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Ecological interrelationships of zooplankton in Tokyo Bay*

Sachiko NAGASAWA**

Abstract: This paper describes interrelations (predator-prey relationships and symbiosis) of the most abundant zooplankters and microorganisms in Tokyo Bay. The predation impact by *Sagitta crassa* on *Oithona davisae* was 10%. Polychaetes or unknown predators may eat 0.2% of *S. crassa*, but the predation impact by other animals on chaetognaths is unknown. Peritrich ciliates were attached to 18% of *Centropages abdominalis*. Bacterial attachment was observed in 8.5% of *Acartia omorii*. Ten percent of *S. crassa* suffered from bacteria, whereas parasitic infection took place in 2.7% of this chaetognath. Specimens of *S. crassa* in Tokyo Bay which is heavily eutrophicated by man's activities include normal, shaven, headless and deformed animals.

1. Introduction

Tokyo Bay which has an average depth of 17 m and covers an area of 1000 km^2 is located on the eastern side of Honshu Island, Japan. This bay is surrounded with a densely populated and industrialized area that introduces a large amount of nutrients into the bay. Frequent occurrence of red tide is due to elevated concentrations of nutrients.

This paper describes interrelations of the mos abundant zooplankters (some species of copepods, *Oithona davisae* (NISHIDA, 1985), *Acartia omorii* (UEDA, 1986) and *Centropages abdominalis* and a chaetognath, *Sagitta crassa*) and microorganisms (bacteria, ciliated protozoans and trematode larvae) in Tokyo Bay. Predator-prey relationships and symbiosis are discussed; the former includes *O. davisae* - *S. crassa* and *S. crassa* - polychaetes or unknown predators, whereas the latter includes phoresis (*C. abdominalis* - peritrich ciliate *Zoothamnium*), bacterial colonization (*A. omorii* - bacteria, *S. crassa* - bacteria) and parasitic infection (*S. crassa* - larval trematode *Tergestia* sp. (SHIMAZU, 1982)). Discussion is focused on the ecological aspects of these relationships taking place in the planktonic ecosystem in Tokyo Bay.

2. Materials and methods

Samples used for predator-prey relationships were collected on 13 and 14 July 1979. Water samples of 10 l were collected from depths of 0, 5, 10, 15, 20 and 30 m at 4 stations (see NAGASAWA and MARUMO, 1984a) and were filtered through a 20 μm mesh. The specimens retained on this mesh were preserved in buffered 5% formalin seawater and used for counts of adults and copepodites of *O. davisae* and *S. crassa*. Measurements of water temperature were made at each depth of water sampled. On the basis of the estimated daily ration of this chaetognath (NAGASAWA and MARUMO, 1984a), the consumption of prey/l/day was obtained, and the impact of predation by *S. crassa* on *O. davisae* was calculated. The incidence of shaven chaetognaths (NAGASAWA, 1986a) was examined for five samples consisting of 1056, 1273, 1143, 2447 and 1180 individuals.

The nine samples used to investigate phoresis were obtained from 5 January through 2 May 1985 (see NAGASAWA, 1986b). The incidence of *C. abdominalis* with the peritrich ciliate *Zoothamnium* was determined in Shinhamako (see NAGASAWA, 1984), a saline lake connected to Tokyo Bay.

Fifteen samples obtained from 13 January through 4 July 1983 (see NAGASAWA and NEMOTO, 1986) were used for determination of the incidence of *A. omorii* with bacteria. The percentage of deformed chaetognaths in 27 samples collected on 13 and 14 July 1979, and 24 and 25 June 1982 (see NAGASAWA, 1985; NAGASAWA *et al.*, 1985b) was calculated. Chaetog-

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** Ocean Research Institute, University of Tokyo, Minamidai 1-15-1, Nakano-ku, Tokyo, 164 Japan

naths whose guts were infected by larval trematodes were counted in 12 samples obtained on 13 and 14 July 1979 (NAGASAWA and MARUMO, 1984b). The body lengths of 232 chaetognaths with parasites, 274 deformed animals and 672 normal animals were measured to obtain the size composition of the three groups.

3. Results

1) *Predator-prey relationships*

The water of the inner part of Tokyo Bay was stratified with a thermocline between 10 and 15 m. The average temperature was 24.7°C at the surface and 18.7°C at the near-bottom. The daily ration of *S. crassa* was 7.1 prey (*O. davisae*). The mean abundance of *Sagitta* (3.1 ind./*l*) above the thermocline results in the consumption of 14.9 prey/*l*/day. This is 10% of the adult copepod (*O. davisae*) population (147 ind./*l*) and 1% of the total prey available (1293 ind./*l* including copepodites and adults of this copepod).

