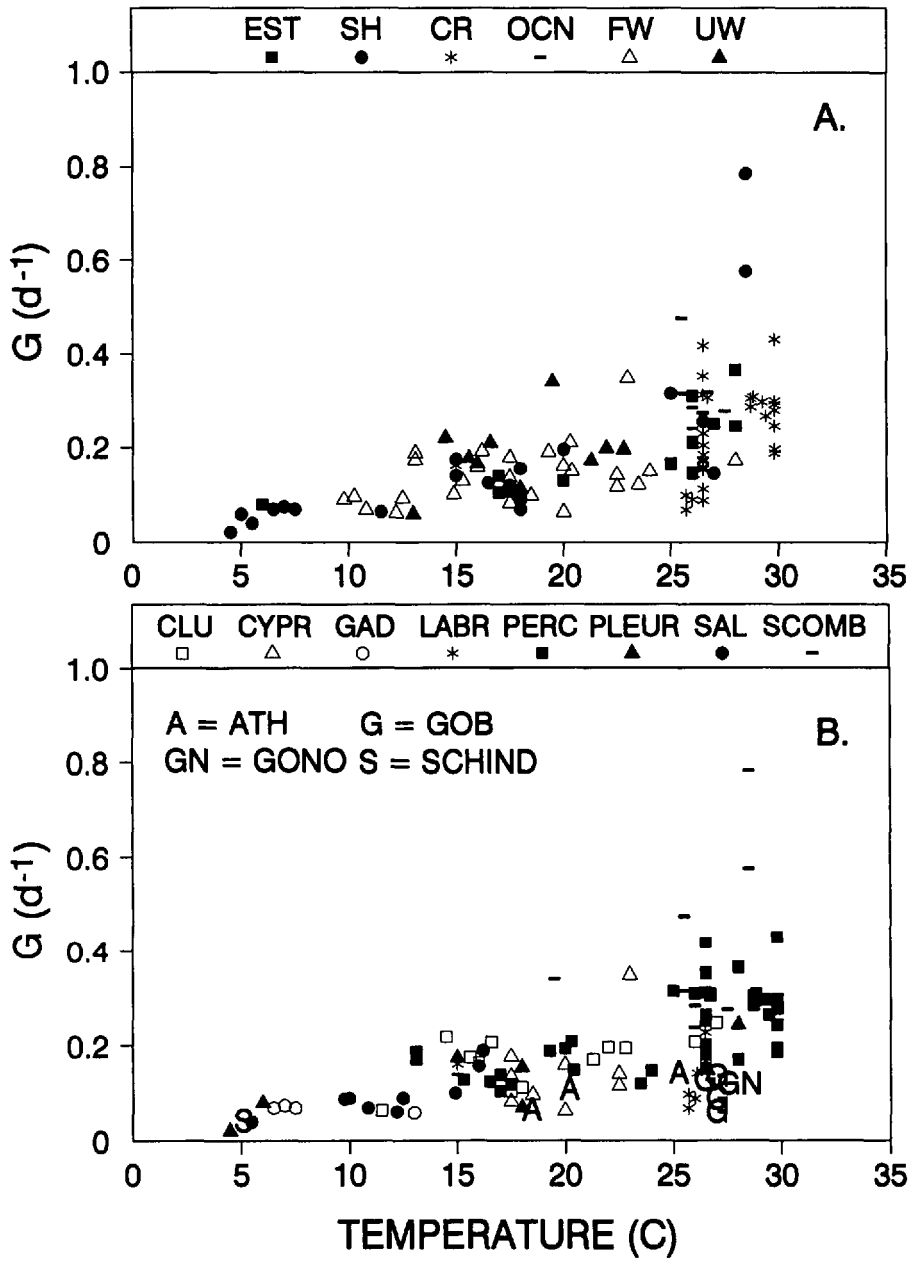


Figure 1. A. Ecosystem- and B. Taxon-specific, weight-specific growth coefficients (G, $d^{-1}$) of teleost larvae in relation to temperature. EST = estuarine, SH = shelf, CR = coral reef, OCN = oceanic, FW = freshwater, UW = upwelling, CLU = Clupeiformes, CYPR = Cypriniformes, GAD = Gadiformes, G = Gobioidei, LABR = Labroidei, PERC = Percoidei, PLEUR = Pleuronectiformes, SAL = Salmoniformes, SCOMB = Scombridae, A = Atheriniformes, GN = Gonorynchiformes, S = Schindleroidei. Each data point is a reported or calculated value. In the case of species with more than one value reported for the variable of concern on temperature, the median value is plotted.

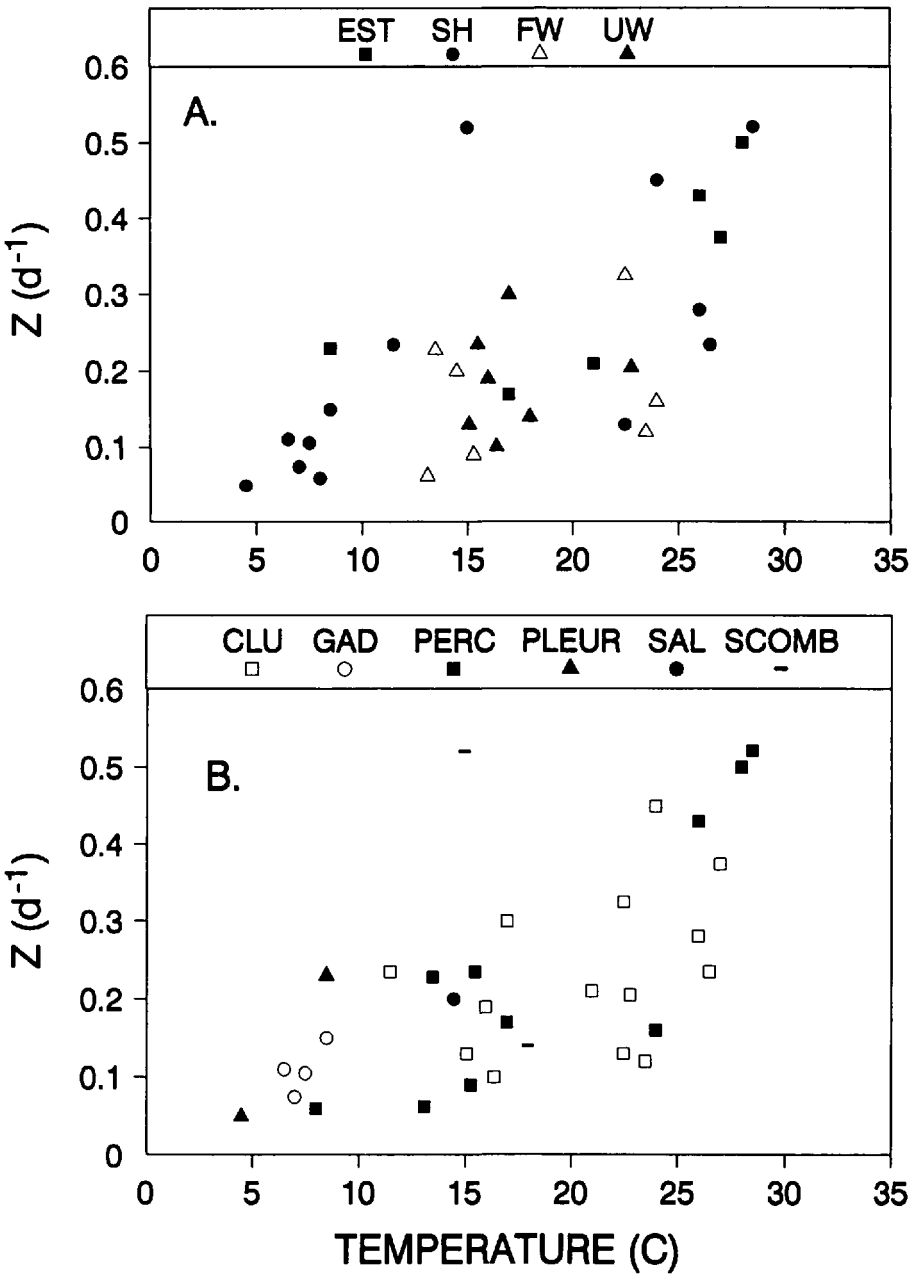


Figure 2. A. Ecosystem- and B. Taxon-specific, instantaneous mortality coefficients (Z, $d^{-1}$) of teleost larvae in relation to temperature. See Figure 1 for keys and explanations.

*Weight at Hatch ($W_0$).*—The mean of reported dry weights at hatch of freshwater larvae were heavier than those of marine larvae. The mean weight at hatch of 20 freshwater species was 339 μg (SE = 74.0 μg) while that of 45 marine species was 47 μg (SE = 9.7 μg). The weight differential is the probable reason for differences between marine and freshwater larvae in oxygen uptake, larval stage durations, and mortality rates that are reported in the following analyses.

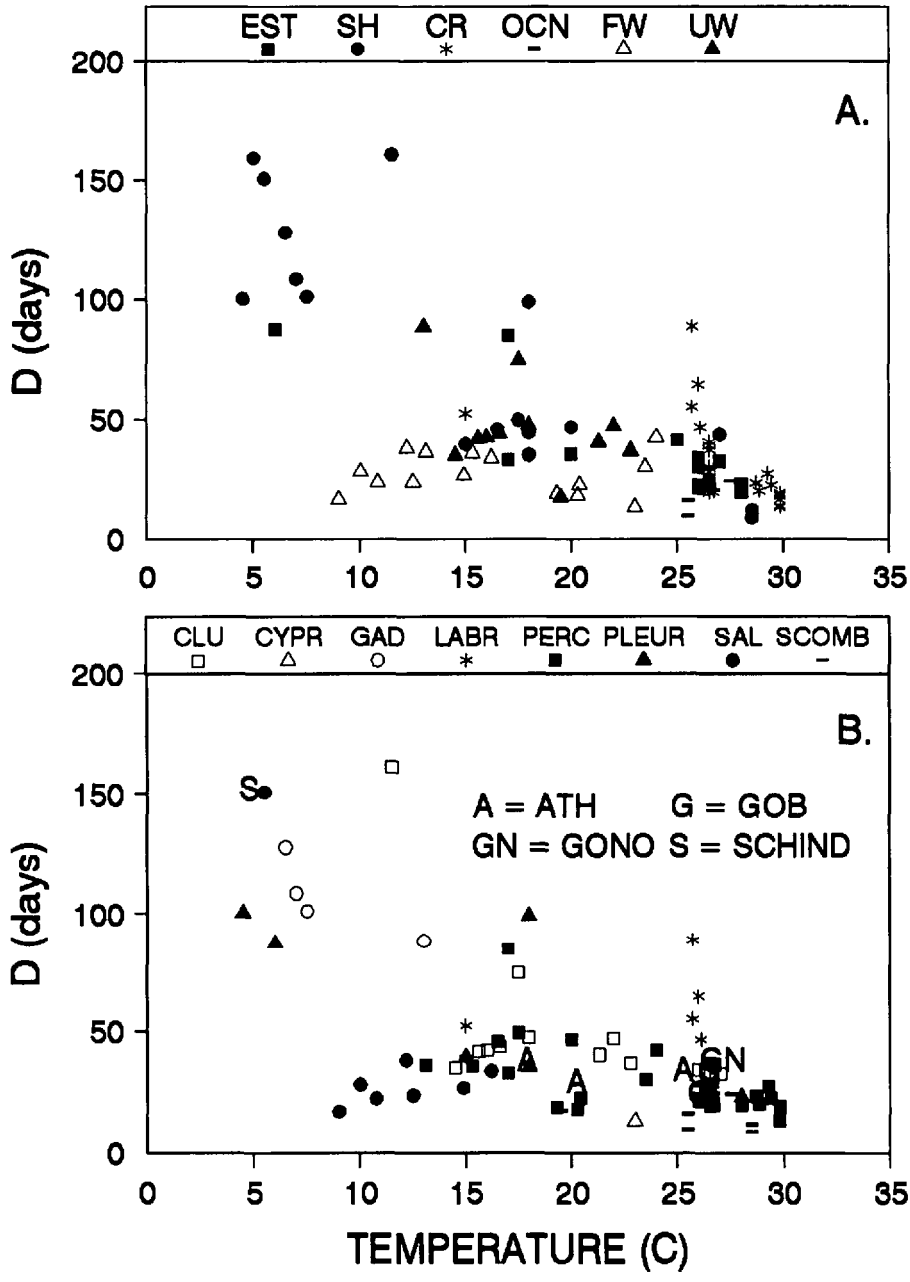


Figure 3. A. Ecosystem- and B. Taxon-specific, stage durations (D, days) of teleost larvae in relation to temperature. See Figure 1 for keys and explanations.

*Growth (G).*—Weight-specific growth rates, which ranged from $0.02 \cdot d^{-1}$ (*Pleuronectes platessa*) to 0.79 (*Scomberomorus maculatus*) generally increased as temperature increased. The mean weight-specific growth coefficient of 106 species was 0.194 (Table 2). On average, $\bar{G}$ of teleost larvae increases by approximately 0.01 for each 1°C rise in temperature.

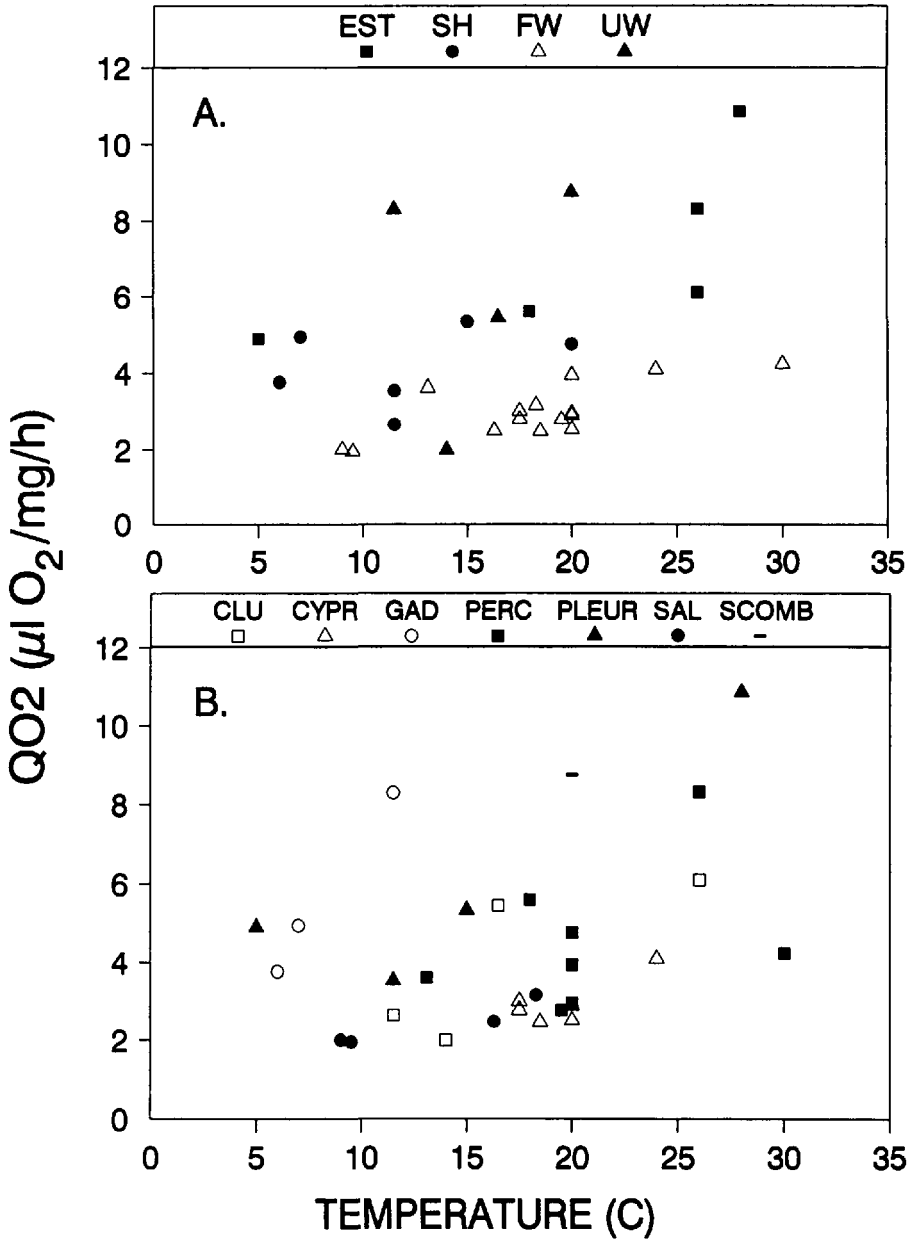


Figure 4. A. Ecosystem- and B. Taxon-specific, weight-specific oxygen uptake rate ($QO_2$, $\mu l\ O_2 \cdot mg^{-1} \cdot h^{-1}$) of teleost larvae in relation to temperature. See Figure 1 for keys and explanations.

The regression coefficients for the relationships of G on T for freshwater and marine taxa (Table 2) did not differ significantly ($P = 0.20$), although the coefficient for marine species (0.0106) appeared to be higher than that of freshwater species (0.0052). The temperature-adjusted $\bar{G}$ values for freshwater and marine taxa, 0.177 and 0.200, respectively, do not differ significantly (ANCOVA, $P = 0.30$).

The adjusted, ecosystem-specific $\bar{G}$ for the marine larvae were: coral reef: 0.159; estuary: 0.195; upwelling: 0.242; oceanic: 0.256; and shelf: 0.269. These means

Table 1. Teleost larvae. Ecosystem-specific and taxon-specific means of variables that were analyzed. (Except for "All Data," means for each category are the temperature-adjusted values from analyses of covariance.)

| Data set | G | Z | D | $K_1$ | $QO_2$ | I* | A |
|---|---|---|---|---|---|---|---|
| All data | 0.194 | 0.222 | 33.06 | 0.301 | 4.35 | 0.530 | 0.65 (18°) |
| Freshwater | 0.177 | 0.160 | 20.65 | 0.319 | 2.79 | 0.458 | 0.56 |
| Marine | 0.200 | 0.239 | 36.14 | 0.291 | 5.90 | 0.572 | 0.65 |
| Marine ecosystems | | | | | | | |
| Estuarine | 0.195 | 0.266 | 35.86 | 0.241 | 6.40 | 0.680 | 0.57 |
| Shelf | 0.269 | 0.250 | 34.14 | 0.296 | 4.78 | 0.477 | 0.54 |
| Upwelling | 0.242 | 0.184 | 36.43 | 0.368 | 6.16 | 0.647 | 0.75 |
| Oceanic | 0.256 | — | 25.94 | — | — | — | — |
| Coral reef | 0.159 | — | 35.88 | — | — | — | — |
| Taxa | | | | | | | |
| Clupeiformes | 0.196 | 0.179 | 43.85 | 0.308 | 4.04 | 0.620 | 0.59 |
| Cypriniformes | 0.162 | — | 14.76 | 0.305 | 2.34 | 0.347 | 0.52 |
| Salmoniformes | 0.195 | 0.244 | 19.59 | 0.256 | 3.28 | 0.589 | 0.47 |
| Gadiformes | 0.196 | 0.265 | 45.71 | 0.325 | 7.77 | 0.422 | 0.82 |
| Percoidei | 0.204 | 0.221 | 29.92 | 0.353 | 3.62 | 0.538 | 0.63 |
| Labroidei | 0.108 | — | 54.20 | — | — | — | — |
| Gobioidei | 0.076 | — | 45.08 | — | — | — | — |
| Scombroidei | 0.329 | 0.342 | 22.54 | 0.319 | 8.03 | 0.973 | 0.65 |
| Pleuronectiformes | 0.188 | 0.309 | 35.32 | 0.214 | 6.65 | 0.625 | 0.54 |

* Values given here are calculated from actual $\bar{G}$ and $\bar{K}$ values. They are the $I_A$ values from Table 7. The alternative, and more general "expected" ingestion $I_E$ values, were calculated from the growth-temperature relationships (Table 2) and $\bar{K}_1$ values (Table 6) (see Methods). The $I_A$ and $I_E$ relationships are illustrated in Figure 15.

differed significantly ($P < 0.05$). Without adjustment, G of coral reef species was high (0.228), but the adjusted $\bar{G}$ of coral reef species was lower than that of larvae from the other marine ecosystems, except estuarine, when the temperature effect was removed (Table 2).

The linear relationships between weight-specific growth coefficient (G) and temperature (T) were significant for the shelf, estuary, and coral reef ecosystems (Table 2, Fig. 1A). In these cases, G increased by 0.01 to 0.02 per 1°C increase in T. There was no significant correlation between G and T for larvae from oceanic and upwelling systems, probably because the available temperature ranges were small for these analyses.

Most taxa had similar temperature-adjusted $\bar{G}$, but there were some significant differences among the nine taxonomic categories (Table 2). Goby larvae had lower $\bar{G}$ values than other taxa except labrids, while scombrids had highest $\bar{G}$ (Figs. 1B, 5). Most of the goby and labrid larvae were coral reef species. If these taxa were removed from the coral reef data, adjusted $\bar{G}$ for coral reef larvae would increase from 0.159 to 0.188, but it would remain the lowest ecosystem $\bar{G}$, although no longer significantly lower (ANCOVA, $P > 0.20$).

*Mortality (Z).*—Instantaneous mortality coefficients ranged from $0.05 \cdot d^{-1}$ (*Pleuronectes platessa*) to 0.52 (*Scomber scombrus*) and generally increased as temperature increased. The unadjusted mean for 33 taxa was $\bar{Z} = 0.222$ (= $19.9\% \cdot d^{-1}$). There was a significant relationship ($P = 0.0001$) between Z and temperature (T) for the 33 taxa (Table 3, Fig. 2). The mortality coefficient, like that for growth, increased by approximately 0.01 for each 1°C temperature increase.

