



## CHAPTER I

### INTRODUCTION

Copepods, the dominating mesozooplankton group in the oceans, play a major role in transferring primary production to higher trophic levels in pelagic ecosystem. Although copepods generally appear to process only a minor fraction of the autotrophically fixed energy, they are, as a group, probably the most important single source of food for planktivorous fishes (Kjørboe, 1991).

Studies on secondary production has recently become important with emphasis on understanding the trophic pathways and the energy transfers (Williams, 1984). Production estimates of intermediate (secondary) trophic levels are limited in temperate areas, and sparse in the tropic. The lack of data on rates of energy flow is a considerable obstacle to understand the functioning of marine ecosystems (Longhurst, 1984). Production estimates of specific groups of organisms should enable us to achieve better knowledge of the energy transfers in the marine ecosystems.

The studies on copepods in Thai waters were mainly on the species composition and distribution. The total of 119 species of copepod were reported in the Gulf of Thailand by Suwanrumpha (1987). In the Andaman Sea, studies on zooplankton abundance and distribution around Phuket Island and in Phang-nga Bay has been carried out by marine biologists of the Phuket Marine Biological Center, for example,

Boonruang (1985) who covered the east coast of Phuket Island.

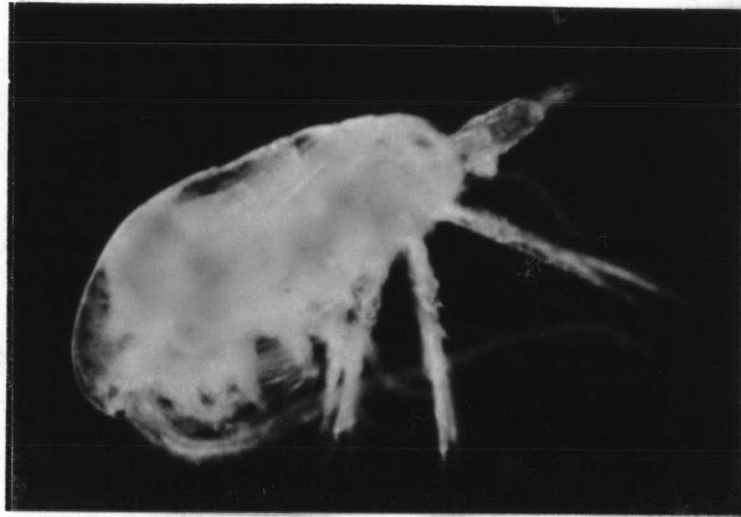
Supongpun (1976) studied the basic biology of harpacticoid copepod, *Schizopera subterranea* Lang, 1948 by rearing in the laboratory. Suvapepun (1976) tried to cultivate five copepods species in the laboratory and only succeeded in two species, *S. subterranea* and *Laophonte* sp. No works yet have been carried out on secondary production.

In this study, calanoid copepod, *Acrocalanus gibber* Giesbrecht 1888 (Fig.1), a neritic species of the Family Paracalanidae, found in the surface water were chosen as a target species. The reasons are ; i) they are easy to be distinguished from other copepod species, ii) they are easily found, and iii) their eggs are released directly into sea water which is an important feature suitable for egg production study in laboratory employing short incubation.


The objectives of this study are :

- 1) To study the pattern of seasonal variations in egg production, abundance, biomass and secondary production of *A. gibber* in relation to environmental factors.

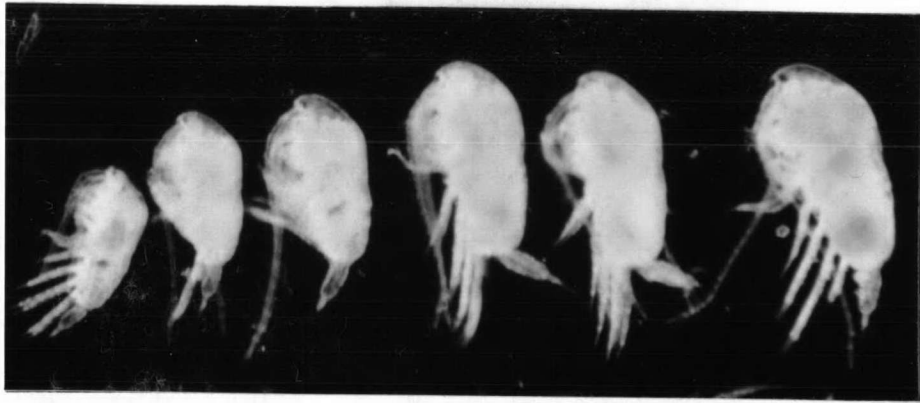
- 2) To study roles of *A. gibber* in the pelagic marine ecosystem by determination of their ingestion rate, gut content analysis of fishes in the same area, and relationship between groups of zooplankton within the zooplankton community.