The incidence of shaven chaetognaths was 0.4, 0.1, 0.3, 0.2 and 0.1% for five samples. The mean value was 0.2% (0.1 SD, standard deviation). This value is far lower than the incidence of chaetognaths with head damage caused by bacterial attack, ranging from 1.6 to 13.3% (NAGASAWA *et al.*, 1984; NAGASAWA, 1985). The rare occurrence of shaven chaetognaths suggests that the predation impact of polychaetes or unknown predators on *S. crassa* occurs in only 0.2% of the population (NAGASAWA, 1986a).

2) *Symbiosis*

Copepods (*C. abdominalis*) carrying peritrich ciliates *Zoothamnium* began to appear on 4 February and disappeared on 18 April. The incidence of such copepods ranged from 0 to 39.8% with a mean of 18.1%. A small number of *A. omorii* and some shrimp larvae were covered with *Zoothamnium*, whereas chaetognaths never carried peritrichs. Two pronounced peaks of incidence were observed, although this does not directly indicate a quantitative temporal variation in peritrich population.

The incidence of copepods (*A. omorii*) with bacteria (cf. NAGASAWA and NEMOTO, 1986) ranged from 0 to 29.1% with a mean of 8.5%; it was low in January and February and increased from January through April, and then decreased in July. The April samples had the highest incidence despite little change in environmental factors such as temperature, salinity and chemical oxygen demand (NAGASAWA and NEMOTO, 1986). On the whole, the difference

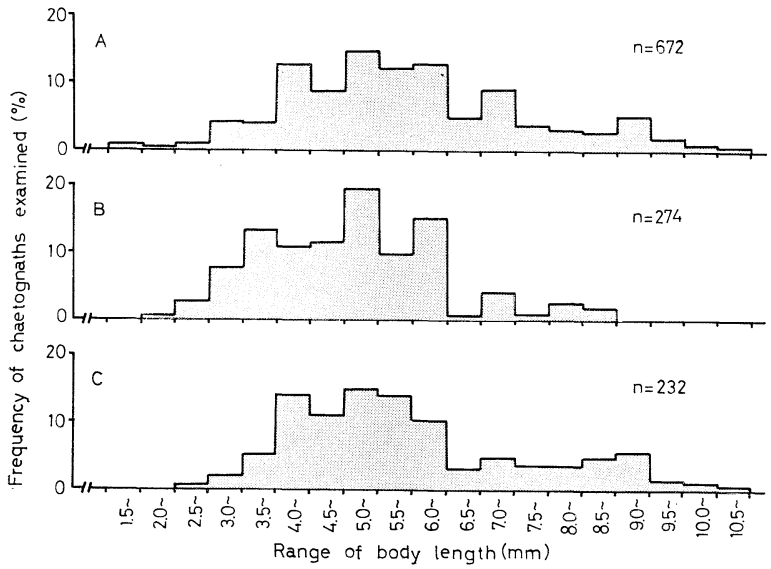

Fig. 1. Size composition of normal chaetognaths (A), deformed ones (B) and those infected with larval trematodes (C) obtained from Tokyo Bay on 13 and 14 July 1979.

in the percentage of copepods with bacteria was seasonally significant at the 1% level.

The percentage of deformed chaetognaths which became abnormally knotty and flabby in July 1979 ranged from 2.5 to 38.5% with a mean of 12.4%. In contrast, the percentage of such abnormal chaetognaths in June 1982 ranged from 0.2 to 19.1% with a mean of 3.9%, which is very low compared with the mean value in July 1979. This difference was significant at the 1% level and may be due to the difference in the year of sampling rather than to differences in month or sampling station location.

The percentage of infection by larval trematodes ranged from 0.8 to 4.7% with a mean of 2.7%. Most infected chaetognaths (88–100%) had one metacercaria and some of them had more than one. The chaetognath population in Tokyo Bay is more frequently infected with larval trematodes than in Suruga Bay (NAGASAWA and MARUMO, 1979) and the East China Sea (NAGASAWA and MARUMO, 1981). The mean body length of chaetognaths infected with larval trematodes, 5.9 mm (1.8 SD), was almost the same as that of normal chaetognaths, 5.8 mm (1.7 SD). Due to the lack of large specimens, however, the mean body length of deformed chaetognaths was 5.0 mm (1.3 SD). The size composition of deformed chaetognaths and those with parasites was similar to that of the normal chaetognaths, although deformed specimens larger than 9.0 mm and specimens infected with parasites less than 2.5 mm were not found (Fig. 1). The absence of larger deformed animals may be due to high mortality and slower growth rates of deformed animals as a result of being handicapped by bacterial colonization and diminished feeding (NAGASAWA, 1985; NAGASAWA *et al.*, 1985b).