There was no significant regression of Z on T for the freshwater fishes, for which only seven estimates of Z were available ($P > 0.50$) (Table 3, Fig. 2A). The linear

Table 2. Weight-specific growth coefficient (G, $d^{-1}$) and its relationship to temperature (T, °C) for all data and for subsets of the data distinguished by ecosystem and taxa. When significant ($\alpha = 0.10$), linear regression equations and related parameters are provided. Adjusted means are based upon analysis of covariance with temperature as covariate. Identical superscripts on adjusted means indicate no significant difference (GLM least square means comparison). $S_b$ = standard error of the regression coefficient

| Data set | Regression equation | *P* | N | $S_b$ | $r^2$ | Mean | SE | Adjusted mean | SE |
|---|---|---|---|---|---|---|---|---|---|
| All data | G = −0.0226 + 0.0102T | <0.0001 | 106 | 0.0013 | .36 | 0.194 | 0.009 | — | — |
| Marine | G = −0.230 + 0.0106T | <0.0001 | 80 | 0.0016 | .35 | 0.211 | 0.011 | $0.200^{a}$ | 0.011 |
| Freshwater | G = 0.0511 + 0.0052T | <0.05 | 26 | 0.0023 | .17 | 0.142 | 0.011 | $0.177^{a}$ | 0.019 |
| Estuary | G = −0.0236 + 0.0098T | <0.01 | 11 | 0.0029 | .55 | 0.195 | 0.019 | $0.195^{abc}$ | 0.029 |
| Shelf | G = −0.0938 + 0.0169T | <0.005 | 20 | 0.0037 | .54 | 0.178 | 0.017 | $0.269^{cd}$ | 0.025 |
| Upwelling | n.s. | >0.25 | 11 | — | — | 0.178 | 0.022 | $0.242^{bcd}$ | 0.031 |
| Oceanic | n.s. | >0.30 | 7 | — | — | 0.312 | 0.028 | $0.256^{bcd}$ | 0.037 |
| Coral reef | G = −0.1300 + 0.0132T | <0.05 | 31 | 0.0059 | .15 | 0.228 | 0.016 | $0.159^{a}$ | 0.020 |
| Clupeiformes | G = 0.0410 + 0.0069T | <0.05 | 11 | 0.0028 | .37 | 0.173 | 0.013 | $0.196^{cde}$ | 0.023 |
| Cypriniformes | n.s. | >0.20 | 9 | — | — | 0.147 | 0.027 | $0.162^{bcde}$ | 0.026 |
| Salmoniformes | G = −0.0293 + 0.0110T | <0.05 | 9 | 0.0029 | .67 | 0.101 | 0.012 | $0.195^{cde}$ | 0.031 |
| Gadiformes | G = 0.0850 − 0.0019T | <0.10 | 4 | 0.0006 | .84 | 0.069 | 0.002 | $0.196^{bcde}$ | 0.045 |
| Percoidei | G = −0.0169 + 0.0103T | <0.0001 | 38 | 0.0021 | .40 | 0.237 | 0.011 | $0.204^{cde}$ | 0.014 |
| Labroidei | n.s. | >0.85 | 8 | — | — | 0.142 | 0.020 | $0.108^{abce}$ | 0.028 |
| Gobioidei | n.s. | >0.55 | 4 | — | — | 0.126 | 0.018 | $0.076^{ab}$ | 0.040 |
| Scombroidei | G = −0.2252 + 0.0236T | <0.10 | 11 | 0.0124 | .29 | 0.366 | 0.049 | $0.329^{f}$ | 0.024 |
| Pleuronectiformes | G = 0.0073 + 0.0079T | <0.05 | 6 | 0.0026 | .70 | 0.124 | 0.020 | $0.188^{cde}$ | 0.034 |

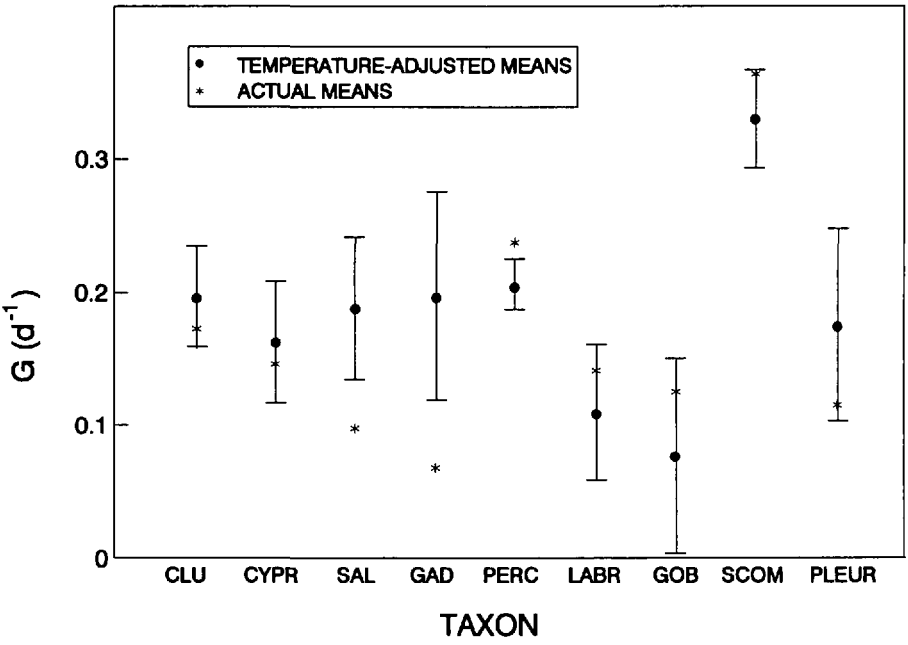


Figure 5. Taxon-specific mean weight-specific growth coefficients (G) of teleost larvae. ● Temperature-adjusted ±2 standard errors. * Actual means. See Figure 1 for taxon keys and explanations.

regression equation for marine species (N = 26) was significant ($P = 0.0001$). Temperature-adjusted $\bar{Z}$ of marine larvae ($\bar{Z} = 0.239$) was significantly higher than that of freshwater larvae ($\bar{Z} = 0.160$) (Table 3; ANCOVA, $P < 0.10$). The mean dry weight at hatch of freshwater species in this particular analysis, 247 μg, was significantly ($P < 0.05$) heavier than that of the marine species, 47 μg, and a probable factor affecting mortality rates.

Ecosystem-specific values of adjusted $\bar{Z}$ for larvae in three systems (Table 3, Fig. 6) were: upwelling: 0.184; shelf: 0.250; and estuary: 0.266. These means did not differ significantly (ANCOVA, $P > 0.15$). Regressions of Z on T were significant for larvae from estuaries and shelves, but not for the upwelling system (Table 3), where data were restricted to a narrow temperature range. Regression coefficients (slopes) relating Z and T for the estuary (0.0137) and shelf (0.0130) larvae were similar (ANCOVA, $P = 0.85$).

Although adjusted $\bar{Z}$ values for taxonomic groups ranged widely from 0.179 to 0.342 (Table 3, Fig. 7), the GLM (least square means) pairwise comparisons indicated that only the highest $\bar{Z}$ (Scombroidei) differed significantly ($P < 0.10$) from the lowest $\bar{Z}$ (Clupeiformes).

*Stage Duration (D).*—The estimated larval stage durations of 94 teleost species ranged from 9 (*Scomberomorus maculatus*) to 161 (*Clupea harengus*) days. Mean D for all taxa was 33.1 d (Table 4). Larval stage duration declines rapidly as temperature increases. The relationship between D and T (Fig. 3) for all data was described by a power function (Table 4).

Mean temperature-adjusted stage duration was 15.4 d shorter for freshwater larvae (20.7 d) than for marine larvae (36.1 d) (Table 4, Fig. 8). The temperature-adjusted $\bar{D}$ differed significantly between the freshwater and marine larvae (ANCOVA, $P < 0.0001$).

Table 3. Instantaneous daily mortality coefficient (Z, $d^{-1}$) and its relationship to temperature (T, °C) for all data and for subsets of the data distinguished by ecosystem and taxa. When significant ($\alpha = 0.10$), linear regression equations and related parameters are provided. Adjusted means are based upon analysis of covariance with temperature as the covariate. Identical superscripts on adjusted means indicate no significant difference (GLM least square means comparison). $S_b$ = standard error of the regression coefficient

| Data set | Regression equation | $P$ | N | $S_b$ | $r^2$ | Mean | SE | Adjusted mean | SE |
|---|---|---|---|---|---|---|---|---|---|
| All data | $Z = 0.0156 + 0.0119T$ | 0.0001 | 33 | 0.0027 | 0.38 | 0.222 | 0.019 | — | — |
| Marine | $Z = 0.0149 + 0.0129T$ | 0.0001 | 26 | 0.0029 | 0.46 | 0.222 | 0.021 | $0.239^{a}$ | 0.021 |
| Freshwater | n.s. | >0.50 | 7 | — | — | 0.169 | 0.036 | $0.160^{b}$ | 0.040 |
| Estuary | $Z = 0.0277 + 0.0137T$ | <0.005 | 6 | 0.0057 | 0.59 | 0.319 | 0.039 | $0.266^{a}$ | 0.044 |
| Shelf | $Z = 0.0314 + 0.0130T$ | <0.05 | 13 | 0.0042 | 0.46 | 0.225 | 0.037 | $0.250^{a}$ | 0.029 |
| Upwelling | n.s. | >0.70 | 7 | — | — | 0.186 | 0.028 | $0.184^{a}$ | 0.041 |
| Clupeiformes | n.s. | >0.10 | 14 | — | — | 0.235 | 0.026 | $0.179^{ab}$ | 0.033 |
| Salmoniformes | — | — | 1 | — | — | 0.200 | — | $0.244^{ab}$ | 0.111 |
| Gadiformes | n.s. | >0.25 | 4 | — | — | 0.110 | 0.013 | $0.265^{ab}$ | 0.068 |
| Percoidei | $Z = -0.1536 + 0.0211T$ | <0.005 | 10 | 0.0050 | 0.74 | 0.246 | 0.030 | $0.221^{ab}$ | 0.036 |
| Pleuronectiformes | n.s. | — | 2 | — | — | 0.140 | — | $0.309^{ab}$ | 0.089 |
| Scombroidei | n.s. | — | 2 | — | — | 0.330 | — | $0.342^{b}$ | 0.078 |

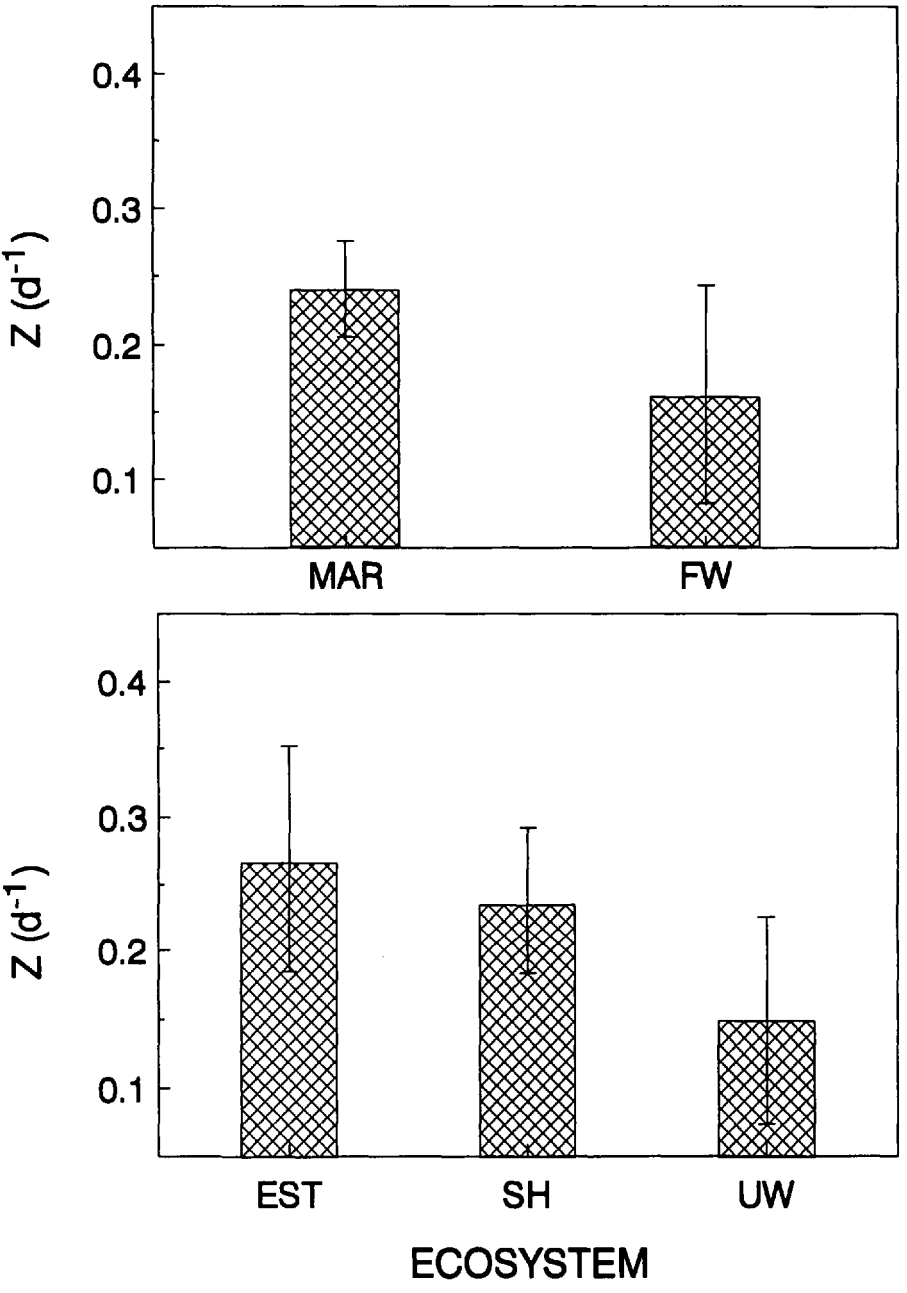


Figure 6. Temperature-adjusted, ecosystem-specific mean instantaneous mortality coefficients (Z) of teleost larvae. See Figure 1 for ecosystem keys and explanations.

The mean dry weights at hatch of freshwater and marine species in the stage-duration analysis were 384 $\mu$g and 48 $\mu$g, respectively. This seven-fold difference in weights at hatch partly accounted for the shorter $\bar{D}$ of freshwater larvae, because there was no difference in growth rates or sizes at metamorphosis of the marine

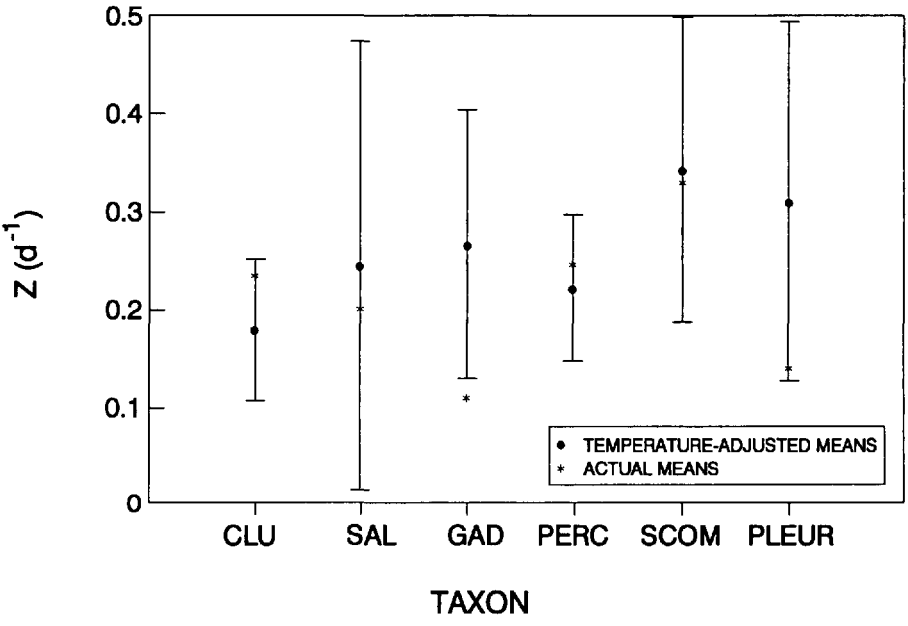


Figure 7. Taxon-specific mean instantaneous mortality coefficients (Z) of teleost larvae. ● Temperature-adjusted ±2 standard errors. * Actual means. See Figure 1 for taxon keys and explanations.

and freshwater species. At $\bar{G} = 0.19$, the average growth rate of marine teleost larvae, it would require 11.0 d for a 48-μg (weight at hatch) larva to grow to 384 μg, the hatch weight of a freshwater larva.

The marine ecosystem $\bar{D}$ values ranged from 20.0 d (oceanic) to 55.7 d (shelf) (Table 4). After temperature adjustment, the $\bar{D}$ were similar (34.1 to 36.4 d) for larvae from all marine systems (Table 4, Fig. 8) except the oceanic (25.9 d), which was represented primarily by fast growing tuna larvae. There was no significant correlation between D and T for larvae from upwelling or oceanic ecosystems, probably because the temperature ranges represented were small (Fig. 3A).

Cypriniform, salmoniform, and scombroid larvae have short temperature-adjusted $\bar{D}$ compared to other taxonomic groups (Table 4, Fig. 9). Clupeiform, gadiform, gobioid, and labroid larvae have long stage durations. The unadjusted $\bar{D}$ ranged from 13.5 d for cypriniform larvae to 105.2 d for gadiform larvae. Temperature-adjusted $\bar{D}$ were less variable, ranging from 14.8 d for cypriniform to 54.2 d for labroid larvae.

*Weight-Specific Oxygen Uptake ($QO_2$).*—Values of $QO_2$ ranged from 2.0 (*Coregonus albula, C. lavaretus* and *Sardinops caerulea*) to 10.9 (*Achirus lineatus*) μl $O_2 \cdot mg^{-1} \cdot h^{-1}$ and increased as temperature increased for the 30 species analyzed (Table 5, Fig. 4). Mean $QO_2$ for all larvae was 4.35 μl $O_2 \cdot mg^{-1} \cdot h^{-1}$.

Linear regressions for freshwater and marine taxa differed strongly in their $QO_2$ on T relationships (Table 5, Fig. 4A). The temperature-adjusted mean $QO_2$ (Fig. 10) for larvae from marine systems (5.90) was more than twice that of freshwater larvae (2.79), a very significant difference (ANCOVA, $P < 0.0001$).

For species in the $QO_2$ analysis, mean weight at hatch of freshwater larvae was 338 μg (range = 107 to 1,200 μg) and that of marine larvae was 44 μg (range = 8 to 200 μg), a 7.7-fold difference in mean weights. Because $QO_2$ is expected to

Table 4. Larval stage duration (D, d) and its relationship to temperature (T, °C) for all data and for subsets of the data distinguished by ecosystem and taxa. When significant ($\alpha$ = 0.10), power function regression equations and related parameters are provided. Adjusted means are based upon analysis of covariance with temperature as the covariate. Identical superscripts on adjusted means indicate no significant difference (GLM least square means comparison). $S_b$ = standard error of the regression coefficient

| Data set | Regression equation | $P$ | N | $S_D$ | $r^2$ | Mean | SE | Ajusted mean | SE |
|---|---|---|---|---|---|---|---|---|---|
| All data | $D = 515.94T^{-0.9213}$ | <0.0001 | 94 | 0.1057 | 0.45 | 33.06 | 1.05 | — | — |
| Marine | $D = 971.63T^{-1.1024}$ | <0.0001 | 79 | 0.1012 | 0.61 | 34.52 | 1.05 | 36.14[a] | 1.05 |
| Freshwater | n.s. | >0.50 | 15 | — | — | 26.36 | 1.09 | 20.65[b] | 1.12 |
| Estuary | $D = 462.28T^{-0.8453}$ | 0.005 | 11 | 0.2291 | 0.60 | 35.48 | 1.10 | 35.86[ab] | 1.13 |
| Shelf | $D = 997.46T^{-1.1161}$ | <0.0001 | 19 | 0.1860 | 0.68 | 55.70 | 1.12 | 34.14[ab] | 1.12 |
| Upwelling | n.s. | >0.20 | 11 | — | — | 43.28 | 1.13 | 36.43[ab] | 1.14 |
| Oceanic | n.s. | >0.15 | 7 | — | — | 19.96 | 1.14 | 25.94[a] | 1.17 |
| Coral reef | $D = 22{,}064.80T^{-2.0372}$ | 0.001 | 31 | 0.5711 | 0.30 | 26.72 | 1.07 | 35.88[b] | 1.09 |
| Clupeiformes | $D = 1{,}393.16T^{-1.1608}$ | <0.05 | 12 | 0.4166 | 0.46 | 46.99 | 1.11 | 43.85[cd] | 1.11 |
| Cypriniformes | n.s. | — | 1 | — | — | 13.50 | — | 14.76[a] | 1.43 |
| Salmoniformes | $D = 722.77T^{-1.2745}$ | <0.10 | 8 | 0.5784 | 0.45 | 34.36 | 1.20 | 19.59[a] | 1.16 |
| Gadiformes | n.s. | >0.10 | 4 | — | — | 105.20 | 1.05 | 45.71[cd] | 1.25 |
| Percoidei | $D = 1{,}061.70T^{-1.1770}$ | <0.0001 | 35 | 0.2201 | 0.46 | 24.89 | 1.05 | 29.92[b] | 1.07 |
| Labroidei | n.s. | >0.60 | 8 | — | — | 44.87 | 1.18 | 54.20[d] | 1.14 |
| Gobioidei | n.s. | >0.45 | 4 | — | — | 34.75 | 1.08 | 45.08[cd] | 1.20 |
| Scombroidei | n.s. | <0.10 | 11 | — | — | 18.49 | 1.14 | 22.54[a] | 1.12 |
| Pleuronectiformes | $D = 286.74T^{-0.6565}$ | <0.10 | 6 | 0.2972 | 0.55 | 54.83 | 1.24 | 35.32[bc] | 1.18 |

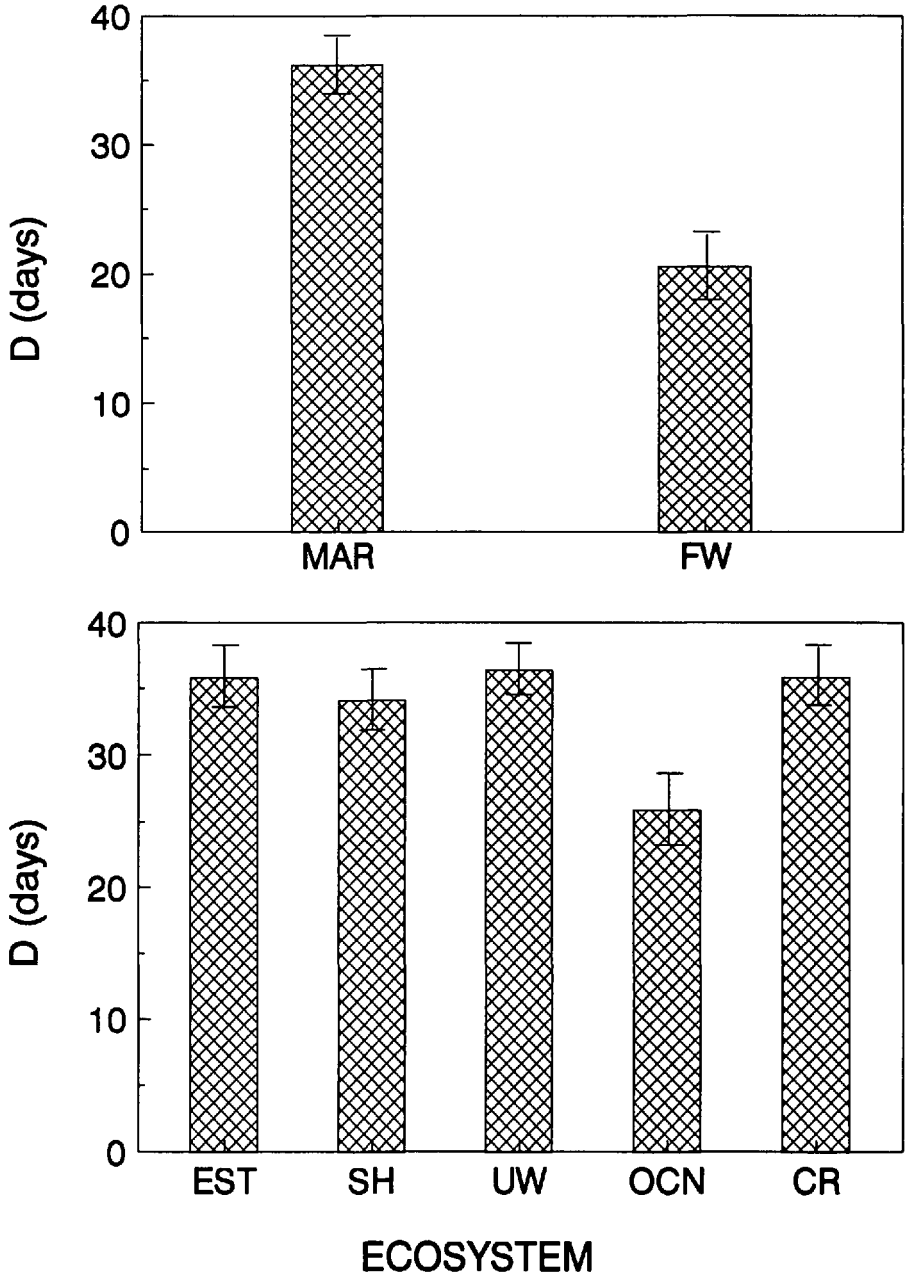


Figure 8. Temperature-adjusted, ecosystem-specific mean stage durations (D) of teleost larvae. See Figure 1 for ecosystem keys and explanations.

decline significantly as weight increases, the weight difference appears to be sufficient to account for the difference in mean $QO_2$ between freshwater and marine larvae (Fig. 11).