a



200  $\mu\text{m}$



b



400  $\mu\text{m}$

Fig. 1 *Acrocalanus gibber* Giesbrecht 1888,  
a) adult female,  
b) different sizes of copepodid stages from net sampling.

## Review of Literatures

The name "copepod" (oar-footed, from Greek kope = oar) refers to the form of thoracic appendages, which are modified to form pair of swimming legs, which are linked by intercoxal sclerites, or couplers. The body is divided into two parts, the anterior called the prosome, cephalothorax, which comprises of the fused segments of the cephalosome (5 segments of the head + 1 fused thoracic segment, bearing a uniramous maxilliped) and the leg-bearing segments of the metasome, or thorax (usually 4 or 5). The posterior part of the body is referred to as the urosome, comprises of 1 to 5 segments.

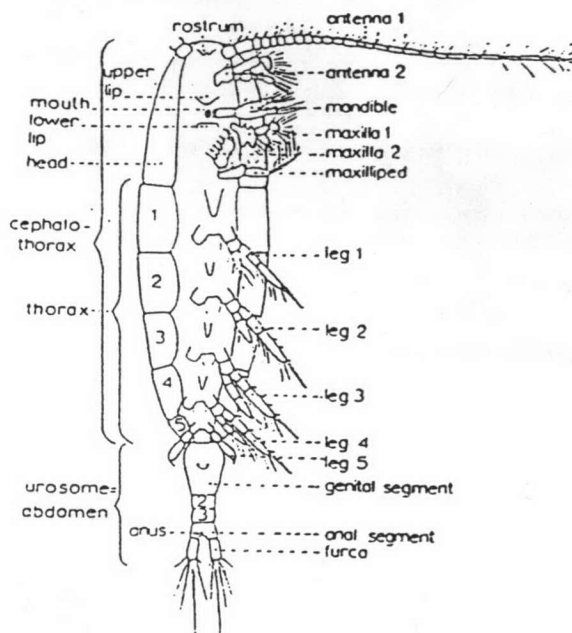


Fig. 2 Diagrammatic representation of calanoid copepod.  
(after McKinnon, 1991).



There are at least 8,000 known species of copepod, of these about 2,000 species are parasitic. About 140 species of calanoid copepods were reported in the eastern tropical Pacific by Chen (1986) and sixty-three species of calanoid copepods were identified. Most of them are found to be oceanic species occurring throughout most of the tropical Pacific. Copepods range in size from less than 0.2 mm to 17 mm in free-living species, while some parasitic species could be as large as 650 mm. On the average, the common size for copepod is 1 mm. The shape of the body varies considerably with taxonomic groups and the habitat of the species concerned.

Copepods have metamorphic life history. Eggs are either carried in egg sacs on the female or shed freely into the water. The eggs hatch into a nauplius stage. There are six nauplii stages which the last stage moults into copepodid stage. There are another six copepodid stages and the last of which is adult. Sexes are separated, though there are some occurrences of parthenogenetic reproduction.

Copepods are found worldwide in a wide variety of aquatic habitats. Some species could even be found in terrestrial environments such as moss forests. Copepods are the most abundant crustaceans of the marine plankton (McKinnon, 1991). Distribution of copepods varied both in time and space, probably due to environmental conditions. Zooplankton, particularly copepods, are able to vertically migrate within 10 to 100 meters every night (Cushing, 1951). The environmental factors, such as species diversity, competition or seasonal factors are playing important roles in modifying the migratory and feeding behaviors (Williams and Conway, 1984). Daro (1985) concluded that all

zooplankton species, particularly copepods, are able to modify their diel rhythms according to the environmental factors. Thus, different patterns exist for each species making part of a global strategy of maximum energy harvest with minimum cost.

