Egg hatching rate of the cyclopoid copepod *Oithona similis* in arctic and temperate waters

**Abstract**

An equation is presented to facilitate estimation of the production of the cosmopolitan cyclopoid copepod *Oithona similis*. The egg hatching rate was studied from Arctic, subarctic, and temperate waters covering a temperature interval from -1 to 20.5 °C. Within the temperature range the hatching rate (HR) increased from 0.03 to 0.06 d⁻¹. Results from all experiments were fitted to a function of temperature ((HR) = a*(T+c) -b) which are mathematically simpler:

\[ HR = (0.0464 + 0.0145 \times T) -1, \quad r^2 = 0.97, \quad P < 0.0001, \quad n=16 \]

HR = 0.4125*e^(1.942), \[ P = 0.001, \quad n=16 \]

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Across the different systems, the environment spanned a broad range (Table 1). The salinity at the different sites was the same (29.0-35 psu), while the temperature obviously increased from the arctic to the temperate regions. Chlorophyll varied in magnitude between locations, but in no systematic pattern with respect to temperature. Egg production rates in copepods are highly variable across all locations.

The eggs in the sars developed relatively synchronously until hatching. On several occasions we observed that nauplii escaped from the egg sacs within minutes of hatching. In other cases hatching appeared to occur over several hours, with nauplii frequently remaining attached to the female for some time by remnants of the opened egg sac. In general the hatching success was high (>95%). During the experiments no female mortality was observed, although during the Disko Bay and Gulf of Alaska cruises some of the females were lost from the webs due to rough waves.

The egg hatching time was inversely related to the water temperature, decreasing from 25.7 to 2.8 d⁻¹ across the temperature range tested (-1.0 to 20.5 °C) (Figure 2). Several equations were fit to the data, many of which provided good overall statistics (Table 2). However, for those models with 31802 parameters at least one parameter was not significant. The linear models (Figure 3) gave the best fit, compared to the exponential models, however, the Haplopoda model with exponent fixed at 2.05 (McLean et al. 1993) proved as satisfactory as the linear model and gave comparable fit. We advocate the linear models between hatching rate (HR, % d⁻¹) or hatching time (H, d) and temperature (T) as being much simpler.

\[ HR = 20.71 \% \times (1-0.8 \times (T+1)), \quad r^2 = 0.99, \quad n=25 \]

\[ H = 10 \times \exp(-0.80 \times T), \quad r^2 = 0.99, \quad n=25 \]

\[ HR = 15.78 \% \times (1-0.8 \times (T+1)), \quad r^2 = 0.99, \quad n=25 \]

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The population specific egg production rate (SEP, d⁻¹) of egg-carrying copepods can be accurately estimated by the egg-rate method (Edmondson, 1971). This method requires knowledge of the eggfertility ratio of the population (i.e. including females not carrying eggs), the egg hatching rate (HR, % d⁻¹) at sub-zero temperature, and the carbon content of the egg and female:

\[ SEP = \frac{Egg}{female} \times HR \times \left(\frac{egg C}{female C}\right) \]

**Results**

Across the different systems, the environment spanned a broad range (Table 1). The salinity at the different sites was the same (29.0-35 psu), while the temperature obviously increased from the arctic to the temperate regions. Chlorophyll varied in magnitude between locations, but in no systematic pattern with respect to temperature. Egg production rates in copepods are highly variable across all locations.

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\[ SEP = \frac{Egg}{female} \times HR \times \left(\frac{egg C}{female C}\right) \]

**Discussion**

Of the egg-carrying marine copepods, the cosmopolitan *Oithona similis* exists over a wide range of temperatures and salinities, and most other marine copepods from temperate brackish coastal waters to subantarctic oligotrophic and subtropical oligotrophic waters (McLean et al. 1993). In cold areas like the arctic and temperate regions, *Oithona* is often the most important winter copepod genus present, and reproduces year round in surface waters (Knutson and Nelson 1934; Jørgensen 1985).

One potential shortcoming of this method is that it presumes the animals incubated are randomly distributed throughout their entire egg-carrying cycle. If egg laying (and hatching) follow a strongly diel cycle (Hopcroft & Roff 1996, Ambient 1999), then there will be a true introdictive, creating a step-like pattern in the percentage cumulative hatching percentage vs. time graph. If this is the case, the equation is invalid, and the estimation of hatching rate. If the method is applied in the tropics, it would appear necessary (and be statistically feasible) to observe both the production and hatching of clutches to estimate the hatching time (e.g. Hopcroft & Roff 1995).

Previous investigations of *Oithona* species hatching or development time cover a higher or smaller temperature range than this study e.g. *Oithona davisae* – 10 to 30 °C (Uye & Sano 1995, 1998) and *Oithona similis* – 4.5 to 14 °C (Eaton 1971). Eaton noted that her value at 4.5 °C might be suspect, as we have confirmed, limiting her reliable data to only 9.4 °C. Thus, our hatching rate measurements at colder and extended temperatures, make the equations applicable for a much larger geographical range.

To our knowledge, this is the first attempt to establish a general equation for estimation of hatching rates of this very important copepod covering the full range of temperatures from arctic to temperate waters. The applied multi-well technique is low cost, space efficient, and allows rapid handling of many replicates – yielding an easy establishment of temperature-dependent hatching rate relationships for copepod species. This facilitates routine estimation of productivity. More importantly, for preserved/ for mesh samples that contain both females and their detached egg sacs, our equations provide a critical step that allows for prediction of secondary production of this abundant but often ignored component of the copepod community.

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