There were no demonstrable differences in larval $QO_2$ among marine ecosystems (Table 5, Fig. 10) for the 15 taxa that were included. Temperature-adjusted mean

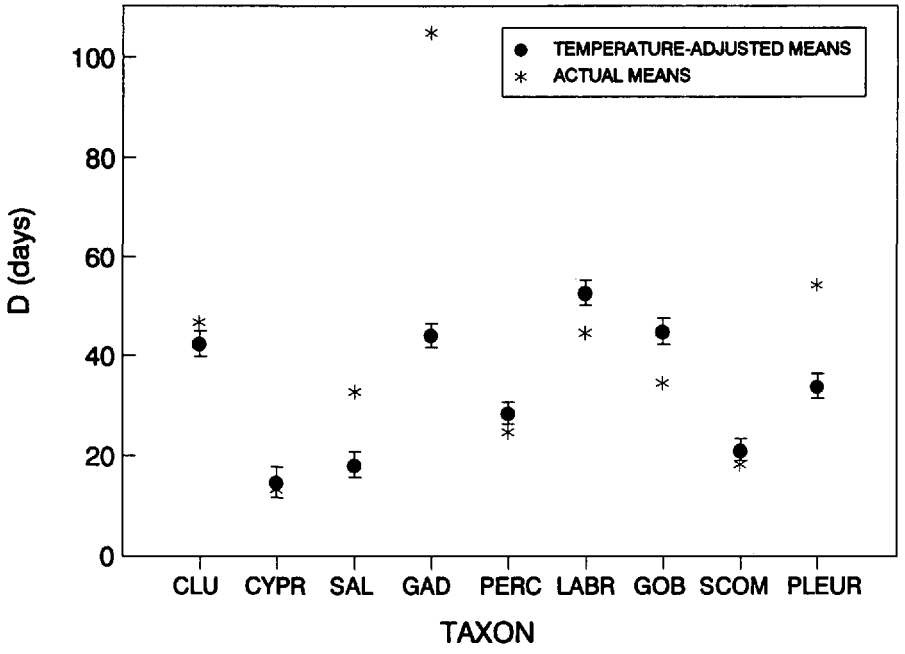


Figure 9. Taxon-specific mean stage durations (D) of teleost larvae. ● Temperature-adjusted ±2 standard errors. * Actual means. See Figure 1 for taxon keys and explanations.

$QO_2$ ranged from 4.78 to 6.40 $\mu l\ O_2 \cdot mg^{-1} \cdot h^{-1}$ for larvae from estuary, shelf, and upwelling systems.

Taxa dominated by marine species generally had higher $QO_2$ than those dominated by freshwater species. The temperature-adjusted means ranged from 2.34 for cypriniform larvae to 8.03 for scombroid larvae (Table 5, Fig. 12) and differed significantly (ANCOVA, $P < 0.0001$). The scombroid, pleuronectiform, and gadiform larvae had higher adjusted mean $QO_2$ than other larvae (ANCOVA, $P < 0.0001$).

*G/Z Ratio.*—The ratio G/Z, an indicator of population biomass increase or decrease during a life stage, ranged from 0.27 to 2.43 and was not correlated with temperature ($P > 0.35$) (Fig. 13). Mean G/Z of 22 taxa for which estimates of G and Z were available (Appendix) was 0.94 (SE = 0.13). The mean G/Z for 5 freshwater species was 1.13 (SE = 0.32) and that for 17 marine species was 0.89 (SE = 0.14). These means were not significantly different ($P > 0.40$). The overall mean G/Z, and G/Z means for marine and freshwater larvae did not differ significantly from a value of 1.0 (Student's $t$-test, $P > 0.25$ in all cases), indicating that population biomasses are relatively constant during the teleost larval stage. The ratio of the regression coefficients from the G on T (Table 2) and Z on T (Table 3) regressions, another index of G/Z, was 0.86 for all larvae, an indication that the ratio is near or slightly less than 1.0.

*Gross Growth Efficiency ($K_1$).*—There was no significant relationship between $K_1$ and temperature (Fig. 14). Mean $K_1$ (±95% confidence limits) for all data was 0.301 ± 0.042 (Table 6). The adjusted $\bar{K}_1$ values of larvae from marine and freshwater ecosystems were 0.291 and 0.319, respectively, values not significantly different ($P > 0.50$). Values of adjusted $\bar{K}_1$ for larvae from estuaries, shelf, and

Table 5. Weight-specific oxygen uptake ($QO_2$, $\mu l\ O_2 \cdot mg^{-1} \cdot h^{-1}$) and its relationship to temperature (T, °C) for all data and for subsets of the data distinguished by ecosystem and taxon. When significant ($\alpha = 0.10$), linear regression equations and related parameters are provided. Adjusted means are based upon analysis of covariance with temperature as the covariate. Identical superscripts on adjusted means indicate no significant difference (GLM least square means comparison). $S_b$ = standard error of the regression coefficient

| Data set | Regression equation | $P$ | N | $S_b$ | $r^2$ | Mean | SE | Adjusted mean | SE |
|---|---|---|---|---|---|---|---|---|---|
| All data | $QO_2 = 2.2896 + 0.1209T$ | <0.10 | 30 | 0.0623 | 0.12 | 4.35 | 0.39 | — | — |
| Marine | $QO_2 = 2.4328 + 0.2067T$ | <0.05 | 15 | 0.0727 | 0.38 | 5.69 | 0.51 | 5.90[a] | 0.38 |
| Freshwater | $QO_2 = 1.2069 + 0.0983T$ | <0.005 | 15 | 0.0259 | 0.53 | 3.00 | 0.13 | 2.79[b] | 0.38 |
| Estuary | n.s. | >0.15 | 5 | — | — | 7.15 | 0.86 | 6.40[a] | 1.00 |
| Shelf | n.s. | >0.50 | 6 | — | — | 4.17 | 0.44 | 4.78[a] | 0.89 |
| Upwelling | n.s. | >0.70 | 4 | — | — | 6.13 | 1.84 | 6.16[a] | 1.01 |
| Clupeiformes | n.s. | >0.15 | 4 | — | — | 4.05 | 0.71 | 4.04[bc] | 0.67 |
| Cypriniformes | $QO_2 = -0.6995 + 0.1871T$ | <0.10 | 6 | 0.0768 | 0.60 | 2.96 | 0.17 | 2.34[b] | 0.57 |
| Salmoniformes | $QO_2 = 0.9259 + 0.1116T$ | <0.10 | 4 | 0.0290 | 0.88 | 2.41 | 0.12 | 3.28[abc] | 0.70 |
| Gadiformes | $QO_2 = -0.8562 + 0.7994T$ | <0.10 | 3 | 0.0659 | 0.99 | 5.67 | 0.16 | 7.77[d] | 0.90 |
| Percoidei | n.s. | >0.30 | 8 | — | — | 4.53 | 0.63 | 3.62[abc] | 0.52 |
| Scombroidei | n.s. | — | 1 | — | — | 8.75 | — | 8.03[d] | 1.36 |
| Pleuronectiformes | n.s. | >0.10 | 4 | — | — | 6.16 | 0.92 | 6.65[d] | 0.68 |

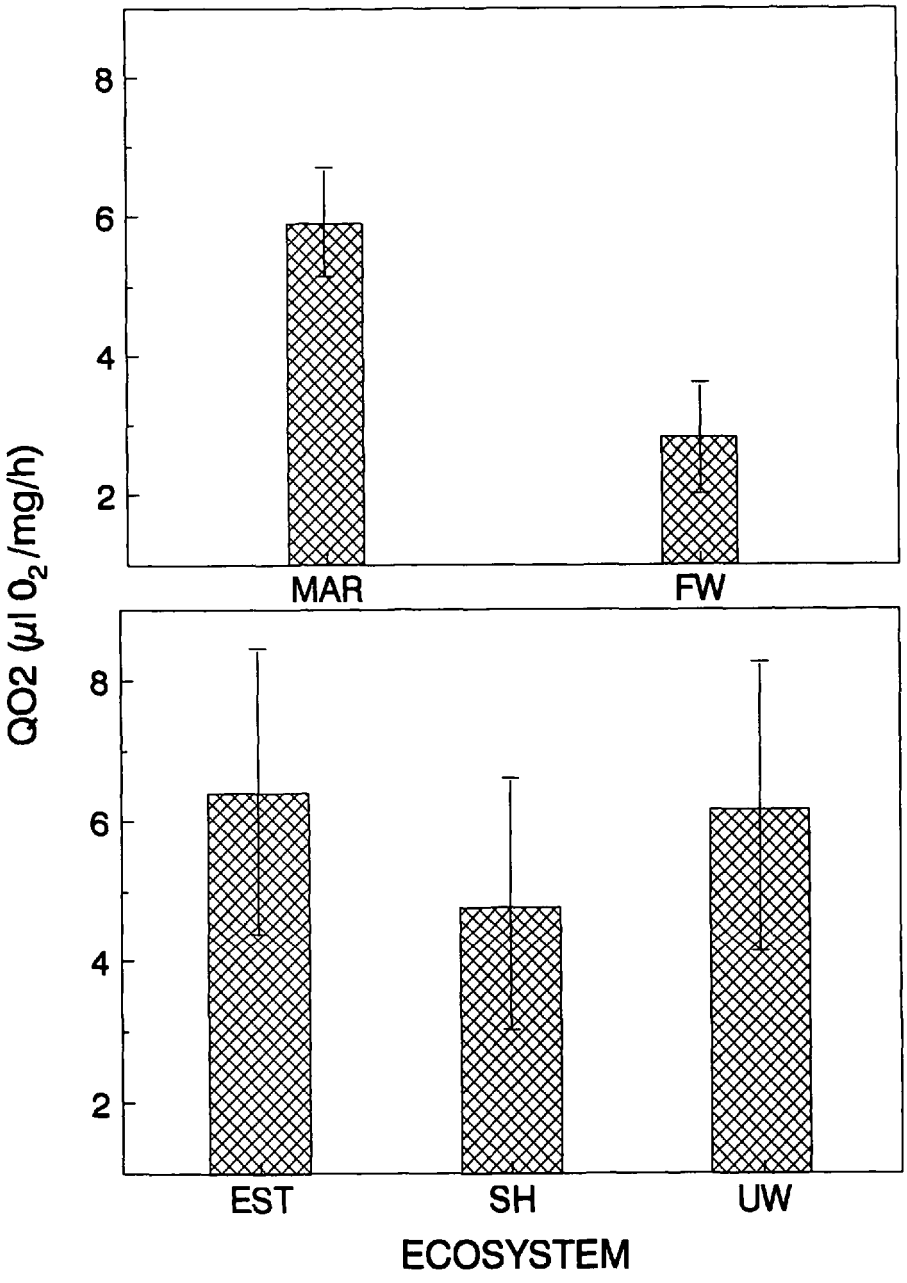


Figure 10. Temperature-adjusted, ecosystem-specific mean weight-specific oxygen uptake rates ($QO_2$) of teleost larvae. See Figure 1 for ecosystem keys and explanations.

upwelling ecosystems were 0.241, 0.296, and 0.368, respectively, and did not differ significantly (ANCOVA, $P > 0.20$) (Table 6).

There also were no clear differences in larval $\bar{K}_1$ among the taxonomic groups. Adjusted values ranged from 0.214 (Pleuronectiformes) to 0.353 (Percoidei) (Table 6). The temperature-adjusted $\bar{K}_1$ values and standard errors generally over-

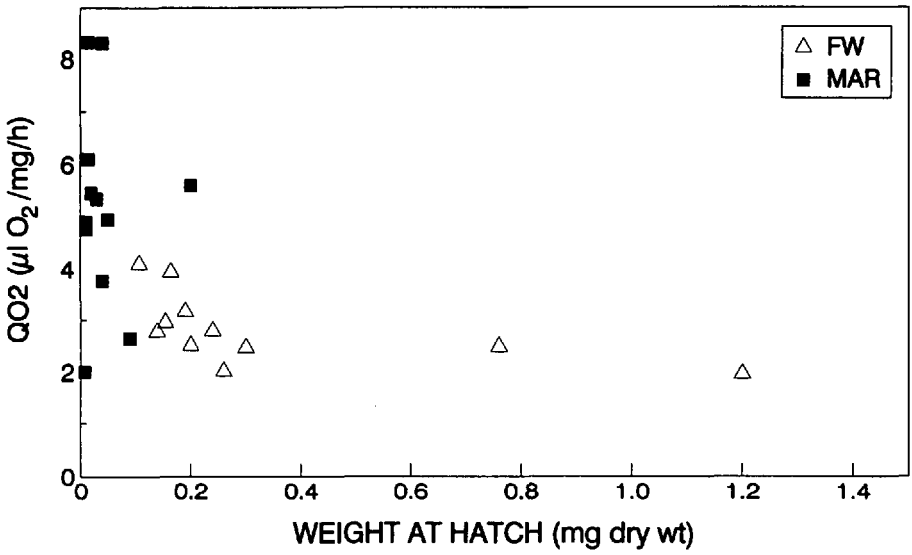


Figure 11. The relationship between weight-specific oxygen uptake rate ($QO_2$) and dry weight at hatch ($W_o$) for marine and freshwater fish larvae. Values are not adjusted for temperature effects. ■ = marine larvae. □ = freshwater larvae.

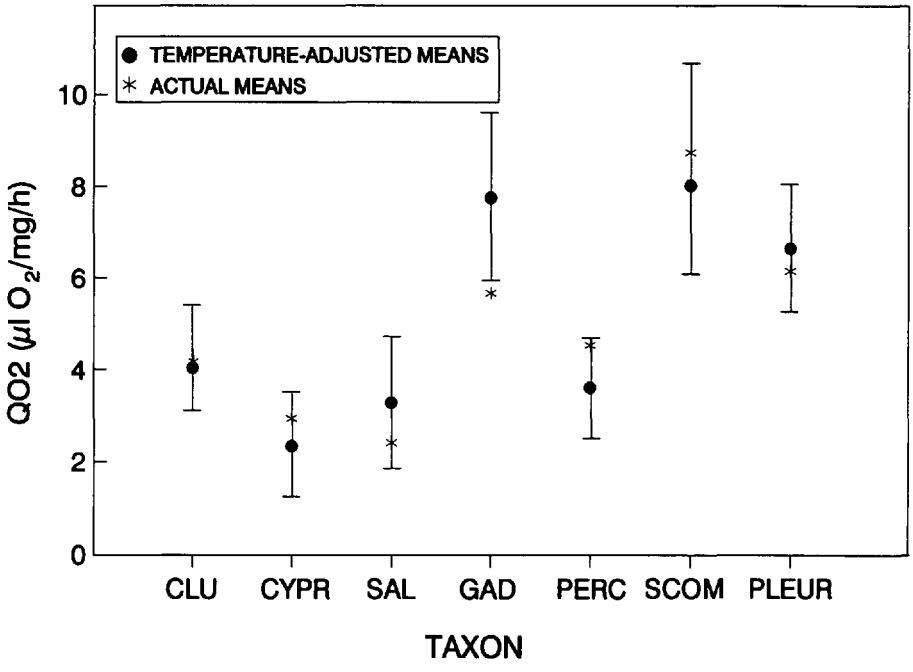


Figure 12. Taxon-specific mean weight-specific oxygen uptake rates $\mu l\ O_2 \cdot mg^{-1} \cdot h^{-1}$ of teleost larvae. ● Temperature-adjusted ±2 standard errors. * Actual means. See Figure 1 for taxon keys and explanations.

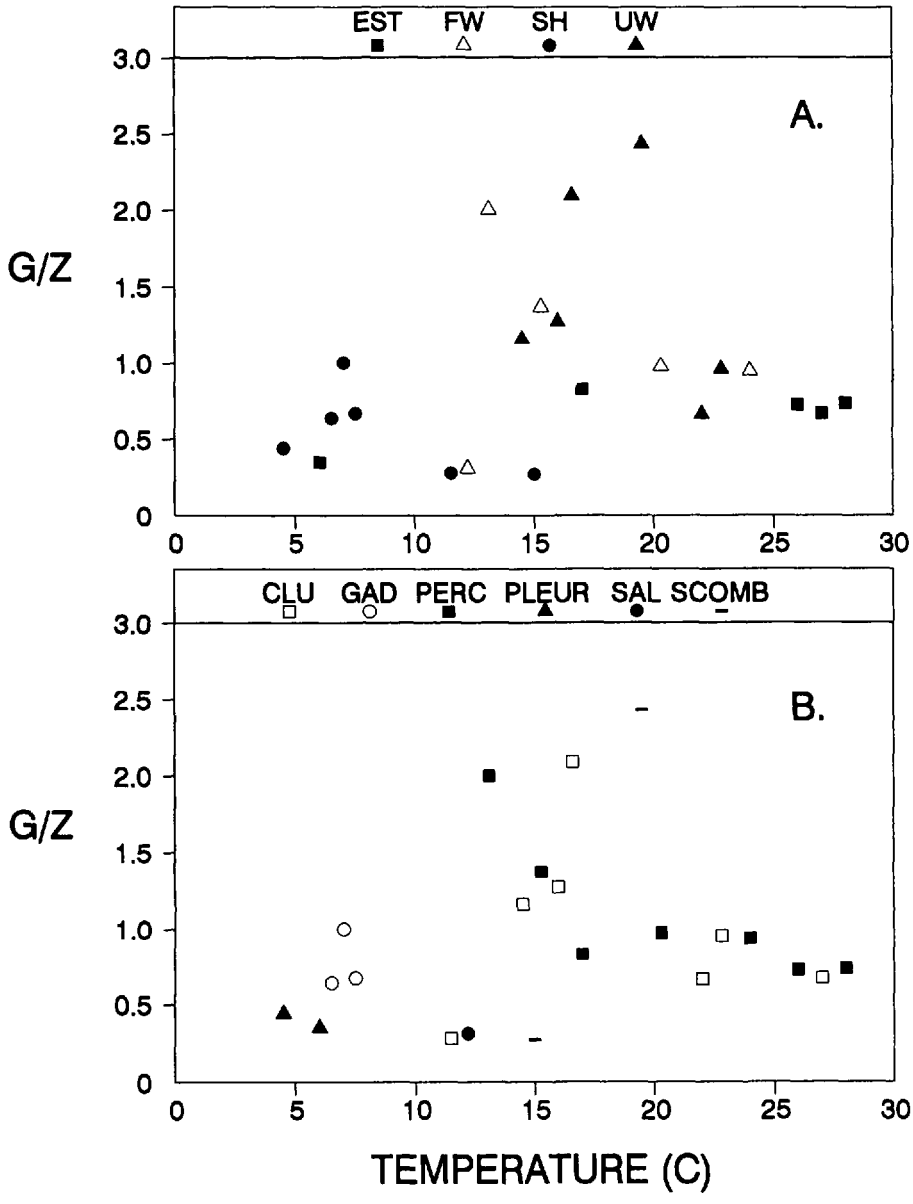


Figure 13. A. Ecosystem- and B. Taxon-specific, ratio of growth coefficient to mortality coefficient values (G/Z) of teleost larvae in relation to temperature. See Figure 1 for keys and explanations.

lapped. The ANCOVA did not detect an overall among-taxa difference in the $\bar{K}_1$ values ($P > 0.50$), but the paired means comparison procedure did indicate that $\bar{K}_1$ of percoid larvae was higher than $\bar{K}_1$ of pleuronectiforms ($P = 0.05$).

*Ingestion (I).*—The weight-specific ingestion rates required for teleost larvae to grow at their mean growth rates were calculated for the 22 taxa (Table 7, Fig. 15) for which estimates of both G and $K_1$ were available. Values of I (=G/$K_1$) ranged from 0.18 (*Clupea harengus*) to 1.16·d$^{-1}$ (*Anchoa mitchilli*). The mean I was

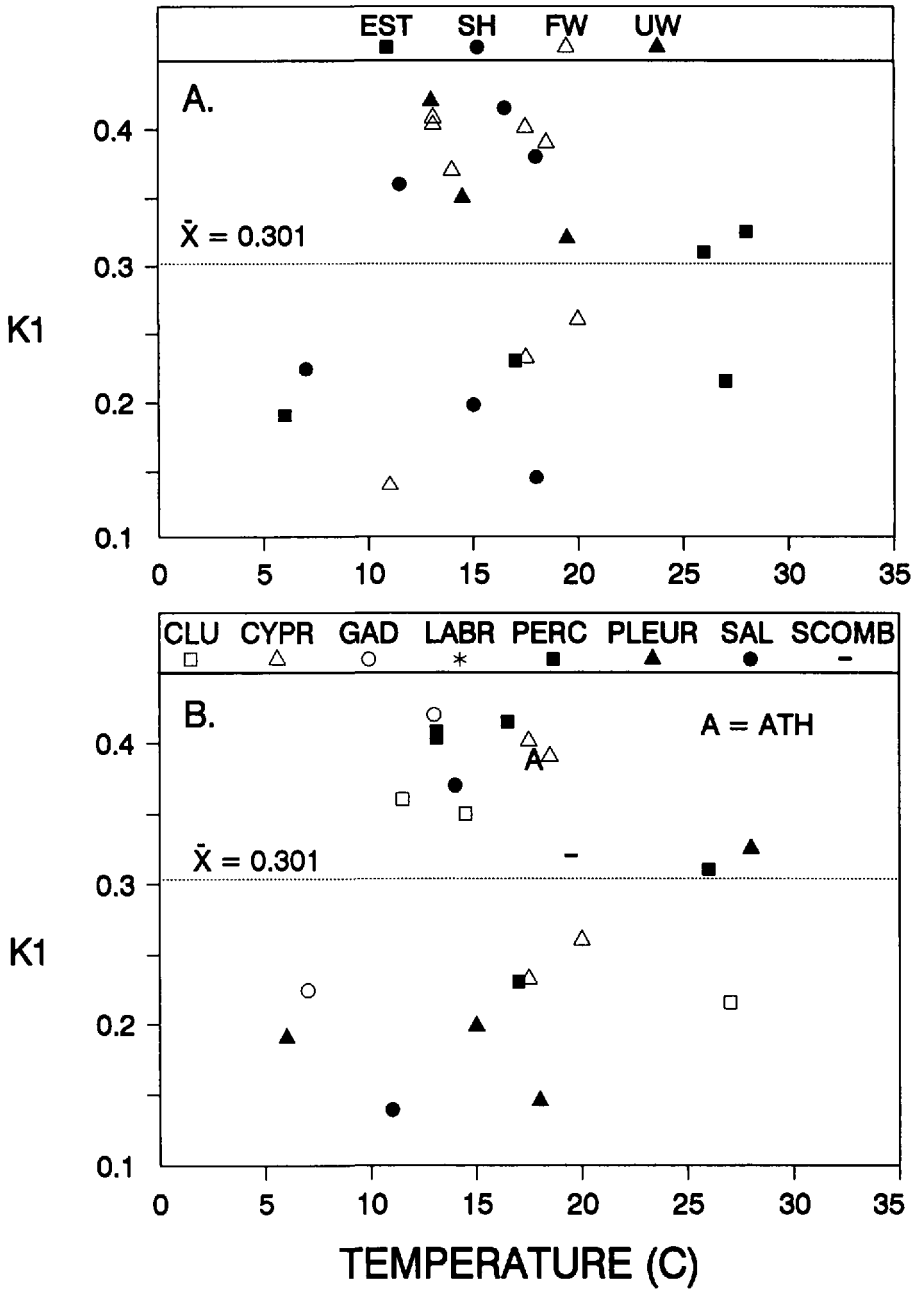


Figure 14. A. Ecosystem- and B. Taxon-specific, gross growth efficiencies ($K_1$) of teleost larvae in relation to temperature. See Figure 1 for keys and explanations.