Landry (1978) reported that other factors could also become very important and shown that the abundance cycle of *Acartia clausii* in a small temperate lagoon on San Juan Island was controlled by annually consistent pattern of copepodid and adult mortality due to predation by the dominant fish species, rather than the influences of tidal inflow, temperature and food availability.

#### Growth Rate (Juvenile Growth Rate and Egg Production Rate)

Growth can be expressed as the increase with time of length, volume, wet or dry weight. In organisms lacking of exoskeleton, length changes continuously, but in crustacea, such as copepods, which have a largely inextensible exoskeleton, growth becomes essentially a discontinuous process. In copepods, growth can be expressed in two parts, one is the somatic growth and the other is the reproductive growth, or on the other hand called juvenile growth and adult growth, respectively. Both could be determined in terms of specific rate within a period of time, such as per day, by means of the increasing weight relative to their own body weight, as it is called specific growth rate for juvenile stages and specific production rate for adult stages.

McLaren (1978) stated that the maximal rate of production of egg biomass by female *Pseudocalanus* was equal to the food-satiated specific growth rate of younger stages. This could be stated as a

reasonable general hypothesis that maximal specific rate of production by adult female is the same as it is in younger stages.

This hypothesis can be evaluated as it applies to other studies (Sekiguchi et al., 1980 ; Fryd, et al., 1981 ; McLaren, 1986 ; Berggreen et al., 1988) which reported the relationship between juvenile and female specific growth rate of copepods with a slope of 1.0. This would support the hypothesis that measurements of female growth rates alone are sufficient to describe the production of the juvenile as well.

Sekiguchi et al. (1980) studied the relationship between growth rate and egg production rate of *Acartia clausi hudsonica* and demonstrated that the juvenile growth rate could also be predicted by observing maximal rate of egg production of the adult females.

Fryd et al. (1981) studied growth and egg production of two copepod species, *Centropages hamatus* and *C. typicus*, in the laboratory and found that the juvenile growth rate of both species were very similar to the specific egg production rates of the adults.

Berggreen et al. (1988) concluded that, for *Acartia tonsa*, food availability was similar for all development stages and juvenile and female specific growth/egg production rate were equal. Female egg production rates were representative of turnover rate (production/biomass) of the entire population and probably in other copepod species as well. Therefore, in situ estimates of female fecundity may be used for a rapid time- and site-specific field estimate of copepod production.

Peterson et al. (1991) reported a fair relation between juvenile and female growth rate of copepods in the Skagerrak, North Sea, but the slope was 0.33 rather 1.0. This suggested that, in their study, juvenile growth rate were relative food-limited rather than female egg production rates.

### Factors Effecting Growth and Egg Production

For marine copepods, laboratory studies of growth, fecundity and development have demonstrated that temperature and food supply are the chief variables controlling these rates. There are still too few studies which have been completed to permit general statements about whether production is temperature-limited or food-limited (Peterson, et al., 1991).

#### 1.1 Influence of Food Concentration

Many laboratory studies have demonstrated that growth rate of zooplankton herbivores can be limited by availability of food. For instance, Vidal (1980) showed that the growth rate of *Calanus pacificus* increased with food availability up to some critical concentration, above which it remains constant. The effect of food concentration on individual growth became progressively stronger with increasing age and body weight of copepods. Runge (1980) conducted a series of feeding experiments with *Calanus pacificus*, and concluded that food densities in the ocean are probably more frequently higher than below the critical concentration.



For adult female copepods, specific egg production rate seems to be food limited much of the time (Durbin, et al., 1983; Frost, 1985; Runge, 1985; Beckman and Peterson, 1986; Kiørboe and Johansen, 1986; Belantoni and Peterson, 1987; Kiørboe, et al., 1988).

Berggreen, et al. (1988) showed the relationship between seven different levels of food concentration and growth rate of *Acartia tonsa* that growth was exponential and constant at all food concentration. Specific growth rate was negative in starved individuals, zero at the lowest food concentration, and then increased to a plateau of 0.45 per day at higher food concentration. Growth was nearly independent of food concentration above 500 microgram carbon per liter of *Rhodomonas baltica*.

### 1.2 Influence of Temperature

Huntley and Lopez (in press) plotted the relationship between instantaneous growth rate from the data of 181 copepod species collected from 50 references as a function of temperature. Fig. 2 showed the temperature-dependent of the copepods growth rate.