4. Discussion

Some ecological features of plankton in Tokyo Bay are summarized in Fig. 2. Chaetognaths feed mostly on copepods as reported by many authors elsewhere. In contrast, data concerning predators of chaetognaths are scarce, although they are sometimes recorded as gut contents of fish or other chaetognaths. Chaetognaths with partial head, which may be attributed to predation by polychaetes or unknown predators, are occasionally found in preserved samples (PIERCE, 1951; GHIRARDELLI, 1968; FEIGENBAUM, 1979; KING, 1979; NAGASAWA, 1986a).

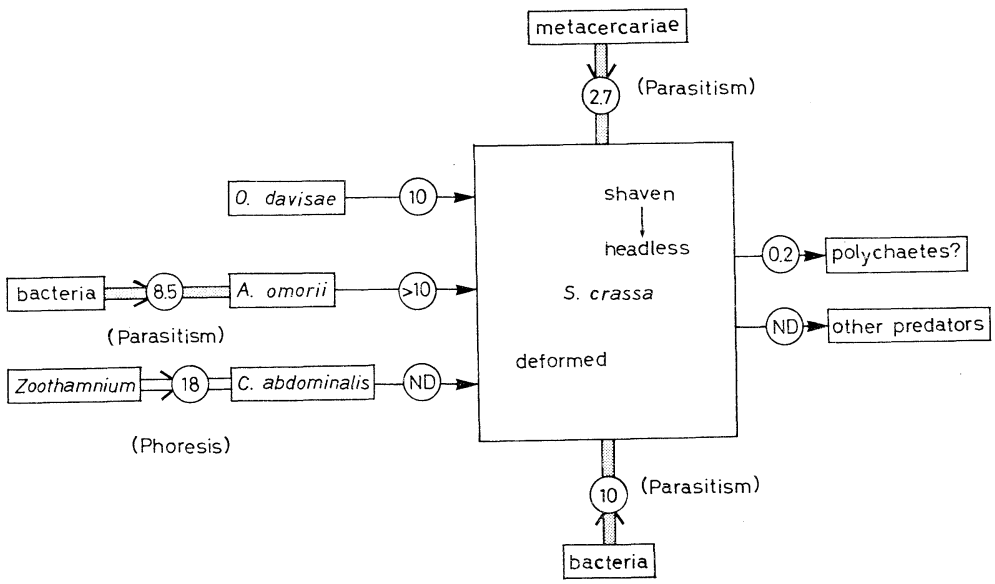

Fig. 2. Summary of interrelations among animals examined in Tokyo Bay. Encircled numbers are the mean percentages of the respective interactions taking place. ND indicates no data. Predator-prey relationships are shown with arrows. Thick shaded lines indicate parasitism, whereas a thick white line indicates phoresis.

Sagitta crassa which is the dominant chaetognath in Tokyo Bay has little impact on the prey available in summer; the number of prey eaten accounted for only 10% of the adult *O. davisae* and 1% of the copepodites and adults of this copepod. In the laboratory *S. crassa* fed on more *A. omorii* than *O. davisae* when these food organisms were separately offered (NAGASAWA and MARUMO, 1984a). They also reported that *S. crassa* 5 to 7 mm in length showed negative electivity for *O. davisae*, indicating that predators avoid *O. davisae* when three copepod species of different size were offered at the same time. The daily ration of *S. crassa* is not available in terms of the number of *A. omorii* in Tokyo Bay. In addition, there are no data on the precise density of *A. omorii*. If the predation impact of *S. crassa* on *A. omorii* which is a more preferable prey than *O. davisae* is determined, it will probably account for more than 10% of the population. Few reports are available which discuss the impact of predation on any species of chaetognath. The present study is the first attempt to estimate the impact of predation by polychaetes or some other animals on *S. crassa*.