$0.530 \cdot d^{-1}$, indicating that, on average, teleost larvae consume more than 50% of their body weight (dry weight basis) daily to grow at mean reported rates.

The two equations derived to describe the relationship between I and T for teleost larvae both indicated that weight-specific ingestion required to support mean growth rates increases by approximately 3% for each 1°C rise in T. The first

Table 6. Gross growth efficiency ($K_1$). Mean values for all larvae data, and mean values for larvae by ecosystem and taxon. Adjusted means are based upon analysis of covariance with temperature as the covariate. Identical superscripts on means indicate no significant difference (GLM least square means comparison)

| Data set | N | Mean | $S_x$ | Adjusted mean | $S_x$ |
|---|---|---|---|---|---|
| All data | 22 | 0.301 | 0.020 | — | — |
| Marine | 14 | 0.292 | 0.025 | 0.291[a] | 0.025 |
| Freshwater | 8 | 0.318 | 0.037 | 0.319[a] | 0.035 |
| Estuary | 5 | 0.254 | 0.027 | 0.241[ab] | 0.042 |
| Shelf | 6 | 0.287 | 0.046 | 0.296[abc] | 0.037 |
| Upwelling | 3 | 0.363 | 0.030 | 0.368[bc] | 0.051 |
| Clupeiformes | 3 | 0.308 | 0.008 | 0.308[ab] | 0.056 |
| Cypriniformes | 4 | 0.321 | 0.052 | 0.305[ab] | 0.049 |
| Salmoniformes | 2 | 0.255 | 0.116 | 0.256[ab] | 0.070 |
| Gadiformes | 2 | 0.322 | 0.098 | 0.325[ab] | 0.073 |
| Percoidei | 5 | 0.353 | 0.037 | 0.353[b] | 0.043 |
| Scombroidei | 1 | 0.320 | — | 0.319[ab] | 0.097 |
| Pleuronectiformes | 4 | 0.215 | 0.034 | 0.214[a] | 0.048 |

($I_A$) is the linear regression of I on T, obtained after estimating I values from reported G and $K_1$ estimates for the 22 taxa (Table 7, Fig. 15). The second ($I_E$) is the expected relationship, derived from the linear regression of G on T (Table 2) and $\bar{K}_1$ (see Methods) for all taxa (Fig. 15).

There were no significant differences in $\bar{I}$ among ecosystems. The temperature-adjusted $\bar{I}$ for marine fish larvae was 0.572 (SE = 0.065), while that for freshwater larvae was 0.458 (SE = 0.087) (Table 7). These means did not differ significantly (ANCOVA, $P > 0.30$). Temperature-adjusted $\bar{I}$ of larvae from estuarine, shelf, and upwelling marine systems also did not differ (Table 7; ANCOVA, $P > 0.50$).

Temperature-adjusted $\bar{I}$ did differ significantly among taxonomic groups, ranging from 0.347 (Cypriniformes) to 0.973 (Scombroidei) (Table 7, Fig. 16). Scombroid larvae have generally higher required $\bar{I}$ than the other taxa and significantly higher $\bar{I}$ than the cypriniform and gadiform larvae ($P < 0.08$).

Estimates of I were strongly affected by temperature. Values of I, calculated for 8, 18, and 28°C (Table 8) indicated that ecosystem- and taxon-specific ingestion rates required to support average growth generally are less than 35% of body weight at 8°C, increase to more than 50% at 18°C, and are near 100% at 28°C. Taxon-specific I at 28°C ranged from 77% (Percoidei) to 137% (Scombroidei) (Table 8).

*Energy Budgets.*—Temperature-specific energy budgets were calculated for 10, 18, and 28°C for all larvae, marine larvae and freshwater larvae (Table 9). Required ingestion increased by more than a factor of three for all larvae and marine larvae, and by a factor of two for freshwater larvae as temperature rose from 10 to 28°C. Caloric allocations to growth increased at higher temperatures but relative allocations (i.e., as a percentage) remained constant because $K_1$ did not change significantly with temperature. The $Q_{10}$ for growth of all larvae and marine larvae in the 10 to 28°C range was 1.95, but for freshwater larvae it was only 1.43. An obvious difference in energy budgets of marine and freshwater larvae was the relatively high allocation to metabolism by the marine larvae (Table 9). The $Q_{10}$ for metabolism was 1.40 for the marine and freshwater larvae. Predicted assim-

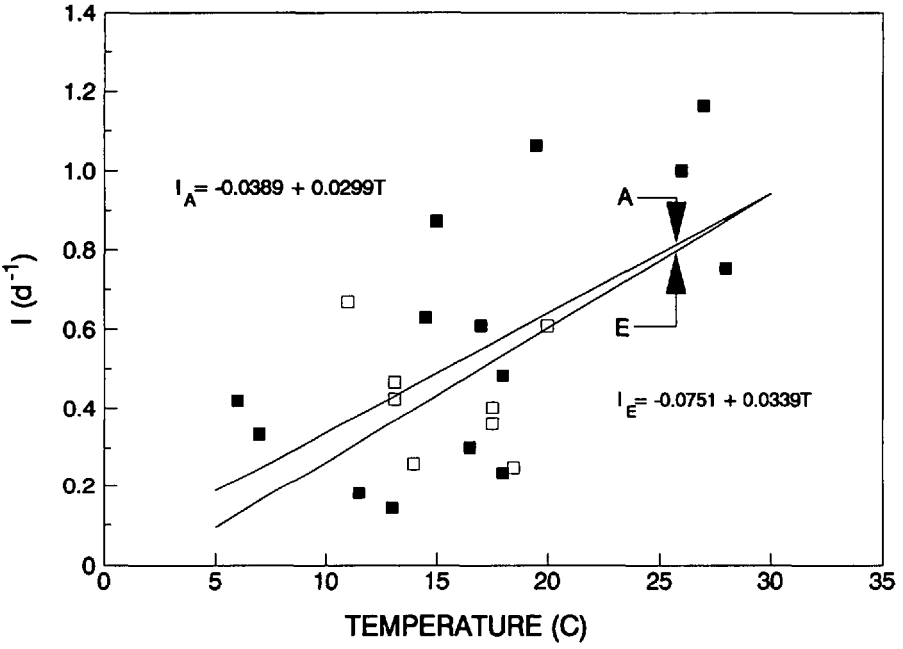


Figure 15. The relationships between estimated weight-specific ingestion (I, $d^{-1}$) and temperature of teleost larvae. $I_A$ regression based upon $\hat{I} = \hat{G}/\bar{K}_1$ for species where both $\hat{G}$ and $\hat{K}_1$ were estimated. $I_E$ is the equation based upon $\hat{I} = \hat{G}/\bar{K}_1$, where $\hat{G} = a + bT$, from the regression for all larvae and $\bar{K}_1 = 0.301$ (Table 1), the mean gross growth efficiency of teleost larvae. ■ = marine larvae. □ = freshwater larvae.

ilation efficiencies of all larvae declined from 81 to 59% in the range of 10 to 28°C. The predicted declines in assimilation efficiency for marine and freshwater larvae in that temperature range were 89 to 65% and 61 to 60%, respectively, suggesting that assimilation rates of freshwater larvae are less sensitive to changes in temperature.

Temperature-adjusted budgets for larvae in the marine and freshwater categories, which allow direct comparison of components because temperature effects have been removed, were derived from the adjusted mean values of G, $QO_2$, and $K_1$ (Tables 2, 5 and 6). The marine larvae had a higher weight-specific ingestion (24% higher) than the freshwater larvae and a much higher allocation to the metabolism category (Table 10). The relative allocation to metabolism by marine larvae was 11.7% higher and, consequently, they had a higher assimilation efficiency (65 vs. 56%).

The estimated weight-specific caloric investment in metabolism is >2 times higher for marine than for freshwater larvae (Table 10). The relationship between $QO_2$ and dry weight at hatch for 12 marine and 11 freshwater species (Fig. 11) indicates that $QO_2$ is affected by weight and that freshwater larvae, being heavier, will have lower metabolic rates.

Within the marine category, temperature-adjusted energy budgets of upwelling species may be different than budgets of estuarine and shelf species (Table 10). The upwelling larvae have relatively high allocations to growth and metabolism, and their assimilation efficiency was estimated to be approximately 20% higher.

The temperature-adjusted energy budgets for seven taxonomic groups indicate

Table 7. Daily food ingestion requirement (I, $d^{-1}$) and its relationship to temperature (T, °C) for all data and for subsets of data distinguished by ecosystem and taxon. When significant ($\alpha = 0.10$), linear regression equations and related parameters are provided. Adjusted means are based upon analysis of covariance with temperature as covariate. Identical superscripts on adjusted means indicate no significant difference (GLM least square means comparison). $S_b$ = standard error of the regression coefficient

| Data set | Regression equation | *P* | N | $S_b$ | $r^2$ | Mean | SE | Adjusted mean | SE |
|---|---|---|---|---|---|---|---|---|---|
| All data | $I_A = 0.0389 + 0.0299T$ | 0.005 | 22 | 0.0095 | 0.33 | 0.530 | 0.052 | — | — |
| Marine | $I_A = 0.0144 + 0.0338T$ | <0.01 | 14 | 0.0110 | 0.44 | 0.586 | 0.071 | 0.572[a] | 0.065 |
| Freshwater | n.s. | >0.50 | 8 | — | — | 0.433 | 0.056 | 0.458[a] | 0.087 |
| Estuary | $I_A = 0.2383 + 0.0265T$ | <0.10 | 5 | 0.0101 | 0.70 | 0.789 | 0.084 | 0.680[a] | 0.131 |
| Shelf | n.s. | >0.70 | 6 | — | — | 0.404 | 0.116 | 0.477[a] | 0.116 |
| Upwelling | n.s. | >0.20 | 3 | — | — | 0.612 | 0.123 | 0.647[a] | 0.157 |
| Clupeiformes | n.s. | >0.10 | 3 | — | — | 0.658 | 0.115 | 0.620[abc] | 0.131 |
| Cypriniformes | n.s. | >0.30 | 4 | — | — | 0.405 | 0.068 | 0.347[ab] | 0.115 |
| Salmoniformes | n.s. | — | 2 | — | — | 0.478 | — | 0.589[abc] | 0.164 |
| Gadiformes | n.s. | — | 2 | — | — | 0.238 | — | 0.422[ab] | 0.164 |
| Percoidei | $I_A = -0.2060 + 0.0447T$ | 0.05 | 5 | 0.0142 | 0.77 | 0.560 | 0.067 | 0.538[abc] | 0.101 |
| Scombroidei | n.s. | — | 1 | — | — | 1.063 | — | 0.973[bc] | 0.131 |
| Pleuronectiformes | n.s. | — | 4 | — | — | 0.636 | 0.116 | 0.625[abc] | 0.113 |

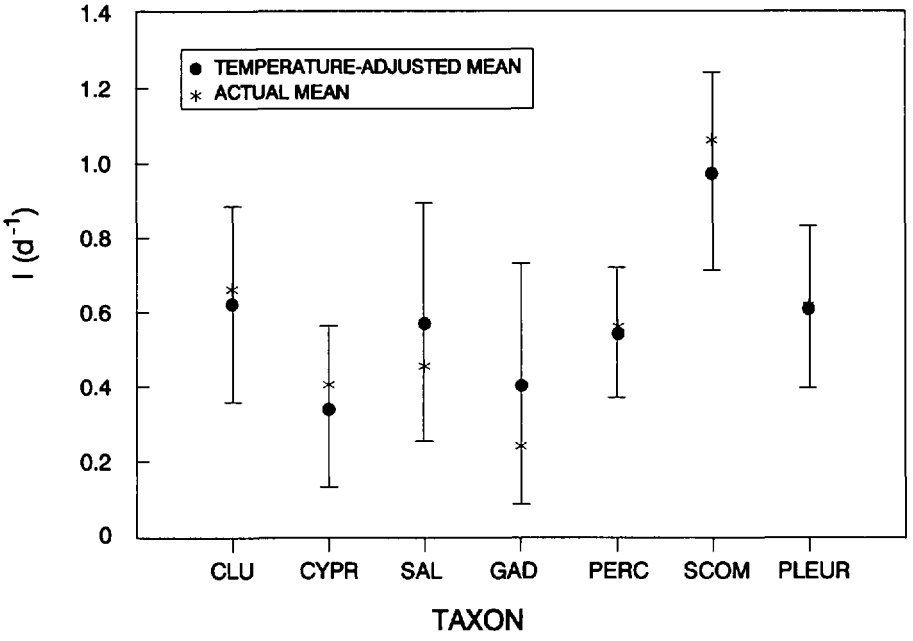


Figure 16. Taxon-specific, mean required ingestion rates (proportion of body weight) of teleost larvae. ● Temperature-adjusted ±2 standard errors. * Actual means. See Figure 1 for taxon keys and explanations.

probable differences among taxa (Table 11). Required weight-specific caloric ingestion to meet mean growth rate varied two-fold from 2.7 (Cypriniformes) to 5.2 $cal \cdot mg^{-1} \cdot d^{-1}$ (Scombroidei). The percentage of ingested energy allocated to growth varied from 21 (Pleuronectiformes) to 35% (Percoidei). Relative metabolic

Table 8. Predicted daily food consumption (i.e., required ingestion, I, $d^{-1}$) required to meet the mean weight-specific growth rates and the relationship of I to temperature (T, °C). The equations are derived from the relationship $I_E = G/\bar{K}_1$, where G = a + bT (Table 2), and temperature-adjusted $\bar{K}_1$ (Table 6) values appropriate for each data set

| Data set | Expected relationship | Predicted ingestion (/d) | | |
|---|---|---|---|---|
| | | 8°C | 18°C | 28°C |
| All data | $I_E = -0.0751 + 0.0339T$ | 0.20 | 0.54 | 0.87 |
| Marine | $I_E = -0.0790 + 0.0364T$ | 0.21 | 0.58 | 0.94 |
| Freshwater | $I_E = 0.1607 + 0.0164T$ | 0.29 | 0.46 | 0.62 |
| Estuary | $I_E = -0.0979 + 0.0407T$ | 0.23 | 0.63 | 1.04 |
| Shelf | $I_E = -0.3169 + 0.0571T$ | 0.14 | 0.71 | 1.28 |
| Upwelling* | $\bar{I} = 0.66$ | — | 0.66 | — |
| Clupeiformes | $I_E = 0.1331 + 0.0244T$ | 0.33 | 0.57 | 0.82 |
| Cypriniformes* | $\bar{I} = 0.51$ | — | 0.53 | — |
| Salmoniformes | $I_E = -0.1154 + 0.0433T$ | 0.23 | 0.66 | 1.10 |
| Gadiformes | $I_E = 0.2625 - 0.0059T$ | 0.31 | 0.37 | — |
| Percoidei | $I_E = -0.0479 + 0.0292T$ | 0.19 | 0.48 | 0.77 |
| Scombroidei | $I_E = -0.7060 + 0.0740T$ | — | 0.63 | 1.37 |
| Pleuronectiformes | $I_E = 0.0341 + 0.0369T$ | 0.33 | 0.70 | 1.07 |

* Upwelling larvae and cypriniform larvae only occurred in the 15 to 20°C range. In these cases, I was calculated as the ratio of temperature-adjusted mean G (Table 2) and mean $K_1$ (Table 6) for each category.

Table 9. Temperature-specific energy budgets of all teleost larvae, marine larvae, and freshwater larvae at 10, 18, and 28°C. Actual budget components are given in cal·mg$^{-1}$·d$^{-1}$ and relative budget components, in parentheses, are percentages. I = ingestion, G = growth, M = metabolism, U = urine, F = feces, A = assimilation efficiency. Budgets were calculated using $\hat{G}$ (Table 2), $\hat{Q}O_2$ (Table 5), unadjusted $\bar{K}_1$ (Table 6) and assumed U = 0.07 I. F was obtained by difference

| Category | Temperature | I | = | G | + | M | + | U | + | F | A |
|---|---|---|---|---|---|---|---|---|---|---|---|
| All | 10 | 1.32 | = | 0.40 | + | 0.58 | + | 0.09 | + | 0.25 | 0.81 |
| | | (100.0) | = | (30.1) | + | (44.2) | + | (7.0) | + | (18.7) | |
| | 18 | 2.67 | = | 0.80 | + | 0.74 | + | 0.19 | + | 0.94 | 0.65 |
| | | (100.0) | = | (30.1) | + | (27.7) | + | (7.0) | + | (35.1) | |
| | 28 | 4.37 | = | 1.32 | + | 0.95 | + | 0.31 | + | 1.80 | 0.59 |
| | | (100.0) | = | (30.1) | + | (21.7) | + | (7.0) | + | (41.2) | |
| Marine | 10 | 1.42 | = | 0.42 | + | 0.75 | + | 0.10 | + | 0.16 | 0.89 |
| | | (100.0) | = | (29.2) | + | (52.7) | + | (7.0) | + | (11.1) | |
| | 18 | 2.87 | = | 0.84 | + | 1.03 | + | 0.20 | + | 0.81 | 0.72 |
| | | (100.0) | = | (29.2) | + | (35.7) | + | (7.0) | + | (28.1) | |
| | 28 | 4.70 | = | 1.37 | + | 1.37 | + | 0.33 | + | 1.63 | 0.65 |
| | | (100.0) | = | (29.2) | + | (29.2) | + | (7.0) | + | (34.6) | |
| Freshwater | 10 | 1.62 | = | 0.52 | + | 0.37 | + | 0.11 | + | 0.63 | 0.61 |
| | | (100.0) | = | (31.8) | + | (22.5) | + | (7.0) | + | (38.7) | |
| | 18 | 2.28 | = | 0.72 | + | 0.50 | + | 0.16 | + | 0.90 | 0.61 |
| | | (100.0) | = | (31.8) | + | (21.8) | + | (7.0) | + | (39.4) | |
| | 28 | 3.09 | = | 0.98 | + | 0.66 | + | 0.22 | + | 1.23 | 0.60 |
| | | (100.0) | = | (31.8) | + | (21.3) | + | (7.0) | + | (39.8) | |

requirements ranged from 14 (Salmoniformes) to 43% (Gadiformes) of the ingested ration. Taxa that are principally or entirely marine (e.g., Gadiformes, Scombroidei, Pleuronectiformes) had the highest metabolic allocations. Estimated assimilation efficiencies ranged from 47 (Salmoniformes) to 82% (Gadiformes).

## Discussion

After temperature effects were removed by analysis of covariance, relatively few differences in rates or properties emerged that were specific to larvae from particular ecosystems or taxonomic groups. But, some significant differences in rates and energetics properties were found that are indicative of taxa-and ecosystem-specific differences in teleost early life histories. Marine and freshwater teleost larvae had similar weight-specific growth and ingestion rates, and similar gross growth efficiencies. Temperature-adjusted mean mortality rate of marine larvae was 6.5%·d$^{-1}$ higher than the mean rate of freshwater larvae. Marine larvae had significantly higher oxygen uptake rates and longer stage durations. The temperature-adjusted mean oxygen uptake rate of freshwater larvae was only one half that of marine larvae and mean stage duration of freshwater larvae was 15.5 d shorter.

Differences in $O_2$ uptake rates, stage durations, and mortality rates between marine and freshwater larvae probably are attributable to differences in weight at hatch. Freshwater larvae in our analyses averaged nearly seven times heavier than marine larvae. Weight-specific $O_2$ uptake in fishes is negatively related to body weight (Rombough, 1988) and this relationship may be particularly strong during early life (Wieser and Forstner, 1986). The larval stage is relatively brief in freshwater because, while freshwater larvae are large at hatch, their growth rates and sizes at metamorphosis are similar to those of marine larvae. Our comparative

Table 10. Temperature-adjusted energy budgets of marine and freshwater teleost larvae. Actual budgets in cal·mg$^{-1}$·d$^{-1}$ and relative budgets, in parentheses, in percentages. Symbols as in Table 9. Budgets were calculated from adjusted mean G (Table 2), $QO_2$ (Table 5), and $K_1$ (Table 6). U was assumed to equal 0.07 I. F was obtained by difference

| Category | I | = | G | + | M | + | U | + | F | A |
|---|---|---|---|---|---|---|---|---|---|---|
| Marine | 3.44 | = | 1.00 | + | 0.98 | + | 0.24 | + | 1.21 | 0.65 |
| | (100.0) | = | (29.1) | + | (28.6) | + | (7.0) | + | (35.3) | |
| Estuary | 4.06 | = | 0.98 | + | 1.07 | + | 0.28 | + | 1.73 | 0.57 |
| | (100.0) | = | (24.1) | + | (26.3) | + | (7.0) | + | (42.6) | |
| Shelf | 4.54 | = | 1.34 | + | 0.80 | + | 0.32 | + | 2.08 | 0.54 |
| | (100.0) | = | (29.6) | + | (17.5) | + | (7.0) | + | (45.9) | |
| Upwelling | 3.29 | = | 1.21 | + | 1.03 | + | 0.23 | + | 0.82 | 0.75 |
| | (100.0) | = | (36.8) | + | (31.2) | + | (7.0) | + | (25.0) | |
| Freshwater | 2.78 | = | 0.89 | + | 0.47 | + | 0.19 | + | 1.23 | 0.56 |
| | (100.0) | = | (31.9) | + | (16.9) | + | (7.0) | + | (44.2) | |

analysis of marine and freshwater larvae supports the proposed inverse relationship between larval mortality and size (McGurk, 1986, 1987; Miller et al., 1988). Pepin (1991) found an ontogenetic effect of declining mortality as length increased in marine fish larvae, although neither he nor Houde (1990, in press) could demonstrate an effect of size at hatch on larval mortality rate.

Temperature-adjusted $\bar{G}$ values were similar among larvae from shelf, upwelling, and oceanic ecosystems, ranging from 0.24 to 0.27. After temperature adjustment, larval stage durations were similar (34 to 36 d) in all of the marine ecosystems except the oceanic (26 d). Data from the oceanic system were predominantly for fast-growing tuna larvae. Adjusted mean mortality rates may have been lower for upwelling-system larvae ($\bar{Z} = 0.18$) than for larvae from estuaries or shelves ($\bar{Z} = 0.27$ and 0.25). Neither the adjusted mean oxygen uptake rates nor ingestion rates were significantly different among marine ecosystems but, in each case, shelf species had slightly lower values.