Runge (1984) showed that the mean weight specific rate of *Calanus finmarchicus*, observed in the laboratory, varied from 0.13 per day at 8 °C to 0.21 per day at 15 °C. Egg production rate of females, in the sea off Nova Scotia, taken to the laboratory and fed superabundance food, ranged from 27 eggs per female per day at 5 °C to 62 eggs per female per day at 13.5 °C (Runge, 1985).

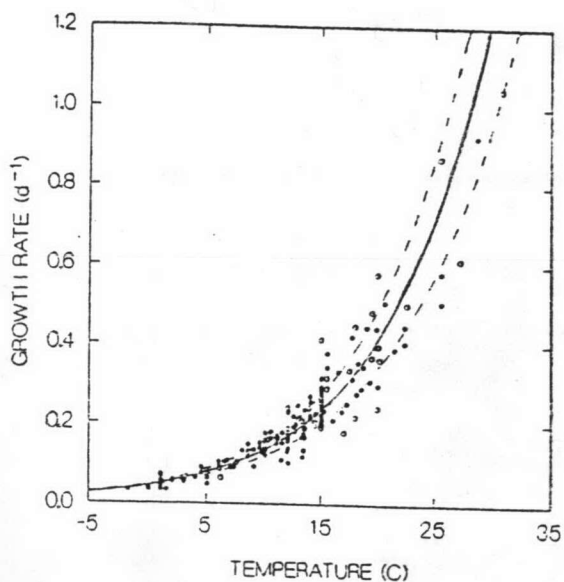


Fig. 3- Instantaneous growth as a function of temperature. Dash lines are 95% confidence limits. There is no significant difference between the relationship for field populations ( $n=101$ , closed circles) and that for laboratory populations ( $n=80$ , open circles). (From Huntley and Lopez, in press)

### Ingestion

The feeding of copepods has been studied in the light of their significant roles in the transformation of organic matter in marine pelagic ecosystem.

Feeding rates can be estimated either directly from the rate of removal of particle from suspension or by incorporation rate of radio-labelled into zooplankton. Feeding rates can also be determined indirectly from the rate of female egg production.

Adult copepods generally feed upon particles 5-10 micrometers in size or larger (Mullin, 1980). Since the morphology of the feeding appendages in nauplii differs from that of copepodites (Fernandez, 1979), their preferences for particle size are presumably different.

Owing to their smaller body size, one might, therefore, hypothesize that nauplii are able to feed on smaller particles.

Berggreen et al. (1988) studied food size spectra of *Acartia tonsa*. The lower size limit for particle captured was between 2 and 4 micrometers for all development stages. Optimum particle size and upper size limit increased during development from about 7 micrometers and 10-14 micrometers for nauplius stage II-III to 14-70 micrometers and about 250 micrometers for adults, respectively. It is obvious that clearance depends consistently on algal size in most of the experiments. Paffenhöfer (1976) showed that feeding performance of copepods depends on the size and shape of the food particle as well as their concentration.

#### Length-Weight Relationship

One approach to assess the energy content of copepods is to determine their biomass or dry weight. Ideally, unpreserved individuals of all stages of each copepod species of interest from selected field samples should be processed to determine the basic length-weight relationships in a standard form,

$$Y = a L^b$$

Biomass and production of taxa can be almost instantaneously calculated, using appropriate length-weight relationships and growth rates (Roff and Hopcroft, 1986).

Considerable variation in the length-weight relationship for the various copepod species (Table 1) is to be expected because of

Table 1 Length-weight relationship for several copepods from various literatures (after Cohen and Lough, 1981).