Ciliated protozoans might be used to indicate the condition of activated sludge (CURDS and COCKBURN, 1970). *Zoothamnium* on copepods occurred in Tokyo Bay waters in 1985 for the first time since 1982 when I began to examine zooplankton there. This suggests that the quality of water is changing, although it remains obscure whether the quality is improving or not.

Unlike phoresis, bacterial colonization of copepods (*Acartia* spp.) occurred prior to 1985 not only in Tokyo Bay but also in coastal waters in different parts of the world (NAGASAWA, 1986c). Very little data on viable bacterial counts and microflora in the areas studied are available. The tendency for bacteria to become attached to copepods may depend on the physiological activity and developmental stages of copepods rather than on bacterial numbers in the water (NAGASAWA, 1986c). Vibrionaceaen bacteria were few or absent in the inner part of Tokyo Bay in 1972 (SIMIDU *et al.*, 1977), whereas they accounted for 20 to 40% of bacterial flora in 1964 to 1965 (KANEKO *et al.*, 1969). Such a change in bacterial flora may indicate the advance of eutrophication in Tokyo Bay, since the abundance of Vibrionaceae is low in the seawater of eutrophic areas as reported by SIMIDU and TAGA (1980). Although the species of bacteria associated with copepods were not determined, it is likely that *Vibrio* are present in colonies of bacteria as SIMIDU *et al.* (1971) and NAGASAWA *et al.* (1985a) suggested. The growth of *Vibrio* is inhibited by *Skeletonema costatum* in mixed culture (KOGURE *et al.*, 1979). In January a red tide of *S. costatum* occurred at the time of plankton collection. This implies that the presence of *S. costatum* has an effect of the numbers of *Vibrio*. It is of importance to examine this relation in Tokyo Bay where red tides of *S. costatum* frequently occur and the incidence of copepods with bacteria seasonally changes.

Copepod-bacteria associations can be parasitic, since scars representing sites of previous bacterial attachment which seem to have damaged the copepod exoskeleton can be found (NAGASAWA, 1986d), and in addition the bacterial invasion of the inner part of the copepod was shown to occur in some individuals (NAGASAWA, 1986d).

Bacterial colonization was often found in the muscles of deformed chaetognaths, and the musculature of the body wall looked as though it had degenerated (NAGASAWA, 1985; NAGASAWA *et al.*, 1985b). As a result, chaetognaths with bacteria changed shape and appeared quite distinct from normal animals. I found deformed chaetognaths with food, sperm balls (NAGASAWA, 1987) and parasites. In other words, some chaetognaths with bacteria not only contained copepods and parasites in their guts but also had sperm balls on the body evidencing reproductive behaviour. However, feeding and reproductive activity are greatly reduced in these deformed animals (NAGASAWA, 1985; NAGASAWA *et al.*, 1985b), further suggesting that chaetognath-bacteria associations are paracitic.

Chaetognath-metacercaria associations are a common form of parasitism. This parasitic infection was found in 2.7% of the chaetognath population in Tokyo Bay. Chaetognath-bacteria associations were higher (12.4%) than or similar (3.9%) to parasitic infections. Copepod-bacteria associations were observed in 8.5% of the copepod population. In short, more or less 10% of

each of copepod and chaetognath population in Tokyo Bay suffer from bacteria and such chaetognaths are somewhat more abundant than those with parasites. In addition, the mean body length of deformed chaetognaths was smaller than that of normal chaetognaths as well as those infected with parasites. These findings suggest that bacterial colonization of chaetognaths is more serious than parasitic infection and that the former has substantial effects on the mortality and/or growth rate of chaetognath populations.

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東京湾における動物プランクトンの生態的相互関係

永　沢　祥　子

要旨: 東京湾に卓越する動物プランクトンどうし及び動物プランクトンと微生物の相互関係（捕食-被捕食および共生）について述べる。やむし *Sagitta crassa* によるかいあし類 *Oithona davisae* への捕食圧は10%であった。多毛類などによる *S. crassa* への捕食圧は約0.2%と計算されたが，多毛類以外の生物によるやむしへの捕食の実態はまだ不明である。つりがねむしはかいあし類 *Centropages abdominalis* の18%に付着していた。細菌の付着はかいあし類 *Acartia omorii* の 8.5% に観察された。*S. crassa* の 10% が細菌に感染していたのに対し，寄生虫の感染は2.7%のやむしに起こっていた。人間活動の影響を強く受けて富栄養化した東京湾にすむ *S. crassa* は，正常なもの，著しく変形したもの，坊主になったもの，頭のないものを含んでいる。