Temperature clearly is not the only important factor that affects rates and energetics properties of fish larvae. Body size is important and has been proposed as a primary factor controlling rates (Peterson and Wroblewski, 1984; McGurk,

Table 11. Taxon-specific, temperature-adjusted energy budgets of teleost larvae. Actual budgets in cal·mg$^{-1}$·d$^{-1}$ and relative budgets, in parentheses, in percentages. Symbols as in Table 9. Budgets were calculated from adjusted mean G (Table 2), $QO_2$ (Table 5), and $K_1$ (Table 6). U was assumed to equal 0.07 I. F was obtained by difference

| Taxonomic group | I | = | G | + | M | + | U | + | F | A |
|---|---|---|---|---|---|---|---|---|---|---|
| Clupeiformes | 3.18 | = | 0.98 | + | 0.67 | + | 0.22 | + | 1.31 | 0.59 |
| | (100.0) | = | (30.8) | + | (21.2) | + | (7.0) | + | (41.0) | |
| Gadiformes | 3.02 | = | 0.98 | + | 1.30 | + | 0.21 | + | 0.53 | 0.82 |
| | (100.0) | = | (32.5) | + | (42.9) | + | (7.0) | + | (17.6) | |
| Salmoniformes | 3.82 | = | 0.98 | + | 0.55 | + | 0.27 | + | 2.03 | 0.47 |
| | (100.0) | = | (25.6) | + | (14.3) | + | (7.0) | + | (53.1) | |
| Cypriniformes | 2.66 | = | 0.81 | + | 0.39 | + | 0.19 | + | 1.27 | 0.52 |
| | (100.0) | = | (30.5) | + | (14.7) | + | (7.0) | + | (47.8) | |
| Percoidei | 2.89 | = | 1.02 | + | 0.60 | + | 0.20 | + | 1.07 | 0.63 |
| | (100.0) | = | (35.3) | + | (20.9) | + | (7.0) | + | (36.8) | |
| Scombroidei | 5.16 | = | 1.65 | + | 1.34 | + | 0.36 | + | 1.81 | 0.65 |
| | (100.0) | = | (31.9) | + | (26.0) | + | (7.0) | + | (35.1) | |
| Pleuronectiformes | 4.38 | = | 0.94 | + | 1.11 | + | 0.31 | + | 2.02 | 0.54 |
| | (100.0) | = | (21.4) | + | (25.3) | + | (7.0) | + | (46.3) | |

1986, 1987; Miller et al., 1988; Beyer, 1989; Pepin, 1991). MacKenzie et al. (1990) reported that temperature, body size, and prey abundance explained 85% of the variance in laboratory-estimated ingestion rates of marine fish larvae. Werner and Gilliam (1984) argued that ontogenetic shifts occur, causing rates to change as growth proceeds. Our analyses did not consider probable ontogenetic changes, but have estimated averaged values of G, Z, $K_1$, and $QO_2$ during the larval stage. Pepin (1991) indicated that temperature, but not initial size, affected mortality rates of eggs and yolk-sac larvae of marine teleosts, but that body size also affected mortality rates of postlarval fish. Houde (1990, in press) partitioned marine fish larvae data into species with hatch weights $<50$ μg dry wt and those $>50$ μg dry wt. At that level he was unable to show a weight-specific effect on growth or mortality rates and concluded that temperature probably was a more important factor during early life.

Energy budgets integrate the effects of different rates and properties that were estimated. Temperature-adjusted energy budgets (Table 10) of freshwater larvae differ in some respects from those of marine larvae. On a weight-specific basis, freshwater larvae apparently require only 81% as much ingested energy and only 48% as much energy for metabolism as marine larvae to meet estimated mean growth rates. Despite the lower metabolic requirement, freshwater larvae do not have significantly higher gross growth efficiency. Consequently, the estimated assimilation efficiency of marine larvae is 9% higher than that of freshwater larvae, mostly attributable to higher metabolic requirements.

The mean assimilation efficiencies (A) of both the marine and freshwater larvae are lower than expected for juvenile carnivorous fishes, which have a reported mean A of 80% (Brett and Groves 1979). Only the gadiform larvae have a mean A at that level (Table 11). Our estimated A values are dependent upon the highly variable estimates of growth, metabolism, and ingestion. The A values have been calculated and are presented as the probable efficiencies, recognizing that their accuracies are uncertain.

Ingestion rate required to support average growth rates increased by a factor of two to four as temperature increased from 10 to 28°C. MacKenzie et al. (1990) estimated that maximum ingestion by an average marine fish larva at 18.7°C was 57% of the body weight, based upon a model that included temperature, body weight, and prey density as independent variables. Our ingestion estimates for an average teleost larva at 18.7°C from the $I_A$ and $I_E$ relationships (Table 7, Fig. 15), in which temperature is the only independent variable, are 60 and 56%, respectively, results essentially the same as obtained by MacKenzie et al. (1990).

MacKenzie et al. (1990), based upon laboratory-derived functional response relationships, calculated that consumption rates of marine fish larvae in the sea should be resource constrained and thus less than maximum. But, their estimated in situ ingestion rates of eight species of fish larvae indicated that these larvae had consumed food at maximum rates, leading the authors to hypothesize that variable encounter rates and temporal-spatial variability in distributions of larvae and prey had enhanced feeding success. In our analysis, the $Q_{10}$ value for growth and ingestion for all and for marine teleost larvae was 1.95, indicating that mean ingestion and growth rates of larvae that survived are approximately those expected, based solely upon enzyme kinetics and without considering prey densities or complex predator-prey behaviors. In reality, it is certain that prey density, its distribution, and the probability of encounter between larvae and prey all affect individual growth rates and variability in growth, but at the aggregated taxa or ecosystem levels, survivors were growing, on average, at mean rates that were governed primarily by temperatures that they experienced.

The taxon-specific ingestion estimates in the energy budgets do not necessarily indicate different sensitivities to food limitation among first feeding stages. The numbers of prey required depends not only upon the caloric weight-specific demand (Table 11), but also upon larva size and size of prey that can be consumed. If teleost larvae ate primarily copepod nauplii of mean dry weight 0.25 $\mu$g and the mean body weights of newly hatched larvae were 47 $\mu$g (marine) and 339 $\mu$g (freshwater), then numbers of prey required for larvae to grow at mean expected rates would differ more between these ecosystems than would weight-specific caloric intakes. For example, marine larvae have a higher weight-specific ration (Table 7), but they require relatively few prey when they first feed (108 nauplii/d) because the larvae are small at hatch. In contrast, if the freshwater taxa ate 0.25 $\mu$g nauplii at first feeding, they would require, on average, 621 nauplii$\cdot d^{-1}$. For taxa that eat prey larger than 0.25 $\mu$g mean weight (e.g., *Coregonus* spp., Salmoniformes), the actual required prey numbers would be considerably lower than these calculated values.

Growth rates and mortality rates of marine fish larvae were demonstrated to be highly correlated (Houde, 1990; Pepin, 1991). In previous analyses that were restricted to marine fish larvae, Houde (1989b, 1990) found that the ratio G/Z was $<1.0$, implying a loss of biomass during the larval stage. Morse (1989) reported G/Z $>1.0$ for several northwest Atlantic fish larvae and suggested that if ratios are $<1.0$, sampling bias associated with gear avoidance by larger larvae is the probable cause. Our present analysis, on an expanded data base, indicated mean G/Z of 0.94 for all larvae, a value near 1.0. Results for all larvae, marine larvae (G/Z = 0.89), and freshwater larvae (1.13) did not differ significantly from 1.0, suggesting that biomasses during the teleost larval stage are relatively stable.

If G/Z is near 1.0 and gross growth efficiency is constant during the larval stage, then the daily ingestion of a cohort required to support mean growth rate would remain approximately constant throughout larval life. A cohort's biomass normally will increase at some stage of development and the G/Z eventually will exceed 1.0, a consequence of relatively fast decline in Z as larvae grow (Ware, 1975; Beyer, 1989). The cohort's daily ingestion of its prey resources then will increase. It is easy to demonstrate from our compiled and analyzed data that small changes in either G or Z can cause two-fold or greater changes in a cohort's daily ingestion requirement, an ecosystem-level effect that potentially is important in the recruitment process.

We found that larvae of coral reef fishes grow slower than expected under the temperature conditions prevalent in their environment. A major factor contributing to their low adjusted $\bar{G}$ was the surprisingly slow growth of reef labrid and goby larvae. Stage durations of these larvae, based upon otolith increment counts, have repeatedly been found to be long and variable compared to other taxa (Brothers et al., 1983; Victor, 1986, 1987; Thresher and Brothers, 1989). The temperature-adjusted $\bar{G}$ for labrids and gobies are those expected for teleost larvae at only 10 to 13°C, based upon our regression of G on T for all fish larvae (Table 2), despite the fact that coral reef labrids and gobies develop at temperatures $>26$°C. Removing labrid and goby larvae from our analysis did not change the rank of $\bar{G}$ for coral reef larvae. It still was the lowest of the ecosystem-specific adjusted $\bar{G}$, indicating that even the pomacentrids, which dominate the data base (Brothers et al., 1983; Thresher and Brothers, 1989; Wellington and Victor, 1989; Thorrold and Milicich, 1990), grow relatively slowly for temperatures that they inhabit.

Temperature also may explain some of the geographic variability in stage durations that has been observed in coral reef fish larvae. There is a complex literature

discussing the biogeography of coral reef teleosts, which relates larval stage durations to observed distribution patterns and ranges of adults. Larval stage duration is presumed to be evolved and adaptive, and closely linked to dispersal possibilities and island geography. Although interpretations vary, it appears that stage durations are longer in the western Atlantic and in Hawaii than in the West-Indo Pacific (Thresher and Brothers, 1989; Wellington and Victor, 1989). Our growth and stage duration analyses (Tables 2, 4), suggest that a large fraction of the geographic variability in G and D might be explained by temperature. Published reports on coral reef larvae seldom provide temperatures, but atlases of sea surface temperature (Robinson, 1973; Bramwell, 1977) indicate that annual means are 24.3°C (Hawaii), 26.8°C (Caribbean), and 28.1°C (West-Indo Pacific). Expected stage durations at those temperatures, calculated from our relationship between D and T for coral reef larvae (Table 4), range from 24.2 d (West-Indo Pacific), to 27.2 d (Caribbean), to 33.2 d (Hawaii). There appears to be a strong physiological influence of temperature, in addition to adaptive components, in life histories of reef fish larvae that contributes to stage duration variability.

While results of our analyses and of other recent conceptual analyses (Miller et al., 1988; Houde, 1989; Morse, 1989; Pepin, 1991) should not be used to predict responses of individual species, determining species-specific deviations from expected dynamics or energetics values may serve to identify particular life-history strategies and specific adaptations. Ecosystem- and taxon-specific ingestion estimates and derived energy budgets of fish larvae can be compared with those of other zooplankton. Given seasonal surveys of ichthyoplankton abundance, diversity, temperature, and larva weight-frequency distributions, the weight-specific growth and ingestion estimates of larval teleost assemblages could be obtained. Temporal and spatial variability in ingestion, growth, and production could be estimated and incorporated into ecosystem and recruitment models.

In future research, more effort should be made to obtain weights as well as lengths of ichthyoplankton to allow dynamics of larvae to be linked in a meaningful way to population- and community-level energetics processes. Good temperature data are essential to estimate the production potential of ichthyoplankton in any ecosystem, including tropical systems, where seasonal temperature differences, though small, can still have important consequences for fish early life histories. We did not examine effects of ontogeny and body size on vital rates or energetics, but there is a need to do it, as Miller et al. (1988) and Beyer (1989) proposed and Pepin (1991) has done. A further consideration is the possibility that dynamics of teleost larvae and energetics properties are related in a predictable way to overall ecosystem productivity. That hypothesis and others related to community-level dynamics of fish larvae can be tested as better data on bioenergetics and vital rates become available for ichthyoplankton assemblages.

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## Literature Cited

Almatar, S. M. 1984. Effects of acute changes in temperature and salinity on the oxygen uptake of larvae of herring (*Clupea harengus*) and plaice (*Pleuronectes platessa*). Mar. Biol. 80: 117–124.

Anderson, J. T. 1984. Early life history of redfish (*Sebastes* spp.) on Flemish Cap. Can. J. Fish. Aquat. Sci. 41: 1106–1116.

Bailey, K. M. 1982. The early life history of the Pacific hake, *Merluccius productus*. Fish. Bull., U.S. 80: 589–598.

——— and C. L. Stehr. 1986. Laboratory studies on the early life history of the walleye pollock, *Theragra chalcogramma* (Pallas). J. Exper. Mar. Biol. Ecol. 99: 233–246.

Bailey, R. S. 1974. The life history and biology of the blue whiting in the northeast Atlantic. I. The planktonic phase in the Rockall area. Mar. Res., Department of Agriculture and Fisheries for Scotland 1974(1): 1–29.

Balbontin, F. and M. Garreton. 1977. Desove y primeras fases de desarrollo de la sardina Espanola, *Sardinops sagax musica*, en Valparaiso. Rev. Biol. Mar. Depart. Oceanol., Universidad de Chile 16: 171–181.

Bannister, R. C. A., D. Harding and S. J. Lockwood. 1974. Larval mortality and subsequent year-class strength in the plaice (*Pleuronectes platessa* L.). Pages 21–37 *in* J. H. S. Blaxter, ed. The early life history of fish. Springer-Verlag, New York.

Barahona-Fernandes, M. H. 1978. Effect of aeration on the survival and growth of sea bass (*Dicentrarchus labrax* L.) larvae: a preliminary study. Aquaculture 14: 67–74.

———. 1979. Some effects of light intensity and photoperiod on the sea bass larvae (*Dicentrarchus labrax* L.) reared at the Centre Oceanologique de Bretagne. Aquaculture 17: 311–321.

——— and M. Girin. 1977. Effect of different food levels on the growth and survival of laboratory-reared seabass larvae (*Dicentrarchus labrax* L.). Act Collo. Cent. Nat. Expl. Oceans 4: 69–84.

Beck, A. D. and H. A. Poston. 1980. Effects of diet on survival and growth of the Atlantic silverside. Prog. Fish-Cult. 42: 138–143.

Bergen, R., G. Laurence, C. Oviatt and L. Buckley. 1985. Effect of thermal stratification on the growth and survival of haddock (*Melanogrammus aeglefinus*). Int. Coun. Explor. Sea, C.M. 1985/ Mini-Symposium/No. 6.

Beyer, J. E. 1989. Recruitment stability and survival—simple size-specific theory with examples from the early life dynamics of marine fish. Dana 7: 45–147.

Blaxter, J. H. S. 1969. Experimental rearing of pilchard larvae, *Sardina pilchardus*. J. Mar. Biol. Assoc. U.K. 49: 557–575.

Borgmann, U. and K. M. Ralph. 1985. Feeding, growth and particle-size-conversion efficiency in white sucker larvae and young common shiners. Environ. Biol. Fish. 14: 269–279.

Bramwell, M., ed. 1977. The Rand McNally atlas of the oceans. Rand McNally, New York.

Brett, J. R. and T. D. D. Groves. 1979. Physiological energetics. Pages 280–344 *in* W. S. Hoar, D. J. Randall and J. R. Brett, eds. Fish physiology, Vol. 8. Biogenetics and growth. Academic Press, New York.

Brooke, L. T. and P. J. Colby. 1980. Development and survival of embryos of lake herring at different constant oxygen concentrations and temperatures. Prog. Fish-Cult. 42: 3–9.

Brothers, E. B., E. D. Prince and D. W. Lee. 1983. Age and growth of young-of-the-year bluefin tuna, *Thunnus thynnus*, from otolith microstructure. Pages 49–59 *in* E. D. Prince and L. M. Pulos, eds. Proceedings of the International workshop on age determination of oceanic pelagic fishes: tunas, billfishes and sharks. NOAA Tech. Rep. NMFS 8.

———, D. McB. Williams and P. F. Sale. 1983. Length of larval life in twelve families of fishes at "One Tree Lagoon," Great Barrier Reef, Australia. Mar. Biol. 76: 319–324.

Brownell, C. L. 1987. Cannibalistic interactions among young anchovy: a first attempt to apply laboratory behavioral observations to the field. South Afric. J. Mar. Sci. 5: 503–511.

Bryant, P. L. and A. J. Matty. 1980. Optimisation of artemia feeding rate for carp larvae (*Cyprinus carpio* L.). Aquaculture 21: 203–212.

Buckley, L. J. 1979. Relationships between RNA-DNA ratio, prey density, and growth rate in Atlantic cod (*Gadus morhua*) larvae. J. Fish. Res. Board Can. 36: 1497–1502.

———. 1982. Effects of temperature on growth and biochemical composition of larval winter flounder *Pseudopleuronectes americanus*. Mar. Ecol. Prog. Ser. 8: 181–186.

——— and D. W. Dillman. 1982. Nitrogen utilization by larval summer flounder, *Paralichthys dentatus* (Linnaeus). J. Exper. Mar. Biol. Ecol. 59: 243–256.

——— and R. G. Lough. 1987. Recent growth, biochemical composition, and prey field of larval haddock (*Melanogrammus aeglefinus*) stocks: influence of stock size and climate. Can. J. Fish. Aquat. Sci. 44: 14–25.

———, T. A. Halavik, A. S. Smigielski and G. C. Laurence. 1987. Growth and survival of the larvae of three species of temperate marine fishes reared at discrete prey densities. Am. Fish. Soc. Symp. 2: 82–92.

———, S. I. Turner, T. A. Halavik, A. S. Smigielski, S. M. Drew and G. C. Laurence. 1984. Effects of temperature and food availability on growth, survival, and RNA-DNA ratio of larval sand lance (*Ammodytes americanus*). Mar. Ecol. Prog. Ser. 15: 91–97.

Butler, J. L. and B. R. DeMendiola. 1985. Growth of larval sardines off Peru. Calif. Coop. Oceanic Fish. Invest. Rep. 26: 113–118.

Cada, G. F. and G. L. Hergenrader. 1980. Natural mortality rates of freshwater drum larvae in the Missouri River. Trans. Am. Fish. Soc. 109: 479–483.
Cetta, C. M. and J. M. Capuzzo. 1982. Physiological and biochemical aspects of embryonic and larval development of the winter flounder *Pseudopleuronectes americanus*. Mar. Biol. 71: 327–337.
Charlon, N. and P. Bergot. 1984. Rearing system for feeding fish larvae on dry diets. Trial with carp. (*Cyprinus carpio* L.) larvae. Aquaculture 41: 1–9.
Chavance, P., C. Flores-Coto and A. Sanchez-Iturbe. 1984. Early life history and adult biomass of sea bream in the Terminos Lagoon, Southern Gulf of Mexico. Trans. Am. Fish. Soc. 113: 166–177.
Checkley, D. M., Jr. 1984. Relation of growth to ingestion for larvae of Atlantic herring *Clupea harengus* and other fish. Mar. Ecol. Prog. Ser. 18: 215–224.
Chesney, E. J. 1986. Multiple environmental factors as determinants of survival and growth in larval striped bass, *Morone saxatilis*. Int. Coun. Explor. Sea, C.M. 1986/M:26.
Chitty, N. 1981. Behavioral observations of feeding larvae of bay anchovy, *Anchoa mitchilli*, and bigeye anchovy, *Anchoa lamprotaenia*. Rapp. Réun., Cons. Int. Explor. Mer 178: 320–321.
Clady, M. D. 1976. Influence of temperature and wind on the survival of early stages of yellow perch, *Perca flavescens*. J. Fish. Res. Board Can. 33: 1887–1893.
Clarke, M. E. 1984. Feeding behavior of larval walleye pollock Theragra chalcogramma (Pallas), and food availability to larval pollock in the southeastern Bering Sea. Ph.D. Thesis, University of California, San Diego, California. 208 pp.
Comyns, B. H., J. Lyczkowski-Shultz, D. L. Nieland and C. A. Wilson. 1991. Reproduction of red drum, *Sciaenops ocellatus*, in the Northcentral Gulf of Mexico: seasonality and spawner biomass. Pages 17–26 *in* R. D. Hoyt, ed. Larval fish recruitment and research in the Americas. NOAA Tech. Rep. NMFS 95.
———, J. Shultz-Lyczkowski, C. F. Rakocinski and J. P. Steen, Jr. 1989. Age and growth of red drum larvae in the North-Central Gulf of Mexico. Trans. Am. Fish. Soc. 118: 159–167.
Conand, F. 1977. Oeufs et larves de la sardinelle ronde (*Sardinella aurita*) au Senegal; distribution, croissance mortalite, variations d'abondance de 1971 a 1976. Cah. ORSTOM (Sér. Océanogr.) 15: 201–214.
Conover, D. O. 1990. The relation between capacity for growth and length of growing season: evidence for and implications of counter gradient variation. Trans. Am. Fish. Soc. 119: 4165–430.
——— and T. M. C. Present. 1990. Counter gradient variation in growth rate: compensation for length of the growing season among Atlantic silvesides from different latitudes. Oecologia 83: 316–324.
Cowen, R. K. 1991. Variation in the planktonic larval duration of the temperate wrasse *Semicossyphus pulcher*. Mar. Ecol. Prog. Ser. 69: 9–15.
Crecco, V., T. Savoy and L. Gunn. 1983. Daily mortality rates of larval and juvenile American shad (*Alosa sapidissima*) in the Connecticut River with changes in year-class strength. Can. J. Fish. Aquat. Sci. 40: 1719–1728.
Dabrowski, K. R. 1975. Point of no return in the early life of fishes. An energetic attempt to define the food minimum. Wiad. Ekol. 21: 277–293.
———. 1976. How to calculate the optimal density of food for fish larvae. Environ. Biol. Fish. 1: 87–89.
———. 1986. Active metabolism in larval and juvenile fish: ontogenetic changes, effect of water temperature and fasting. Fish Physiol. Biochem. 1: 125–144.
——— and S. J. Kaushik. 1984. Rearing of coregonid (*Coregonus schinzi* Palea Cuv. et. Val.) larvae using dry and live food. II. Oxygen consumption and nitrogen excretion. Aquaculture 41: 333–344.
——— and ———. 1985. Rearing of coregonid (*Coregonus schinzi* palea Cuv. et. val.) larvae using dry and live food. III. Growth of fish and developmental characteristics related to nutrition. Aquaculture 48: 123–135.
———, ——— and P. Luquet. 1984. Metabolic utilization of body stores during the early life history of whitefish, *Coregonus lavaretus* L. J. Fish Biol. 24: 721–729.
Davenport, J. and S. Lonning. 1980. Oxygen uptake in developing eggs and larvae of the cod, *Gadus morhua*. J. Fish Biol. 16: 249–256.
DeMendeliola, B. R. and O. Gomez. 1981. Daily rings in otoliths of larval anchovy (*Engraulis ringins*) Rapp. Réun., Cons. Int. Explor. Mer 178: 565–566.
DeSilva, C. D. and P. Tytler. 1973. The influence of reduced environmental oxygen on the metabolism and survival of herring and plaice larvae. Neth. J. Sea Res. 7: 345–362.
———, S. Premawansa and C. N. Keemiyahetty. 1986. Oxygen consumption in *Oreochromis niloticus* (L.) in relation to development, salinity, temperature and time of day. J. Fish Biol. 29: 267–277.
DeVries, D. A., C. B. Grimes, K. L. Lang and D. B. White. 1990. Age and growth of king and

spanish mackerel larvae and juveniles from the Gulf of Mexico and U.S. South Atlantic Bight. Environ. Biol. Fish. 29: 135–143.