| Literature source               | Species                        | Equation  | Size (mm) <sup>a</sup>                          | Region                       |   |
|---------------------------------|--------------------------------|---|---|------------------------------|---|
| * Anonymous (MS 1976)           | <i>Pseudocalanus elongatus</i> | $W = 0.0237 L^{2.745}$                          | ?   | Georges Bank                 |   |
|                                 | <i>Centropages typicus</i>     | $W = 0.0214 L^{2.67}$                           | ?   | "                            |   |
|                                 | <i>Calanus finmarchicus</i>    | $W = 0.0257 L^{2.141}$                          | 1.3-4.0   | "                            |   |
| * Chislenko (1968) <sup>b</sup> | Pseudocalanidae                | $W = 0.0181 L^{2.0864}$                         | ?   | ?                            |   |
|                                 | Paracalanidae                  |   |   |                              |   |
|                                 | Calanidae                      |   |   |                              |   |
|                                 | Centropagidae                  |   | $W = 0.02937 L^{2.0111}$                        | ?                            | ? |
|                                 | <i>Oithona</i> sp.             |   | $W = 0.0309 L^{2.088}$                          | ?                            | ? |
|                                 | Acartiidae                     | $W = 0.0090 L^{2.988}$                          | ?   | ?                            |   |
| Corkett and McLaren (1978)      | <i>Pseudocalanus</i> sp.       | $W = 0.0119 L^{2.64}$                           | ?   | Canadian Arctic              |   |
| Davis (MS 1977)                 | <i>Pseudocalanus minutus</i>   | $W = e^{1.6097L - 0.7551} \quad (r^2 = 0.95)$   | ?   | Georges Bank <sup>c</sup>    |   |
| Durbin and Durbin (1978)        | <i>Acartia clausi</i>          | $W = 0.013185 L^{2.1850} \quad (r^2 = 0.77)$    | C1  | Narragansett Bay             |   |
|                                 | <i>Acartia clausi</i>          | $W = 0.009923 L^{2.0778} \quad (r^2 = 0.98)$    | C2-C5   | "                            |   |
|                                 | <i>Acartia clausi</i>          | $W = 0.01237 L^{2.8276} \quad (r^2 = 0.94)$     | C6  | "                            |   |
| * Gruzov and Alekseyeva (1970)  | Pseudocalanidae                | $W = 0.015 L^{2.818}$ (mean error, $\pm 17\%$ ) | ?   | Gulf of Guinea               |   |
|                                 | Paracalanidae                  |   |   |                              |   |
|                                 | Calanidae                      |   |   |                              |   |
|                                 | Centropagidae                  |   | $W = 0.028 L^{2.009}$ (mean error, $\pm 15\%$ ) | ?                            | " |
|                                 | Acartiidae                     | $W = 0.017 L^{2.088}$ (mean error, $\pm 20\%$ ) | ?   | "                            |   |
| * Kamshilov (1951)              | <i>Calanus finmarchicus</i>    | $W = (0.313 L - 0.083)^2$                       | ?   | Barents Sea                  |   |
|                                 | <i>Calanus hyperboreus</i>     |   |   |                              |   |
| * Krylov (1968)                 | <i>Calanus finmarchicus</i>    | $W = 0.0242 L^3$                                | ?   | Barents Sea                  |   |
|                                 | <i>Calanus finmarchicus</i>    | $W = 0.0292 L^3$                                | ?   | North Atlantic               |   |
|                                 | <i>Centropages hamatus</i>     | $W = 0.0281 L^3$                                | ?   | "                            |   |
|                                 | <i>Centropages hamatus</i>     | $W = 0.0445 L^3$                                | ?   | White Sea                    |   |
|                                 | <i>Centropages typicus</i>     | $W = 0.0362 L^3$                                | ?   | Adriatic Sea                 |   |
|                                 | <i>Paracalanus parvus</i>      | $W = 0.0426 L^3$                                | ?   | North Atlantic               |   |
|                                 | <i>Paracalanus parvus</i>      | $W = 0.0392 L^3$                                | ?   | Black Sea                    |   |
|                                 | <i>Paracalanus parvus</i>      | $W = 0.0435 L^3$                                | ?   | Adriatic Sea                 |   |
|                                 | <i>Pseudocalanus elongatus</i> | $W = 0.0364 L^3$                                | ?   | White Sea                    |   |
|                                 | <i>Pseudocalanus elongatus</i> | $W = 0.0336 L^3$                                | ?   | Black Sea                    |   |
|                                 | <i>Oithona similis</i>         | $W = 0.0159 L^3$                                | ?   | White Sea                    |   |
|                                 | <i>Oithona similis</i>         | $W = 0.0234 L^3$                                | ?   | Black Sea                    |   |
|                                 | <i>Oithona similis</i>         | $W = 0.0080 L^3$                                | ?   | North Atlantic               |   |
| * Pertsova (1967)               | <i>Centropages hamatus</i>     | $W = (0.334 L + 0.0142)^2$                      | 0.4-1.4   | White Sea                    |   |
|                                 | <i>Pseudocalanus elongatus</i> | $W = (0.300 L + 0.0372)^2$                      |   | "                            |   |
| Robertson (1968)                | Pseudocalanidae                | $W = 0.01816 L^{2.30} \quad (r^2 = 0.65)$       | C5-C6   | North Atlantic and North Sea |   |
|                                 | Paracalanidae                  |   |   |                              |   |
|                                 | <i>Centropages hamatus</i>     |   |   |                              |   |
|                                 | <i>Calanus finmarchicus</i>    | $W = 0.006458 L^{2.9} \quad (r^2 = 0.77)$       | C5-C6   | "                            |   |
|                                 | <i>Acartia clausi</i>          | $W = 0.01318 L^{2.88} \quad (r^2 = 0.78)$       | C5-C6   | "                            |   |
| Schwartz (MS 1977)              | <i>Calanus finmarchicus</i>    | $W = 0.002305 \times 10^{2.0888L}$              | ?   | Georges Bank <sup>d</sup>    |   |
| * Shmeleva (1963)               | <i>Paracalanus parvus</i>      | $W = 0.034 L^{2.410}$                           | ?   | Adriatic Sea                 |   |
|                                 | <i>Oithona similis</i>         | $W = 0.016 L^{2.213}$                           | ?   | "                            |   |
|                                 | <i>Oithona atlanticus</i>      |   |   |                              |   |
|                                 | <i>Oithona</i> sp.             | $W = 0.013 L^{2.174}$                           | ?   | Atlantic and Adriatic Sea    |   |