Dey, W. P. 1981. Mortality and growth of young-of-the-year striped bass in the Hudson River estuary. Trans. Am. Fish. Soc. 110: 151–157.

Divanach, P. 1985. Contribution a la connaissance de la biologie et de l'elevage de 6 sparides Mediterraneens: *Sparus aurata, Diplodus sargus, Diplodus vulgaris, Diplodus annularis, Lithognathus mormyrus, Puntazzo puntazzo* (Poissons teleosteens). Thesis, Docteur d'Etat, Universite des Sciences et Techniques du Languedoc, France.

Drouin, M. A., R. B. Kidd, and J. D. Hynes. 1986. Intensive culture of lake whitefish (*Coregonus clupeaformis* Mitchell) using artemia and artificial feed. Aquaculture 59: 107–118.

Duray, M. and T. Bagarinao. 1984. Weaning of hatchery-bred milkfish larvae from live food to artificial diets. Aquaculture 41: 325–332.

Eldridge, M. B., T. Echeverria and J. A. Whipple. 1977. Energetics of Pacific herring (*Clupea harengus pallasi*) embryos and larvae exposed to low concentrations of benzene, a monoaromatic component of crude oil. Trans. Am. Fish. Soc. 106: 452–461.

———, J. A. Whipple and M. J. Bowers. 1982. Bioenergetics and growth of striped bass, *Morone saxatilis,* embryos and larvae. Fish. Bull., U.S. 80: 461–474.

———, ———, D. Eng, M. J. Bowers and B. M. Jarvis. 1981. Effects of food and feeding factors on laboratory-reared striped bass larvae. Trans. Am. Fish. Soc. 110: 111–120.

Erlich, K. F., J. H. S. Blaxter and R. Pemberton. 1976. Morphological and histological changes during the growth and starvation of herring plaice larvae. Mar. Biol. 35: 105–118.

Franklin, D. R. and L. L. Smith, Jr. 1963. Early life history of the northern pike, *Esox lucius* L., with special reference to the factors influencing the numerical strength of year classes. Trans. Am. Fish. Soc. 92: 91–110.

Freeburg, M. H., W. W. Taylor and R. W. Brown. 1990. Effect of egg and larval survival on year-class strength of lake whitefish in Grand Traverse Bay, Lake Michigan. Trans. Am. Fish. Soc. 119: 92–100.

Fuchs, J. 1982. Production du juveniles de sole (*Solea solea*) en conditions intensives. I. Le premier mois d'elevage. Aquaculture 26: 321–337.

Fukahara, O. 1983. Development and growth of laboratory reared *Engraulis japonica* (Houttuyn) larvae. J. Fish Biol. 23: 641–652.

——— and K. Takao. 1988. Growth and larval behavior of *Engraulis japonica* in captivity. J. Appl. Ichthy. 4: 158–167.

Fukusho, K. M., S. Okauchi, S. Nuraini, A. Tsujigado and T. Watanabe. 1984. Food value of a rotifer *Brachionus plicatilis,* cultured with *Tetraselmis tetrathele* for larvae of red seabream *Pagrus major.* Bull. Jap. Soc. Sci. Fish. 50: 1439–1444.

Fushimi, T. and S. Nakatani. 1977. Studies on artificial production of seedling in red sea bream, *Pagrus major* (Temminck et Schlegel)—VII. The optimum quantities of food organisms on rearing larvae and juveniles. Bull. Hiroshima Fish. Exper. Sta. 8: 1–8.

Galat, D. L. and A. W. Eipper. 1975. Presence of food organisms in the prolarval environment as a factor in the growth and mortality of larval musellunge (*Esox masquinongy*). Trans. Am. Fish. Soc. 104: 338–341.

Gamble, J. C. and E. D. Houde. 1984. Growth, mortality and feeding of cod (*Gadus morhua* L.) larvae in enclosed water columns and in laboratory tanks. Pages 123–143 *in* E. Dahl, D. S. Danielssen, E. Moksness and P. Solemdal, eds. The propogation of cod, Gadus morhua L. Flødevigen Rapportserie 1.

———, P. MacLachlan and D. D. Seaton. 1985. Comparative growth and development of autumn and spring spawned herring larvae reared in large enclosed ecosystems. Mar. Ecol. Prog. Ser. 26: 19–33.

Gatesoupe, F. J. and P. Luquet. 1981. Practical diet for mass culture of the rotifer *Brachionus plicatilis*: application to larval rearing of sea bass, *Dicentrarchus labrax.* Aquaculture 22: 149–164.

——— and ———. 1982. Weaning of the sole (*Solea solea*) before metamorphosis. Aquaculture 26: 359–368.

——— and J. H. Robin. 1982. The dietary value for sea-bass larvae (*Dicentrarchus labrax*) of the rotifer *Brachionus plicatilis* fed with or without a laboratory-cultured algae. Aquaculture 27: 121–127.

Girin, M. 1975. La ration alimentaire dans l'élevage larvaire du bar, *Dicentrarchus labrax* (L.). Pages 171–188 *in* G. Persoone and E. Jaspers, eds. Tenth European Symposium on Marine Biology, Vol. 2. Research in mariculture at laboratory- and pilot scale. Universa Press, Wetteren, Belgium.

———. 1979. Methodes de production des juveniles chez trois poissons marins, le bar, la sole et le turbot. C. Nat. L'Expl. Oceans Rapt's. Sci. Tech. 39. 202 pp.

———, M. H. Barahona-Fernandes and A. LeRoux. 1975. Larval rearing of sea bass (*Dicentrarchus labrax* L.) with a high survival. Int. Coun. Explor. Sea. Res. Docu. C.M. 1975/G:14. 5 pp.
Graham, J. J. and D. W. Townsend. 1985. Mortality, growth, and transport of larval Atlantic herring *Clupea harengus* in Maine coastal waters. Trans. Am. Fish. Soc. 114: 490–498.
Hamai, I., K. Kyushin and T. Kinoshita. 1974. On the early larval growth, survival and variation of body form in the walleye pollock, *Theragra chalcogramma* (Pallas), in rearing experiment feeding the different diets. Bull. Facul. Fish. Hokkaido Univ. 25: 20–35.
Harding, D. and J. W. Talbot. 1973. Recent studies on the eggs and larvae of the plaice (*Pleuronectes platessa* L.) in the Southern Bight. Rapp. Réun., Cons. Int. Explor. Mer 164: 261–269.
Harding, J., J. H. Nichols and D. S. Tungate. 1978. The spawning of plaice (*Pleuronectes platessa* L.) in the southern North Sea and English Channel. Rapp. Réun., Cons. Int. Explor. Mer 172: 102–113.
Hart, T. F. and R. G. Werner. 1987. Effects of prey density on growth and survival of white sucker, *Catastomus commersoni* and pumpkinseed, *Lepomis gibbosus*, larvae. Environ. Biol. Fish. 18: 41–50.
Hayashi, A., Y. Yamashita, K. Kawaguchi and T. Ishii. 1989. Rearing method and daily otolith ring of Japanese sardine larvae. Nippon Suisan Gakkaishi 55: 997–1000.
Herrera, G. E., G. Aguilera and P. Berhal. 1985. Growth of anchovy larvae *Engraulis ringins* in central Chile, determined by daily increment counts in otoliths. Biol. Pesq. 14: 11–15.
Hewitt, R. P. 1981. The value of pattern in the distribution of young fish. Rapp. Réun., Cons. Int. Explor. Mer 178: 229–236.
——— and R. D. Methot. 1982. Distribution and mortality of northern anchovy larvae in 1978 and 1979. Calif. Coop. Oceanic Fish. Inv. Rep. 23: 226–245.
———, G. H. Theilacker and N. C. H. Lo. 1985. Causes of mortality in young jack mackerel. Mar. Ecol. Prog. Ser. 26: 1–10.
Hiyashi, S. 1966. A note on the biology and fishery of the Japanese anchovy *Engraulis japonica*. Calif. Coop. Oceanic Fish. Inv. Rep. 11: 44–57.
Hokanson, K. and G. Lein. 1986. Effects of diet on growth and survival of larval walleyes. Prog. Fish-Cult. 48: 250–258.
———, H. H. McCormick and B. R. Jones. 1973. Temperature requirements for embryos and larvae of the northern Pike, *Esox lucius* (Linnaeus). Trans. Am. Fish. Soc. 102: 89–100.
Holliday, F. G. T., J. H. S. Blaxter and R. Lasker. 1964. Oxygen uptake of developing eggs and larvae of the herring (*Clupea harengus*). J. Mar. Biol. Assoc. U.K. 44: 711–723.
Houde, E. D. 1975. Effects of stocking density and food density on survival, growth and yield of laboratory-reared larvae of sea bream, *Archosargus rhomboidalis* (L.) (Sparidae). J. Fish Biol. 7: 115–127.
———. 1977a. Abundance and potential yield of the round herring, *Etrumeus teres*, and aspects of its early life history in the eastern Gulf of Mexico. Fish. Bull., U.S. 75: 61–89.
———. 1977b. Abundance and potential yield of the thread herring, *Opisthonema oglinum*, and aspects of its early life history in the eastern Gulf of Mexico. Fish. Bull., U.S. 75: 493–512.
———. 1977c. Abundance and potential yield of the scaled sardine, *Harengula jaguana*, and aspects of its early life history in the eastern Gulf of Mexico. Fish. Bull., U.S. 75: 613–628.
———. 1977d. Food concentration and stocking density effects on survival and growth of laboratory-reared larvae of bay anchovy *Anchoa mitchilli* and lined sole *Achirus lineatus*. Mar. Biol. 43: 333–341.
———. 1978. Critical food concentrations for larvae of three species of subtropical marine fishes. Bull. Mar. Sci. 29: 395–411.
———. 1987. Fish early life dynamics and recruitment variability. Am. Fish. Soc. Symp. 2: 17–29.
———. 1989a. Subtleties and episodes in the early life of fishes. J. Fish Biol. 35(Supplement A): 29–38.
———. 1989b. Comparative growth, mortality and energetics of marine larvae: temperature and implied latitudinal effects. Fish. Bull., U.S. 87: 471–495.
———. 1990. Temperature-dependent and size-dependent variability in vital rates of marine fish larvae. Int. Coun. Explor. Sea C.M. 1990/L:3. 15 pp.
———. In press. Temperature-dependent and size-dependent variability in vital rates of marine fish larvae. Kuwait Bull. Mar. Sci.
——— and L. Lubbers III. 1986. Survival and growth of striped bass, *Morone saxatilis*, and *Morone* hybrid larvae: laboratory and pond enclosure experiments. Fish. Bull., U.S. 84: 905–914.
——— and W. J. Richards. 1969. Rearing larval tunas in the laboratory. Comm. Fish. Rev. 31: 32–34.
——— and R. C. Schekter. 1981. Growth rates, rations and cohort consumption of marine fish larvae in relation to prey concentrations. Rapp. Réun., Cons. Int. Explor. Mer 178: 441–453.
——— and ———. 1983. Oxygen uptake and comparative energetics among eggs and larvae of three subtropical marine fishes. Mar. Biol. 72: 283–293.

Hovenkamp, F. 1989. Within-season variation in growth of larval plaice (*Pleuronectes platessa* L.). Rapp. Réun., Cons. Int. Explor. Mer 191: 248–257.

Hunter, J. R. 1976. Culture and growth of northern anchovy, *Engraulis mordax,* larvae. Fish. Bull., U.S. 74: 81–88.

———. 1981. Feeding ecology and predation of marine fish larvae. Pages 33–77 *in* R. Lasker, ed. Marine fish larvae: morphology, ecology and relation to fisheries. Washington Sea Grant Program, University Washington Press, Seattle.

——— and C. A. Kimbrell. 1980. Egg cannibalism in the northern anchovy, *Engraulis mordax.* Fish. Bull., U.S. 78: 811–816.

Hussain, N., S. Akatsu and C. El-Zahr. 1981. Spawning, egg and early larval development, and growth of *Acanthopagrus cuvieri.* Aquaculture 22: 125–136.

Inoue, M., Y. Iwasaki, M. Aoki, K. Tutumi and H. Nagaoka. 1974. Some notes on the artificial fertilization and rearing of larvae in frigate mackerel and yellowfin tuna, cultured with seawater-acclimatized *Chlorella* as a basic diet. J. Fac. Mar. Sci. Technol., Tokai Univ. 8: 27–36.

Jenkins, G. P. and T. L. O. Davis. 1990. Age, growth rate, and growth trajectory determined from otolith microstructure of southern bluefin tuna *Thunnus maccoyii* larvae. Mar. Ecol. Prog. Ser. 63: 93–104.

Jitariu, P., M. Badilita and E. Costea. 1971. Oxygen consumption during early stages in some selected breeds of carp in comparison with a local nonselected breed. Stud. Cercet. Biol. Ser. Zoologie 23: 213–217.

Jones, R. 1973. Density dependent regulation of the numbers of cod and haddock. Rapp. Réun., Cons. Int. Explor. Mer 107: 10–15.

Jones, A., R. Alderson and B. R. Howell. 1974. Progress towards the development of a successful rearing technique for larvae of the turbot, *Scophthalmus maximus* L. Pages 731–737 *in* J. H. S. Blaxter, ed. The early life history of fish. Springer-Verlag, New York.

Kamler, E. 1972. Variability of respiration and body composition during early developmental stages of carp. Polskie Arch. Hydrobiol. 23: 431–485.

———, O. Matlak and K. Srokosz. 1974. Further observations of the effect of sodium salt of 2,4-D on early developmental stages of carp *Cyprinus carpio.* Polsk. Arch. Hydrobiol. 21: 481–502.

———, M. Szlaminska, A. Przybyl, B. Barska, M. Jakublas, M. Kuczynski and K. Raciborski. 1990. Developmental response of carp, *Cyprinus carpio,* larvae fed different foods or starved. Environ. Biol. Fish. 29: 303–313.

Karakiri, M. and H. von Westernhagen. 1989. Daily growth patterns in otoliths of larval and juvenile plaice (*Pleuronectes platessa* L.): influence of temperature, salinity and light conditions. Rapp. Réun., Cons. Int. Explor. Mer 191: 376–382.

Kaushik, S. J. and K. Dabrowski. 1983. Postprandial metabolic changes in larval and juvenile carp (*Cyprinus carpio*). Reprod. Nutr. Dev. 23: 223–234.

Kendall, A. W., Jr. and D. Gordon. 1981. Growth rate of Atlantic mackerel (*Scomber scombrus*) larvae in the middle Atlantic Bight. Rapp. Réun., Cons. Int. Explor. Mer 178: 337–341.

———, M. E. Clarke, M. M. Yoklavich and G. W. Boehlert. 1987. Distribution, feeding and growth of larval walleye pollock, *Theragra chalcogramma,* from Shelikof Strait, Gulf of Alaska. Fish. Bull., U.S. 85: 499–521.

Kim, S. and D. R. Gunderson. 1989. Cohort dynamics of walleye pollock in Shelikof Strait, Gulf of Alaska, during the egg and larval periods. Trans. Am. Fish. Soc. 118: 264–273.

Kiørboe, T. and P. Munk. 1986. Feeding and growth of larval herring, *Clupea harengus,* in relation to density of copepod nauplii. Environ. Biol. Fish. 17: 133–139.

———, ——— and K. Richardson. 1987. Respiration and growth of larval herring *Clupea harengus*: relation between specific dynamic action and growth efficiency. Mar. Ecol. Prog. Ser. 40: 1–10.

Kitajima, C., T. Arakawa, F. Oowa, S. Fujita, O. Imada, T. Watanabe and Y. Yone. 1980. Dietary value for red sea bream larvae of rotifer *Brachionus plicatilis* cultured with a new type of yeast. Bull. Jap. Soc. Sci. Fish. 46: 43–46.

Kolman, R. and M. Luczynski. 1986. Survival and growth rates of whitefish (*Coregonus lavaretus* L.) larvae after experimentally delayed hatching. Aquaculture 51: 207–210.

Konchin, V. V. 1981. Analysis of the rate of gas exchange in young roach *Rutilis rutilis.* J. Ichthy. 21: 122–132.

Kondo, K. 1974. Ecological monograph of the Japanese anchovy, *Engraulis japonica* (Houttuyn)—the perspective, methodology, results and problems for the future. Reprint from Section III of the Indo-Pacific Fisheries Council Proceedings, 15th Session. Symp. Coast. High Seas Pelag. Res. IPFC Procs, 15(III), pp. 195–211. Wellington, New Zealand, 18-27 October 1972.

Korwin-Kosskowski, M., G. Jowko and B. Jerierska. 1981. The influence of group effect on oxygen consumption of carp (*Cyprinus carpio* L.) larvae. Rocz. Nauk Roln. Ser. H. Rybactwo 99: 49–62.

Kramer, R. H. and L. L. Smith, Jr. 1960. First-year growth of the largemouth bass, *Micropterus salmoides* Lacépède), and some related ecological factors. Trans. Am. Fish. Soc. 89: 222–233.

Kudrinskaya, O. I. 1969. Metabolic rate in the larval of pike-perch, perch, carp-bream and roach. Hydrobiol. J. 5: 68–72.

———. 1970. Food and temperature as factors affecting the growth, development and survival of pike-perch and perch larvae. J. Ichthy. 10: 779–788.

Kuhlmann, D., G. Quantz and U. Witt. 1981. Rearing of turbot larvae (*Scophthalmus maximus* L.) on cultured food organisms and postmetamorphosis growth on natural and artificial food. Aquaculture 23: 183–196.

Kuronuma, K. and K. Fukusho. 1984. Rearing of marine fish larvae in Japan. International Development Research Center, Ottawa, Canada. 109 pp.

Kuznetsov, V. A. 1973. The growth pattern of the larvae and young of some freshwater fish at different stages of development. J. Ichthy. 12: 433–442.

Lasker, R. and G. H. Theilacker. 1962. Oxygen consumption and osmoregulation by single Pacific sardine eggs and larvae (*Sardinops caerulea,* Girard). J. Cons. 27: 25–33.

Laurence, G. C. 1969. The energy expenditure of largemouth bass larvae, *Micropterus salmoides,* during yolk absorption. Trans. Am. Fish. Soc. 98: 398–405.

———. 1974. Growth and survival of haddock (*Melanogrammus aeglefinus*) larvae in relation to planktonic prey concentration. J. Fish. Res. Board Can. 31: 1415–1419.

———. 1975. Laboratory growth and metabolism of the winter founder *Pseudopleuronectes americanus* from hatching through metamorphosis at three temperatures. Mar. Biol. 32: 223–229.

———. 1977. A bioenergetic model for the analysis of feeding and survival potential of winter flounder, *Pseudopleuronectes americanus,* larvae during the period from hatching to metamorphosis. Fish. Bull., U.S. 75: 529–546.

———. 1978. Comparative growth, respiration and delayed feeding abilities of larval cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) as influenced by temperature during laboratory studies. Mar. Biol. 50: 1–7.

———, A. S. Smigielski, T. A. Halavik and B. R. Burns. 1981. Implications of direct competition between larval cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) in laboratory growth and survival studies at different food densities. Rapp. Réun., Cons. Int. Explor. Mer 178: 304–311.

Leak, J. C. and E. D. Houde. 1987. Cohort growth and survival of bay anchovy *Anchoa mitchilli* larvae in Biscayne Bay, Florida. Mar. Ecol. Prog. Ser. 37: 109–122.

Lee, W. Y., G. J. Holt and C. R. Arnold. 1984. Growth of red drum larvae in the laboratory. Trans. Am. Fish. Soc. 113: 243–246.

Lenarz, W. H. 1973. Dependence of catch rates on size of fish larvae. Rapp. Réun., Cons. Int. Explor. Mer 164: 270–275.

Li, S. and J. A. Mathias. 1982. Causes of high mortality among cultured larval walleye. Trans. Am. Fish. Soc. 111: 710–721.

Liao, I.-C., J. V. Juario, S. Kumagai, H. Nakajima, M. Natividad and P. Buri. 1979. On the induced spawning and larval rearing of milkfish, *Chanos chanos* (Forskal). Aquaculture 18: 75–93.

Lough, R. C., G. R. Bolz, M. Pennington and M. D. Grosslein. 1985. Larval abundance and mortality of Atlantic herring (*Clupea harengus* L.) spawned in the Georges Bank and Nantucket Shoals areas, 1971–78 seasons, in relation to spawning stock size. J. Northwest Atla. Fish. Sci. 6: 21–35.

Luczynski, M. and R. Kolman. 1985. Survival and growth rates of Vendace (*Coregonus albula* L.) larvae after experimentally delayed hatching. Aquaculture 50: 13–21.

MacKenzie, B. R., W. C. Leggett and R. H. Peters. 1990. Estimating larval fish ingestion rates: can laboratory derived values be reliably extrapolated to the wild? Mar. Ecol. Prog. Ser. 67: 209–225.

Margulies, D. 1986. Effects of food concentration and temperature on development, growth, survival and susceptibility to predation of larval white perch (*Morone americana*). Ph.D. Thesis, University of Maryland, College Park, Maryland. 168 pp.

May, R. C. 1971. Effects of delayed initial feeding on larvae of the grunion, *Leuresthes tenius.* Fish. Bull., U.S. 69: 411–425.

McCormick, J. H., B. R. Jones and R. F. Syrett. 1971. Temperature requirements for growth and survival of larval ciscos (*Coregonus artedii*). J. Fish. Res. Board Can. 28: 924–927.

McFarland, W. N., E. B. Brothers, J. C. Ogden, M. J. Shulman, E. L. Bermingham and N. M. Kotchian-Prentiss. 1985. Recruitment patterns in young French grunts, *Haemulon flavolineatum* (Family Hamulidae), at St. Croix, Virgin Islands. Fish. Bull., U.S. 83: 413–426.

McGurk, M. D. 1984. Effects of delayed feeding and temperature on the age of irreversible starvation and on the rates of growth and mortality of Pacific herring larvae. Mar. Biol. 84: 13–26.

———. 1986. Natural mortality of marine pelagic fish eggs and larvae: role of spatial patchiness. Mar. Ecol. Prog. Ser. 34: 227–242.

———. 1987. Natural mortality and spatial patchiness: reply to Gulland. Mar. Ecol. Prog. Ser. 39: 201–206.

———. 1989. Advection, diffusion and mortality of Pacific herring larvae *Clupea harengus pallasi* in Bamfield Inlet, British Columbia. Mar. Ecol. Prog. Ser. 51: 1–18.

McMullen, D. M. and D. P. Middaugh. 1985. The effect of temperature and food density on survival and growth of *Menidia peninsulae* larvae (Pisces: Atherinidae). Estuaries 8: 39–47.

Methot, R. D. and D. Kramer. 1979. Growth of northern anchovy, *Engraulis mordax,* larvae in the sea. Fish. Bull., U.S. 77: 413–423.

Miller, D. J. 1952. Development through the prolarval stage of artificially fertilized eggs of the Pacific sardine (*Sardinops caerulea*). Calif. Fish Game 38: 587–596.

Miller, T. J., L. B. Crowder, J. A. Rice and E. A. Marshall. 1988. Larval size and recruitment mechanisms in fishes: toward a conceptual framework. Can. J. Fish. Aquat. Sci. 45: 1657–1670.

Moksness, E. 1982. Food uptake, growth and survival of capelin larvae (*Mallotus villosus* Muller) in an outdoor constructed basin. Fiskeridir. Skr. Ser. Havunders. 17: 267–285.