<sup>a</sup> C refers to copepodite stage.

<sup>b</sup> Equations generated from nomographs based upon shape most closely resembling species of interest.

<sup>c</sup> Winter.

<sup>d</sup> Spring.

differences in length and weight measurements, laboratory methods, area and season of sampling (Cohen and Lough, 1981). Comparisons of these equations within species are difficult because of geographical and seasonal differences in copepods body size. Both length and weight are positively correlated with food concentration and inversely related to temperature (Durbin and Durbin, 1978).

Chisholm and Roff (1990a) determined the size-weight relationships in nine genera of neritic tropical copepods, at Lime Cay, Jamaica. The copepod community at Lime Cay was represented by 32 species including 18 calanoids, 10 cyclopoid and 4 harpacticoid copepods. In contrast to the temperate species, the body size of the tropical copepods showed no systematic seasonal variation and the length-weight regression did not varied significantly over time. This is likely due to the relatively constant temperature and food regime (Hopcroft and Roff, 1990). Thus any of the length-weight regression should be used during the course of the whole year.

### Production

The cycle of material production in the sea is usually described in simple terms starting with the incorporation of solar energy into autotrophic production in the euphotic zone. The amount of solar energy is restrained by the availability of nutrients and grazing activity of the herbivores/ omnivores. The secondary production is then passed onto the tertiary consumer. The production of any organism is equal to the quantity of food it ingested multiplied by the growth coefficient, or multiply growth rate with their biomass.

The ratio of production to biomass (P/B) is an important characteristic of the population of a given species under known condition. This coefficient is constant for a population with a constant age structure and biomass, but changed in a fluctuating population. It is only a mean value which is true for a defined period of time (Williams, 1984). Secondary production can be determined from biomass data by using P/B coefficients.

Burkill and Kendall (1982) measured the production of *Eurytemora affinis* in Bristol channel, found that the population P/B quotients varied between 0.03 and 0.13 per day, giving an annual P/B of 33 per year. It was suggested that food and predation might influence production more than salinity.

Kjørboe and Johansen (1986) estimated copepod production in the Buchan Sea, assuming that the specific rate of egg production was a measure of the population production (P/B) ratio, the production reached a peak of 225 microgram carbon per cubic meters per day in mix and transitional water and a low of about 50 microgram carbon per cubic meter per day in strongly stratified water.

Chisholm and Roff (1990b) estimated production of copepod community in tropical neritic water based on biomass and growth rate measurements. At Lime Cay, Jamaica, seasonal copepodites production followed a bimodal pattern similar to that observed for abundance and biomass, peaked in October to September and May to June corresponding to the rainy season.