Monteleone, D. M. and W. T. Peterson. 1986. Feeding ecology of American sand lance *Ammodytes americanus* larvae from Long Island Sound. Mar. Ecol. Prog. Ser. 30: 133–143.

Mori, K., S. Ueyangi and Y. Nishikawa. 1971. The development of artificially fertilized and reared larvae of the yellowfin tuna, *Thunnus albacares.* Bull. Far Seas Fish. Res. Lab. 5: 219–232.

Morse, W. W. 1989. Cathability, growth and mortality of larval fishes. Fish. Bull., U.S. 87: 417–446.

Nakai, Z. and S. Hattori. 1962. Quantitative distribution of eggs and larvae of the Japanese sardine by year 1949 through 1951. Bull. Tokai Reg. Fish. Res. Lab. 9: 23–60.

Nishimura, A. and J. Yamada. 1984. Age and growth of larval and juvenile walleye pollock, *Theragra chalcogramma* (Pallas), as determined by otolith daily growth increments. J. Exper. Mar. Biol. Ecol. 82: 191–205.

Noble, R. L. 1968. Mortality rates of pelagic fry of the yellow perch, *Perca flavescens* (Mitchell), in Oneida Lake, New York, and an analysis of the sampling problem. Ph.D. Thesis, Cornell University, Ithaca, New York. 104 pp.

Øiestad, V. 1985. Predation on fish larvae as a regulatory force, illustrated in mesocosm studies with large groups of larvae. N. Atl. Fish. Organ. Sci. Coun. Stud. 8: 25–32.

Oikawa, S., Y. Itazawa and M. Gotoh. 1991. Ontogenetic change in the relationship between metabolic rate and body mass in a sea bream *Pagrus major* (Temminck and Schlegel). J. Fish Biol. 38: 483–496.

Palomera, I. and J. Lleonart. 1989. Field mortality estimates of anchovy larvae, *Engraulis encrasicolus,* in the western Mediterranean. J. Fish Biol. 35(Supplement A): 133–138.

———, B. Morales-Nin and J. Lleonart. 1988. Larval growth of anchovy, *Engraulis encrasicolus* in the western Mediterranean Sea. Mar. Biol. 99: 283–291.

Palomares, M. L., P. Much, J. Mendo, E. Chuman, O. Gomez and D. Pauly. 1987. Growth of the Peruvian anchoveta (*Engraulis ringens*), 1953 to 1982. Pages 117–141 *in* D. Pauly and I. Tsukayama, eds. The Peruvian anchoveta and its upwelling ecosystem: three decades of change. ICLARM Stud. Rev. 15. International Center for Living Aquatic Resources Management (ICLARM), Manila, Philippines. 351 pp.

Panov, D. A., Y. I. Sorokin and L. G. Montenkova. 1969. Experimental study of the feeding of young silver carp (*Hypophthalmichthys molitrix*). Prob. Ichthy. 9: 101–112.

Paulsen, H., P. Munk and T. Kiørboe. 1985. Extensive rearing of turbot larvae (*Scophthalmus maximus* L.) on low concentrations of natural plankton. Int. Coun. Explor. Sea, C.M. 1985/F: 33. 8 pp.

Pearcy, W. G. 1962a. Ecology of an estuarine population of winter flounder, *Pseudopleuronectes americanus* (Walbaum). II. Distribution and dynamics of larvae. Bull. Bingham Oceanog. Collect. 18: 16–37.

———. 1962b. Ecology of an estuarine population of winter flounder, *Pseudopleuronectes americanus* (Walbaum). II. Distribution, abundance, growth, and production of juveniles, survival of larvae and juveniles. Bull. Bingham Oceanog. Collect. 18: 39–64.

Peebles, E. B. and S. G. Tolley. 1988. Distribution, growth and mortality of larval spotted seatrout, *Cynoscion nebulosus*: a comparison between two adjacent estuarine areas of southwest Florida. Bull. Mar. Sci. 42: 397–410.

Pepin, P. 1991. Effect of temperature and size on development, mortality, and survival rates of the pelagic life history stages of marine fish. Can. J. Fish. Aquat. Sci. 48: 503–518.

Person-LeRuyet, J., D. L'Elchat and G. Nedelec. 1981. Research on rearing turbot (*Scophthalmus maximus*): results and perspectives. J. World Maricult. Soc. 12: 143–152.

Peterson, I. and J. S. Wroblewski. 1984. Mortality rates of fishes in the pelagic ecosystem. Can. J. Fish. Aquat. Sci., Spec. Publ., 41: 1117–1120.

Post, J. R. 1990. Metabolic allometry of larval and juvenile yellow perch (*Perca flavescens*): in situ estimates and bioenergetic models. Can. J. Fish. Aquat. Sci. 47: 554–560.

Prokes, M. 1973. The oxygen consumption and respiratory surface area of the gills of *Coregonus lavaretus* and of *Coregonus peled.* Zool. Listy 22: 375–384.

Quantz, G. 1985. Effect of temperature and prey density on feeding of turbot (*Scophthalmus maximus*): larvae under laboratory conditions. Int. Coun. Explor. Sea, C.M. 1985/F:51. 5 pp.

Raisanen, G. R. and D. J. Behmer. 1982. Rearing lake whitefish to fingerling size. Prog. Fish-Cult. 44: 33–36.

Rana, K. J. 1985. Influence of egg size on the growth, onset of feeding, point-of-no-return, and survival of unfed *Oreochromis mossambicus* fry. Aquaculture 46: 119–131.

Reed, R. K., L. S. Incze and J. D. Schumacher. 1989. Estimation of the effects of flow on dispersion of larval pollock, *Theragra chalcogramma*, in Shelikof Strait, Alaska. Can. J. Fish. Aquat. Sci., Spec. Publ. 108: 280–294.

Rice, J. A., L. B. Crowder and F. P. Binkowski. 1985. Evaluating otolith analysis for bloater *Coregonus hoyi*: do otoliths ring true? Trans. Am. Fish. Soc. 114: 532–539.

———, ——— and ———. 1987b. Evaluating potential sources of mortality for larval bloater (*Coregonus hoyi*): starvation and vulnerability to predation. Can. J. Fish. Aquat. Sci. 44: 467–472.

———, ———, and M. E. Holey. 1987a. Exploration of mechanisms regulating larval survival in Lake Michigan bloater: a recruitment analysis based on characteristics of individual larvae. *Trans. Am. Fish. Soc.* 116: 703–718.

Robinson, M. K. 1973. Atlas of monthly mean sea surface and subsurface temperature and depth of the top of the thermocline, Gulf of Mexico and Caribbean Sea. Scripps Inst. Oceanog., SIO Reference. 73-8.

Rogers, B. A. and D. T. Westin. 1981. Laboratory studies on effects of temperature and delayed initial development of striped bass larvae. Trans. Am. Fish. Soc. 110: 100–110.

Rombough, P. J. 1988. Respiratory gas exchange, aerobic metabolism, and effects of hypoxia during early life. Pages 55–61 *in* W. S. Hoar and D. J. Randall, eds. Fish physiology, Vol. XI. The physiology of developing fish. A. Eggs and larvae. Academic Press, San Diego, California.

Saksena, V. P. and W. J. Richards. 1975. Description of eggs and larvae of laboratory-reared white grunt, *Haemulon plumieri* (Lacépède) (Pices, Pomadasyidae). Bull. Mar. Sci. 25: 523–536.

Scofield, E. C. 1934. Early life history of the California sardine (*Sardina caerulea*), with special reference to distribution of eggs and larvae. Bull. Calif. Dept. Fish Game 41: 1–48.

Sette, O. E. 1943. Biology of the Atlantic mackerel (*Scomber scombrus*) of North America. Part I: early life history, including the growth, drift, and mortality of the egg and larval populations. Fish. Bull., U.S. 50: 149–237.

Smigielski, A. S., T. A. Halavik, L. J. Buckley, S. M. Drew and G. C. Laurence. 1984. Spawning, embryo development and growth of the American sand lance *Ammodytes americanus* in the laboratory. Mar. Ecol. Prog. Ser. 14: 287–292.

Smith, P. E. 1985. Year-class strength and survival of O-group clupeoids. Can. J. Fish. Aquat. Sci. 42(Supplement 1): 69–82.

Solberg, T. and S. Tilseth. 1984. Growth, energy consumption and prey density requirements in first feeding larvae of cod (*Gadus morhua* L.). Pages 145–166 *in* E. Dahl, D. P. Danielssen, E. Moskness and P. Solemdal, eds. The propogation of cod *Gadus morhua*. Flødevigen Rapportserie 1.

Spoor, W. A. 1984. Oxygen requirements of larvae of the smallmouth bass *Micropterus dolomieui*. J. Fish Biol. 25: 587–592.

Stepien, W. P. 1976. Feeding of laboratory-reared larvae of the sea bream *Archosargus rhomboidalis* (Sparidae). Mar. Biol. 38: 1–16.

Sundby, S., H. Bjørke, A. V. Soldal and S. Olsen. 1988. Mortality rates during early life stages and year-class strengths of northeast Arctic cod (*Gadus morhua* L.). Rapp. Réun., Cons. Int. Explor. Mer 191: 351–358.

Swedburg, D. V. and C. H. Walburg. 1970. Spawning and early life history of the freshwater drum in Lewis and Clark Lake, Missouri River. Trans. Am. Fish. Soc. 99: 560–570.

Taggart, C. T. and K. T. Frank. 1990. Perspectives on larval fish ecology and recruitment processes. Probing the scales of relationships. Pages 151–164, *in* K. Sherman, L. M. Alexander and B. D. Gold, eds. Large marine ecosystems: patterns, processes and yields. American Association for the Advancement of Science, Washington, D.C.

——— and W. C. Leggett. 1987. Short-term mortality in post-emergent larval capelin *Mallotus villosus*. II. Importance of food and predator density, and density-dependence. Mar. Ecol. Prog. Ser. 41: 219–229.

Tandler, A. and S. Helps. 1985. The effects of photoperiod and water exchange rate on growth and survival of gilthead sea bream (*Sparus aurata*, Linnaeus; Sparidae) from hatching to metamorphosis in mass rearing systems. Aquaculture 48: 71–82.

Taniguchi, A. K. 1979. Survival and growth of larval spotted seatrout (*Cynoscion nebulosus*) in relation to temperature, prey abundance and stocking densities. Int. Coun. Explor. Sea, ELH Symposium, RA: 1–14.

———. 1981. Survival and growth of larval spotted seatrout (*Cynoscion nebulosus*) in relation to

temperature, prey abundance and stocking densities. Rapp. Réun., Cons. Int. Explor. Mer 178: 507–508.
Taylor, W. W. and M. H. Freeburg. 1984. Effect of food abundance on larval lake whitefish, *Coregonus clupeaformis* Mitchell, growth and survival. J. Fish Biol. 25: 733–741.
Theilacker, G. H. 1987. Feeding ecology and growth energetics of larval northern anchovy, *Engraulis mordax*. Fish. Bull., U.S. 85: 213–228.
——— and K. Dorsey. 1980. Larval fish diversity, a summary of laboratory and field research. UNESCO, Int. Oceanogr. Comm. Works. Rep. 28: 105–142.
Thorrold, S. R. and M. J. Milicich. 1990. Comparison of larval duration and pre- and post-settlement growth in two species of damselfish, *Chromis atripectoralis* and *Pomacentrus coelestis* (Pisces: Pomacentridae), from the Great Barrier Reef. Mar. Biol. 105: 375–384.
Thresher, R. E. and E. B. Brothers. 1989. Evidence of intra- and inter-oceanic regional differences in the early life history of reef-associated fishes. Mar. Ecol. Prog. Ser. 57: 187–205.
Tisa, M. S. and J. J. Ney. 1991. Compatibility of alewives and gizzard shad as reservoir forage fish. Trans. Am. Fish. Soc. 120: 157–165.
Toetz, D. W. 1966. The change from endogenous to exogenous sources of energy in bluegill sunfish larvae. Invest. Indiana Lakes Streams 7: 115–146.
Treasurer, J. W. 1988. The distribution and growth of lacustrine 0+ perch, *Perca fluviatilis*. Environ. Biol. Fish. 21: 37–44.
Tuncer, H. 1988. Growth, survival and energetics of larval and juvenile striped bass (*Morone saxatilis*) and its white bass hybrid (*M. saxatilis* × *M. chrysops*). Master's Thesis, University of Maryland, College Park, Maryland. 136 pp.
Uchida, R. N. 1981. Synopsis of biological data on frigate tuna, *Auxis thazard*, and bullet tuna, *A. rochei*. NOAA Tech. Rep. NMFS Circ. 436. 64 pp.
Ueyanagi, S., Y. Nishikawa and T. Matsuoka. 1974. Artificial fertilization and larval development of skipjack tuna, *Katsuwonus pelamis*. Bull. Far Seas Fish. Res. Lab. 10: 179–188.
Uotani, I. 1985. The relation between feeding mode and feeding habit of the anchovy larvae. Bull. Jap. Soc. Sci. Fish. 51: 1057–1065.
Van der Meeren, T. 1991. Selective feeding and prediction of food consumption in turbot larvae (*Scophthalmus maximus* L.) reared on the rotifer *Brachionus plicatilis* and natural zooplankton. Aquaculture 93: 35–55.
Victor, B. C. 1986. Duration of the planktonic larval stage of one hundred species of Pacific and Atlantic wrasses (family Labridae). Mar. Biol. 90: 317–326.
———. 1987. Growth, dispersal, and identification of planktonic labrid and pomacentrid reef-fish larvae in the eastern Pacific Ocean. Mar. Biol. 95: 145–152.
Walline, P. D. 1985. Growth of larval walleye pollock related to domains within the SE Bering Sea. Mar. Ecol. Prog. Ser. 21: 197–203.
———. 1987. Growth and ingestion rates of larval fish populations in the coastal waters of Israel. J. Plankton Res. 9: 91–102.
Ware, D. M. 1975. Relation between egg size, growth, and natural mortality of larval fish. J. Fish. Res. Board Can. 32: 2503–2512.
——— and T. C. Lambert. 1985. Early life history of Atlantic mackerel (*Scomber scombrus*) in the southern Gulf of St. Lawrence. Can. J. Fish. Aquat. Sci. 42: 577–592.
Watanabe, T. 1970. Morphology and ecology of early stages of life in Japanese common mackerel, *Scomber japonicus* Houttuyn, with special reference to fluctuations of populations. Bull. Tokai Reg. Fish. Res. Lab. 61: 1–283.
Wellington, G. M. and B. C. Victor. 1989. Planktonic larval duration of one hundred species of Pacific and Atlantic damselfishes (Pomacentridae). Mar. Biol. 101: 557–567.
Werner, E. E. and J. F. Gilliam. 1984. The ontogenetic niche and species interactions in size-structured populations. Annu. Rev. Ecol. Syst. 15: 393–425.
Wieser, W. and H. Forstner. 1986. Effects of temperature and size on the routine rate of oxygen consumption and on the relative scope for activity in larval cyprinids. J. Comp. Physiol. 156: 791–796.
——— and N. Medgyesy. 1990. Aerobic maximum for growth in the larvae and juveniles of a cyprinid fish, *Rutilus rutilus* (L.): implications for energy budgeting in small poikilotherms. Funct. Ecol. 4: 233–242.
———, H. Forstner, N. Medgyesy and S. Hinterleitner. 1988. To switch or not to switch: partitioning of energy between growth and activity in larval cyprinids (Cyprindiae: Teleostei). Funct. Ecol. 2: 499–507.
———, ———, F. Schiemer and W. Mark. 1988. Growth rates and growth efficiencies in larvae and juveniles of *Rutilus rutilus* and other cyprinid species: effects of temperature and food in the laboratory and in the field. Can. J. Fish. Aquat. Sci. 45: 943–950.
Wootton, R. J. 1990. Ecology of teleost fishes. Chapman and Hall, London. 404 pp.

Yamashita, Y. and K. M. Bailey. 1989. A laboratory study of the bioenergetics of larval walleye pollock, *Theragra chalcogramma*. Fish. Bull., U.S. 87: 525–536.
Young, J. W. and T. L. O. Davis. 1990. Feeding ecology of larvae of southern bluefin, albacore and skipjack tunas (Pisces: Scombride) in the eastern Indian Ocean. Mar. Ecol. Prog. Ser. 61: 17–29.

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Appendix A. Ecosystem-specific and taxon-specific vital rates and energetics data for teleost larvae. Values in the Table are those reported by the authors or calculated by us from data and information that the authors provided. Length–weight relationships, particularly for coral reef (CR) species, frequently were used to convert reported lengths to weights when weight data were not provided in the published papers. ECOS = ecosystem: FW = freshwater, CR = coral reef, EST = estuarine, OCN = oceanic, SH = shelf, UW = upwelling. SP = species. Taxa: CYPR = Cypriniformes, CLU = Clupeiformes, PERC = Percoidei, SAL = Salmoniformes, GOB = Gobioidei, LABR = Labroidei, PLEUR = Pleuronectiformes, ATH = Atheriniformes, SCOM = Scombroidei, SCHIND = Schindlerioidei, GONO = Gonorhynchiformes, GAD = Gadiformes. G = weight-specific growth coefficient ($d^{-1}$). D = stage duration (d). Z = instantaneous daily mortality coefficient ($d^{-1}$). $QO_2$ = weight-specific oxygen uptake rate ($\mu l\ O_2 \cdot mg^{-1} \cdot h^{-1}$). $K_1$ = gross growth efficiency. I = weight-specific ingestion rate ($\mu g \cdot \mu g^{-1} \cdot d^{-1}$). $W_0$ = dry weight at hatch ($\mu g$). $W_{met}$ = dry weight at metamorphosis ($\mu g$). Ref. = references, coded by number. Code numbers and citations at foot of Appendix table are listed in Literature Cited

| ECOS | SP | Taxa | T (°C) | G | D | Z | $QO_2$ | G/Z | $K_1$ | I | $W_0$ | $W_{met}$ | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FW | *Abramis brama* | CYPR | 17.5 | 0.178 | — | — | 2.52 (20°) | — | — | — | 200 | — | 1, 2, 3 |
| FW | *Alburnus alburnus* | CYPR | 22.5 | 0.142 | — | — | — | — | — | — | — | — | 4 |
| FW | *Alosa pseudoharengus* | CLU | 23.5 | — | — | 0.12 | — | — | — | — | — | — | 5 |
| FW | *Aplodinotus grunniens* | PERC | 24.0 | 0.157 | 42.0 | 0.16 | — | 0.98 | — | — | 455 | 33,200 | 6, 7 |
| FW | *Catostomus commersoni* | CYPR | 20.0 | 0.160 | — | — | — | — | 0.260 | 0.608 | — | — | 8 |
| FW | *Chalcalburnus chalcoides* | CYPR | 20.0 | 0.064 | — | — | 2.90 | — | — | — | — | — | 4 |
| FW | *Coregonus albula* | SAL | 10.0 | 0.090 | 28.0 | — | 2.01 (9°) | — | — | — | 260 | 3,200 | 3, 9 |
| FW | *Coregonus artedii* | SAL | 10.5 | 0.075 | 25.8 | — | — | — | — | — | 890 | 6,180 | 214, 215 |
| FW | *Coregonus clupeaformis* | SAL | 12.2 | 0.062 | 40.4 | 0.20 (14.5) | — | 0.31 | — | — | 800 | 9,820 | 10, 11, 12, 13 |
| FW | *Coregonus hoyi* | SAL | 12.5 | 0.100 | 23.6 | — | — | — | — | — | 700 | 7,440 | 14, 15 |
| FW | *Coregonus lavaretus* | SAL | 9.5 | 0.095 | 19.2 | — | 1.96 (9.5°) | — | 0.139 (11°) | 0.683 (11°) | 1,200 | 7,440 | 3, 16, 17, 18, 39 |
| FW | *Coregonus schinzi* | SAL | 14.9 | 0.101 | 29.0 | — | 2.49 (16.3°) | — | 0.370 (14°) | 0.273 (14°) | 760 | 14,190 | 19, 20, 21 |
| FW | *Cyprinus carpio* | CYPR | 23.0 | 0.348 | 12.9 | — | 4.09 (24°) | — | — | — | 107 | 9,900 | 22, 23, 24, 25, 26, 27, 28, 29 |
| FW | *Dorosoma cepedianum* | CLU | 22.5 | — | — | 0.325 | — | — | — | — | — | — | 5 |
| FW | *Esox lucius* | SAL | 16.2 | 0.191 | 33.6 | — | 3.17 (18.3°) | — | — | — | 190 | 10,830 | 2, 3, 30, 32, 33 |
| FW | *Esox masquinongy* | SAL | 16.0 | 0.158 | — | — | — | — | — | — | — | — | 34 |
| FW | *Hypophthalmichthys molitrix* | CYPR | 18.5 | 0.098 | — | — | 2.47 | — | 0.390 | 0.251 | 300 | — | 35 |
| FW | *Lepomis gibbosus* | PERC | 20.4 | 0.150 | 22.4 | — | — | — | — | — | 130 | 3,750 | 36 |
| FW | *Lepomis macrochirus* | PERC | 23.5 | 0.121 | 30.1 | — | — | — | — | — | 150 | 4,970 | 37 |

Appendix A. Continued

| ECOS | SP | Taxa | T (°C) | G | D | Z | $QO_2$ | G/Z | $K_1$ | I | $W_0$ | $W_{mc}$ | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FW | *Leuciscus cephalus* | CYPR | 22.5 | 0.117 | – | – | – | – | – | – | – | – | 4 |
| FW | *Lucioperca lucioperca* | PERC | 13.1 | 0.188 | – | – | 3.62 (20°C) | – | 0.403 (19.3) | 0.466 | – | – | 1, 3, 38 |
| FW | *Micropterus dolomieui* | PERC | 20.0 | – | – | – | 2.96 | – | – | – | 154 | 4,970 | 40 |
| FW | *Micropterus salmoides* | PERC | 19.3 | 0.190 | 18.8 | – | 2.78 (19.5°) | – | – | – | 139 | 4,660 | 41, 42 |
| FW | *Oreochromis mossambicus* | PERC | 28.0 | 0.172 | – | – | – | – | – | – | 130 | – | 43 |
| FW | *Oreochromis niloticus* | PERC | 30.0 | – | – | – | 4.24 | – | – | – | – | – | 44 |
| FW | *Perca flavescens* | PERC | 15.3 | 0.129 | 35.7 | 0.090 (11.8°C) | – | 1.36 | – | – | 114 | 11,500 | 45, 46, 47 |
| FW | *Perca fluviatilis* | PERC | 13.1 | 0.173 | 36.1 | 0.063 | 3.94 (20°) | 2.00 | 0.408 | 0.424 | 164 | 11,600 | 1, 3, 38, 48 |
| FW | *Pseudorasbora parva* | CYPR | 17.5 | 0.083 | – | – | 3.01 | – | 0.232 | 0.358 | – | – | 49 |
| FW | *Rutilus rutilus* | CYPR | 17.5 | 0.136 | – | – | 2.79 | – | 0.339 | 0.401 | 240 | – | 2, 3, 4, 49, 50 |
| FW | *Stizostedion vitreum* | PERC | 20.3 | 0.210 | 18.0 | 0.228 (13.5°) | – | 0.97 | – | – | 110 | 4,820 | 51, 52 |
| CR | *Abudefduf* spp. | PERC | 28.7 | 0.286 | 23.1 | – | – | – | – | – | 16 | 11,671 | 53, 54 |
| CR | *Amblyglyphidodon curacao* | PERC | 29.8 | 0.431 | 13.1 | – | – | – | – | – | 5 | 1,350 | 54 |
| CR | *Amblygobius rainfordi* | GOB | 26.5 | 0.158 | 40.3 | – | – | – | – | – | 14 | 8,390 | 55 |
| CR | *Amphiprion* sp. | PERC | 29.8 | 0.196 | 13.7 | – | – | – | – | – | 116 | 1,694 | 53, 54 |
| CR | *Apogon* sp. | PERC | 26.5 | 0.312 | 20.4 | – | – | – | – | – | 11 | 6,419 | 55 |
| CR | *Chaetodon* spp. | PERC | 26.5 | 0.204 | 37.0 | – | – | – | – | – | 4 | 7,209 | 55 |
| CR | *Cheilodipterus quinquelineata* | PERC | 26.5 | 0.265 | 23.1 | – | – | – | – | – | 11 | 5,017 | 55 |
| CR | *Chelmon rostratus* | PERC | 26.5 | 0.353 | 25.5 | – | – | – | – | – | 4 | 30,448 | 55 |
| CR | *Chromis* spp. | PERC | 29.2 | 0.297 | 27.3 | – | – | – | – | – | 4 | 13,246 | 53, 54, 56 |
| CR | *Chrysiptera* spp. | PERC | 29.8 | 0.291 | 18.9 | – | – | – | – | – | 3 | 740 | 53, 54 |
| CR | *Cirrhilabrus temmincki* | LABR | 26.5 | 0.175 | 28.0 | – | – | – | – | – | 3 | 465 | 55 |
| CR | *Coris variegata* | LABR | 26.5 | 0.170 | 29.7 | – | – | – | – | – | 3 | 532 | 55 |
| CR | *Dascyllus* spp. | PERC | 29.4 | 0.266 | 22.5 | – | – | – | – | – | 6 | 2,372 | 54, 55 |
| CR | *Dischistodus* spp. | PERC | 29.8 | 0.299 | 16.1 | – | – | – | – | – | 44 | 5,158 | 54 |
| CR | *Glyphidodontops rollandi* | PERC | 26.5 | 0.184 | 23.1 | – | – | – | – | – | 116 | 8,134 | 55 |
| CR | *Gobiodon* spp. | GOB | 26.5 | 0.112 | 30.2 | – | – | – | – | – | 6 | 169 | 55 |
| CR | *Haemulon* spp. | PERC | 26.7 | 0.306 | 19.6 | – | – | – | – | – | 20 | 8,000 | 57, 58 |
| CR | *Halichoeres hoeveni* | LABR | 26.1 | 0.143 | 46.5 | – | – | – | – | – | 5 | 3,862 | 55, 59 |

Appendix A. Continued

| ECOS | SP | Taxa | T (°C) | G | D | Z | $QO_2$ | G/Z | $K_1$ | I | $W_0$ | $W_{met}$ | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CR | *Hemiglyphidodon plagiometopon* | PERC | 29.8 | 0.245 | 18.0 | — | — | — | — | — | 65 | 5,366 | 54 |
| CR | *Labroides dimidiatus* | LABR | 26.5 | 0.229 | 26.0 | — | — | — | — | — | 3 | 1,101 | 55 |
| CR | *Neopomacentrus nemurus* | PERC | 29.8 | 0.279 | 19.2 | — | — | — | — | — | 34 | 7,209 | 54 |
| CR | *Paraglyphidodon* spp. | PERC | 29.8 | 0.188 | 19.0 | — | — | — | — | — | 111 | 3,913 | 54 |
| CR | *Paragobiodon* spp. | GOB | 26.5 | 0.088 | 38.8 | — | — | — | — | — | 6 | 177 | 55 |
| CR | *Petroscirtes* spp. | PERC | 26.5 | 0.153 | 24.5 | — | — | — | — | — | 12 | 504 | 55 |
| CR | *Pomacentrus* spp. | PERC | 28.8 | 0.308 | 19.8 | — | — | — | — | — | 4 | 1,786 | 53, 54, 55, 56 |
| CR | *Pseudojulis* sp. | LABR | 25.7 | 0.099 | 55.0 | — | — | — | — | — | 6 | 1,364 | 59 |
| CR | *Scolopsis dubiosus* | PERC | 26.5 | 0.418 | 19.0 | — | — | — | — | — | 11 | 30,449 | 55 |
| CR | *Semicossyphus pulcher* | LABR | 15 | 0.162 | 52.2 | — | — | — | — | — | 6 | 27,876 | 60 |
| CR | *Stegastes* spp. | PERC | 28.7 | 0.304 | 23.3 | — | — | — | — | — | 8 | 9,534 | 53, 54 |
| CR | *Thalassoma* spp. | LABR | 26 | 0.090 | 64.4 | — | — | — | — | — | 5 | 1,645 | 55, 59 |
| CR | *Xyrichtys* sp. | LABR | 25.7 | 0.069 | 88.5 | — | — | — | — | — | 6 | 2,587 | 59 |
| EST | *Achirus lineatus* | PLEUR | 28 | 0.245 | 23.0 | — | 10.80 | — | 0.325 | 0.754 | 11 | 3,100 | 61, 62, 63, 64 |
| EST | *Alosa sapidissima* | CLU | 21 | — | — | 0.21 | — | — | — | — | — | — | 65 |
| EST | *Archosargus rhomboidalis* | PERC | 26 | 0.310 | 21.0 | 0.43 | 8.32 | 0.72 | 0.31 | 1.000 | 15 | 7,000 | 62, 63, 64, 66 67, 68 |
| EST | *Anchoa lamprotaenia* | CLU | 26 | 0.210 | 34.0 | — | — | — | — | — | 20 | 25,000 | 69 |
| EST | *Anchoa mitchilli* | CLU | 27 | 0.250 | 32.4 | 0.375 | 6.1 (26°) | 0.66 | 0.215 | 1.163 | 15 | 25,000 | 61, 62, 63, 64, 70, 71 |
| EST | *Cynoscion nebulosus* | PERC | 28 | 0.365 | 19.4 | 0.500 | — | 0.73 | — | — | 20 | 7,000 | 72, 73, 74 |
| EST | *Gobiosoma bosci* | GOB | 26 | 0.146 | 30.9 | — | — | — | — | — | 20 | 1,821 | 75 |
| EST | *Morone americana* | PERC | 17 | 0.105 | 84.5 | — | — | — | — | — | 20 | 10,000 | 76 |
| EST | *Morone saxatilis* | PERC | 17 | 0.140 | 33.0 | 0.170 | 5.6 (18°) | 0.82 | 0.230 | 0.609 | 200 | 15,000 | 77, 78, 79, 80, 81, 82, 83 |
| EST | *Menidia menidia* | ATH | 20 | 0.130 | 35.4 | — | — | — | — | — | 100 | 10,000 | 84 |
| EST | *Menidia peninsulae* | ATH | 25 | 0.165 | 41.0 | — | — | — | — | — | 30 | 10,000 | 85 |
| EST | *Pseudopleuronectes (=Pleuronectes) americanus* | PLEUR | 6 | 0.080 | 87.0 | 0.230 (8.5°) | 4.9 (5°) | 0.34 | 0.190 | 0.421 | 10 | 1,000 | 86, 87, 88, 89, 90 |
| OCN | *Auxis rochei* | SCOM | 25.5 | 0.315 | 16.0 | — | — | — | — | — | 140 | 21,630 | 91, 92 |
| OCN | *Auxis thazard* | SCOM | 25.5 | 0.476 | 9.5 | — | — | — | — | — | 197 | 18,130 | 92 |
| OCN | *Euthynnus alletteratus* | SCOM | 26 | 0.285 | 24.4 | — | — | — | — | — | 19 | 19,800 | 93 |
| OCN | *Katsuwonus pelamis* | SCOM | 26.7 | 0.318 | 20.2 | — | — | — | — | — | 32 | 19,900 | 91, 94 |
| OCN | *Thunnus albacares* | SCOM | 26.5 | 0.274 | 25.1 | — | — | — | — | — | 21 | 20,200 | 91, 95 |
| OCN | *Thunnus maccoyii* | SCOM | 27.5 | 0.277 | 24.1 | — | — | — | — | — | 25 | 19,580 | 96, 97 |

Appendix A. Continued

| ECOS | SP | Taxa | T (°C) | G | D | Z | $QO_2$ | G/Z | $K_1$ | I | $W_0$ | $W_{mat}$ | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| OCN | *Thunnus thynnus* | SCOM | 26 | 0.240 | 27.9 | — | — | — | — | — | 25 | 20,000 | 98 |
| SH | *Acanthopagrus cuvieri* | PERC | 25 | 0.315 | — | — | — | — | — | — | 5 | 7,000 | 99 |
| SH | *Ammodytes americanus* | SCHIND | 5 | 0.060 | 159.1 | — | — | — | — | — | 40 | 10,000 | 100, 101, 102, 103 |
| SH | *Chanos chanos* | GONO | 27 | 0.145 | 43.5 | — | — | — | — | — | 50 | 25,000 | 104, 105 |
| SH | *Clupea harengus* | CLU | 11.5 | 0.065 | 160.6 | 0.235 | 2.65 | 0.27 | 0.360 | 0.181 | 90 | 25,000 | 106, 107, 108, 109, 110, 111, 112, 113, 114, 115, 116, 177 |
| SH | *Dicentrarchus labrax* | PERC | 16.5 | 0.125 | 45.6 | — | — | — | 0.415 | 0.301 | 60 | 10,000 | 118, 119, 120, 121, 122, 209 |
| SH | *Etrumeus teres* | CLU | 22.5 | — | — | 0.130 | — | — | — | — | — | — | 123 |
| SH | *Gadus morhua* | GAD | 7.5 | 0.070 | 100.9 | 0.105 | 4.95 (7°) | 0.66 | — | — | 50 | 7,000 | 124, 125, 126, 127, 128, 129, 130, 138, 207 |
| SH | *Harengula jaguana* | CLU | 26.0 | — | — | 0.280 | — | — | — | — | — | — | 131 |
| SH | *Leuresthes tenuis* | ATH | 18.0 | 0.090 | 44.2 | — | — | — | 0.380 | 0.237 | 362 | 19,350 | 132 |
| SH | *Mallotus villosus* | SAL | 5.5 | 0.041 | 150.4 | — | — | — | — | — | 15 | 7,160 | 133 |
| SH | *Melanogrammus aeglefinus* | GAD | 6.5 | 0.070 | 127.7 | 0.110 | — | 0.63 | — | — | 70 | 7,000 | 103, 124, 126, 134, 135, 137, 138 |
| SH | *Micromesistius poutassou* | GAD | 8.5 | — | — | 0.150 | — | — | — | — | — | — | 140 |
| SH | *Opisthonema oglinum* | CLU | 26.5 | — | — | 0.235 | — | — | — | — | — | — | 141 |
| SH | *Pagrus major* | PERC | 20.0 | 0.195 | 46.6 | — | 4.76 | — | — | — | 10 | 7,000 | 142, 143, 144, 145, 161 |
| SH | *Paralichthys dentatus* | PLEUR | 18.0 | 0.070 | 98.8 | — | — | — | 0.145 | 0.483 | 50 | 7,000 | 146 |
| SH | *Pleuronectes platessa platessa* | PLEUR | 4.5 | 0.022 | 100.0 | 0.050 | 3.54 (11.5°) | 0.44 | — | — | 101 | 904 | 31, 107, 111, 147, 148, 149, 210, 213 |
| SH | *Sardinella aurita* | CLU | 24.0 | — | — | 0.450 | — | — | — | — | — | — | 150 |
| SH | *Sciaenops ocellatus* | PERC | 26.5 | 0.255 | 22.4 | 0.521 (28.5°) | — | — | — | — | — | — | 151, 211, 212 |
| SH | *Scomber scombrus* | SCOM | 15.0 | 0.140 | 39.5 | 0.520 | — | 0.26 | — | — | 50 | 10,000 | 139, 152, 153, 208 |
| SH | *Scomberomorus cavalla* | SCOM | 28.5 | 0.576 | 11.7 | — | — | — | — | — | 23 | 19,770 | 154 |
| SH | *Scomberomorus maculatus* | SCOM | 28.5 | 0.785 | 8.6 | — | — | — | — | — | 19 | 19,770 | 154 |
| SH | *Scophthalmus maximus* | PLEUR | 15.0 | 0.175 | 39.3 | — | 5.34 | — | 0.198 | 0.884 | 30 | 20,000 | 155, 156, 157, 158, 159, 160 |
| SH | *Sebastes* spp. | PERC | 8.0 | — | — | 0.060 | — | — | — | — | — | — | 162 |

Appendix A. Continued

| ECOS | SP | Taxa | T (°C) | G | D | Z | $QO_2$ | G/Z | $K_1$ | I | $W_0$ | $W_{met}$ | Ref. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| SH | *Solea solea* | PLEUR | 18 | 0.155 | 35.1 | — | — | — | — | — | — | — | 163, 164, 165, 166 |
| SH | *Sparus aurata* | PERC | 17.5 | 0.120 | 49.5 | — | — | — | — | — | 20 | 7,000 | 167 |
| SH | *Theragra chalcogramma* | GAD | 7.0 | 0.075 | 108.3 | 0.075 | 3.77 | 1.00 (6°) | 0.224 | 0.335 | 40 | 10,000 | 138, 139, 168, 169, 170, 171, 172, 173, 174 |
| UW | *Engraulis capensis* | CLU | 18.0 | 0.150 | 47.4 | — | — | — | — | — | 15 | 18,665 | 175 |
| UW | *Engraulis encrasicolus* | CLU | 22.8 | 0.196 | 36.7 | 0.205 | — | 0.95 | — | — | 17 | 22,830 | 176, 177, 178 |
| UW | *Engraulis japonica* | CLU | 22.0 | 0.198 | 47.1 | 0.300 (17°) | — | 0.66 | — | — | 81 | 18,000 | 179, 180, 181, 182 |
| UW | *Engraulis mordax* | CLU | 14.5 | 0.220 | 34.8 | 0.190 (16°) | 5.45 (16.5°) | 1.15 | 0.350 | 0.629 | 20 | 25,000 | 116, 180, 181, 182, 183, 184, 185, 186, 187, 188 |
| UW | *Engraulis ringens* | CLU | 17.5 | 0.105 | 74.3 | — | — | — | — | — | 6 | 12,270 | 189, 190, 191, 196 |
| UW | *Merluccius productus* | GAD | 13.0 | 0.060 | 88.0 | — | 8.30 (11.5°) | — | 0.420 | 0.143 | 40 | 7,000 | 192 |
| UW | *Sardina pilchardus* | CLU | 21.3 | 0.172 | 40.3 | — | — | — | — | — | 12 | 12,500 | 176, 193 |
| UW | *Sardinops sagax* | CLU | 16.6 | 0.209 | 43.8 | 0.10 (16.4°) | — | 2.09 | — | — | 13 | 12,920 | 194, 195, 196, 197 |
| UW | *Scomber japonicus* | SCOM | 19.5 | 0.340 | 17.3 | 0.140 (18°) | 8.75 (20°) | 2.42 | 0.32 | 1.063 | — | — | 198, 199 |
| UW | *Sardinops caeruleus* | CLU | 15.6 | 0.177 | 41.8 | — | 2.00 (14°) | — | — | — | 8 | 12,150 | 200, 201 |
| UW | *Sardinops melanostictus* | CLU | 16.0 | 0.165 | 42.0 | 0.130 (15.1°) | — | 1.26 | — | — | 12 | 12,270 | 202, 203, 204 |
| UW | *Trachurus symmetricus* | PERC | 16.0 | — | — | 0.235 (15.5°) | — | — | — | — | — | — | 205, 206 |

References: 1. Kudrinskaya, 1969; 2. Kuznetsov, 1973; 3. Dabrowski, 1975; 4. Wieser et al., 1988; 5. Tisa and Ney, 1991; 6. Swedburg and Walburg, 1970; 7. Cada and Hergenrader, 1980; 8. Borgmann and Ralph, 1985; 9. Luczynski and Kolman, 1985; 10. Raisanen and Behmer, 1982; 11. Drouin et al., 1986; 12. Taylor and Freeburg, 1984; 13. Freeburg et al., 1990; 14. Rice et al., 1985; 15. Rice et al., 1987a, 1987b; 16. Prokes, 1973; 17. Dabrowski et al., 1984; 18. Dabrowski, 1976; 19. Dabrowski and Kaushik, 1984; 20. Dabrowski and Kaushik, 1985; 21. Dabrowski, 1986; 22. Jitariu et al., 1971; 23. Kamler, 1972; 24. Bryant and Matty, 1980; 25. Korwin-Kosskowski et al., 1981; 26. Kamler et al., 1974; 27. Kaushik and Dabrowski, 1983; 28. Charlon and Bergot, 1984; 29. Kamler et al., 1990; 30. Franklin and Smith, 1963; 31. Erlich et al., 1976; 32. Konchin, 1981; 33. Hokanson et al., 1973; 34. Galat and Eipper, 1975; 35. Panov et al., 1969; 36. Hart and Werner, 1987; 37. Toetz, 1966; 38. Kudrinskaya, 1970; 39. Kolman and Luczynski, 1976; 40. Spoor, 1984; 41. Kramer and Smith, 1960; 42. Laurence, 1969; 43. DeSilva et al., 1986; 44. Rana, 1985; 45. Noble, 1968; 46. Clady, 1976; 47. Post, 1990; 48. Treasurer, 1988; 49. Weiser and Medgyesy, 1990; 50. Wieser and Forstner, 1986; 51. Li and Mathias, 1982; 52. Hokanson and Lein, 1986; 53. Thresher and Brothers, 1989; 54. Wellington and Victor, 1989; 55. Brothers et al., 1983; 56. Thorrold and Milicich, 1990; 57. Saksena and Richards, 1975; 58. McFarland et al., 1985; 59. Victor, 1987; 60. Cowen, 1991; 61. Houde, 1977d; 62. Houde, 1978; 63. Houde and Schekter, 1981; 64. Houde and Schekter, 1983; 65. Crecco et al., 1983; 66. Houde, 1975; 67. Stepien, 1976; 68. Chavance et al., 1984; 69. Chitty, 1981; 70. Leak and Houde, 1987; 71. Houde, in press; 72. Taniguchi, 1979; 73. Taniguchi, 1981; 74. Peebles and Tolley, 1988; 75. Zastrow and Houde, in press; 76. Margulies, 1986; 77. Dey, 1981; 78. Eldridge et al., 1981; 79. Rogers and Westin, 1981; 80. Eldridge et al., 1982; 81. Chesney, 1986; 82. Houde and Lubbers, 1986; 83. Tuncer, 1988; 84. Beck and Poston, 1980; 85. McMullen and Middaugh, 1985; 86. Pearcy, 1962a, 1962b; 87. Laurence, 1975; 88. Laurence, 1977; 89. Buckley, 1982; 90. Cetta and Capuzzo, 1982; 91. Inoue et al., 1974; 92. Uchida, 1981; 93. Houde and Richards, 1969; 94. Ueyanagi et al., 1974; 95. Mori et al., 1971; 96. Jenkins and Davis, 1990; 97. Young and Davis, 1990; 98. Brothers et al., 1983; 99. Hussain et al., 1981; 100. Buckley et al., 1984; 101. Smigielski et al., 1984; 102. Monteleone and Peterson, 1986; 103. Buckley et al., 1987; 104. Liao et al., 1979; 105. Duray and Bagarinao, 1984; 106. Holliday et al., 1964; 107. DeSilva and Tytler, 1973; 108. Eldridge et al., 1977; 109. Almatar, 1984; 110. Checkley, 1984; 111. Gamble et al., 1985; 112. McGurk, 1984; 113. Graham and Townsend, 1985; 114. Lough et al., 1985; 115. Kiorboe and Munk, 1986; 116. McGurk, 1986; 117. Kiorboe et al., 1987; 118. Girin, 1975; 119. Girin et al., 1975; 120. Barahona-Fernandes, 1978, 1979; 121.

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Gatesoupe and Luquet, 1981; 122. Gatesoupe and Robin, 1982; 123. Houde, 1977a; 124. Laurence, 1978; 125. Buckley, 1979; 126. Laurence et al., 1981; 127. Davenport and Lonning, 1980; 128. Gamble and Houde, 1984; 129. Solberg and Tilseth, 1984; 130. Sundby et al., 1988; 131. Houde, 1977c; 132. May, 1971; 133. Moksness, 1982; 134. Jones, 1973; 135. Laurence, 1974; 136. Reed et al., 1989; 137. Bergen et al., 1985; 138. Buckley and Lough, 1987; 139. Kim and Gunderson, 1989; 140. Bailey, 1974; 141. Houde, 1977b; 142. Fushimi and Nakatani, 1977; 143. Kitajima et al., 1980; 144. Fukusho et al., 1984; 145. Kuronuma and Fukusho, 1984; 146. Buckley and Dillman, 1982; 147. Harding and Talbot, 1973; 148. Bannister et al., 1974; 149. Harding et al., 1978; 150. Conand, 1977; 151. Comyns et al., 1991; 152. Kendall and Gordon, 1981; 153. Ware and Lambert, 1985; 154. DeVries et al., 1990; 155. Jones et al., 1974; 156. Kuhlmann et al., 1981; 157. Person-LeRuyet et al., 1981; 158. Paulsen et al., 1985; 159. Quantz, 1985; 160. Van der Meeren, 1991; 161. Oikawa et al., 1991; 162. Anderson, 1984; 163. Girin, 1979; 164. Fuchs, 1982; 165. Gatesoupe and Luquet, 1982; 166. Divanach, 1985; 167. Tandler and Helps, 1985; 168. Hamai et al., 1974; 169. Clarke, 1984; 170. Nishimura and Yamada, 1984; 171. Walline, 1985; 172. Bailey and Stehr, 1986; 173. Kendall et al., 1987; 174. Yamashita and Bailey, 1989; 175. Brownell, 1987; 176. Walline, 1987; 177. Palomera et al., 1988; 178. Palomera and Lleonart, 1989; 179. Hiyashi, 1966; 180. Fukahara, 1983; 181. Uotani, 1985; 182. Fukuhara and Takao, 1988; 183. Hunter, 1976; 184. Methot and Kramer, 1979; 185. Theilacker and Dorsey, 1980; 186. Hewitt and Methot, 1982; 187. Smith, 1985; 188. Theilacker, 1987; 189. DeMendeliola and Gomez, 1981; 190. Herrera et al., 1985; 191. Palomares et al., 1987; 192. Bailey, 1982; 193. Blaxter, 1969; 194. Lasker and Theilacker, 1962; 195. Lenarz, 1973; 196. Balbontin and Garreton, 1977; 197. Butler and DeMendiola, 1985; 198. Watanabe, 1970; 199. Hunter and Kimbrell, *1980*; *200. Scofield, 1934*; *201. Miller, 1952*; *202.* Nakai and Hattori, *1962*; *203.* Kondo, *1974*; *204.* Hayashi et al., *1989*; *205.* Hewitt, *1981*; *206.* Hewitt et al., *1985*; *207. Øiestad, 1985*; 208. Sette, 1943; 209. Barahona-Fernandes and Girin, 1977; 210. Hovenkamp, 1989; 211. Lee et al., 1984; 212. Comyns et al., 1989; 213. Karakiri and von Westernhagen, 1989; 214. McCormick et al., 1971; 215. Brooke and Colby, 1980.