# Cell size variation of Anoplosolenia brasiliensis(calcareous nannoplankton) in the central equatorial Pacific Ocean

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# Cell size variation of *Anoplosolenia brasiliensis* (calcareous nannoplankton) in the central equatorial Pacific Ocean

Hideto Tsutsui and Kozo Takahashi*

**Abstract**

A morphometric analysis on *Anoplosolenia brasiliensis* (calcareous nannoplankton) was conducted employing samples obtained from 0 to 120 m water depths in the central equatorial Pacific Ocean along the equator ranging from 166.3°E to 170.1°W. Measured cell length of *A. brasiliensis* showed the minimum of 39 μm to the maximum of 165 μm. The cell width ranged from the minimum of 1 μm to the maximum of 10 μm. Measured cell volumes ranged from the minimum of 28.3 $\mu m^3$ to the maximum of 2,741 $\mu m^3$. In addition, length/width ratios ranged from the minimum of 6.8 to the maximum of 37.5. The cell size of this taxon is very large compared to that of other calcareous nannoplankton taxa such as *Emiliania huxleyi*. Related factors for such a large cell size appears to be: (1) population density of the own taxon; (2) ambient temperature; (3) ambient dissolved oxygen concentration; and (4) other phytoplankton population density such as that of *E. huxleyi*. The life adaptation of *A. brasiliensis* is interpreted as fundamentally pursuing a K-strategy, but this taxon is also pursuing an r-strategy when appropriate situation arises. The population density of this taxon may be related to ambient nutrient concentrations, intricate balance among several species of nutrients, and competitions with other coccolithophore taxa such as *E. huxleyi*.

**Keywords:** *Anoplosolenia brasiliensis*, calcareous nannoplankton, morphometrics, cell size, K-strategy, central equatorial Pacific Ocean

## 1. Introduction

In the recent years, we have seen a steady progress in morphometric studies (e.g., de Meuter and Symons, 1975; Lazarus, 1986a; Lazarus, 1986b; Lazarus, 1986c; Kurihara and Takahashi, 2002; Schmidt et al., 2004; Tsutsui and Takahashi, 2009a; Tsutsui et al., 2009b). However, these studies were limited by the following reasons. (1) In general, the plankton groups included in the above-cited literature are microscopic in size. Therefore, the work concerning size measurement requires substantial labor employing a light microscope (LM) or a scanning electronic microscope (SEM) under high magnifications. (2) Significant amount of time must be expended when one wisheds to employ an SEM.

Calcareous nannoplankton can be very useful as indicators for deciphering environmental conditions in oceanography and paleoceanography. It is important to characterize basic information for population, distribution, and/or cell size since the nannoplankton can tell us about environmental conditions such as nutrient concentrations.

Therefore, our present study is focused on morphometric analysis of *Anoplosolenia brasiliensis*. This taxon has a comparatively large-sized cell among many calcareous nannoplankton taxa and hence measurements are easier compared to that of other nannoplankton taxa. The cell form of this taxon appears as a very slim figure like the shape of a javelin. Simply put, the exterior calcareous shield of this taxon is composed of a large number of very slim rhomboids, which are geometrically arranged in an orderly manner (Fig. 2). Each member of such a shield is classified as a 'scapholith' type. A scapholith of this taxon represents an appearance like hair comb slits in the central area called as a 'lath' (Winter and Siesser, 1994). The first description of this species was given by

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Lohmann (1919), followed by a re-description by Deflandre (1952). In recent years, Young et al. (2003) transferred and emended *A. brasiliensis* into genus *Calciosolenia* due to the significant similarity in fine coccolith structure of *Calciosolenia murrayi*. Furthermore, Young et al. (2003) also discussed about classification of *A. brasiliensis* based on the presence/absence by dimorphism: *Anoplosolenia brasiliensis* represents a monomorphic stage, and C. *murrayi* represents a dimorphic stage. In our study, we respect the differences in the coccoliths and coccosphere morphology by lath and cell form of genus *Anoplosolenia* and genus *Calciosolenia*, thus this species in question is tentatively defined as *A. brasiliensis* as done by Deflandre (1952). This species belongs to Kingdom Protista, Phylum Haptophyta, Class Haptophyceae, Order Coccolithophorales, Family Calciosoleniaceae (Manton and Oates, 1985; Jordan and Kelijne, 1994; Heimdal, 1997; Young et al., 2003; Edvardsen and Medlin, 2007). *Anoplosolenia brasiliensis* belongs to heterococcolithophores group (Jordan and Kelijne, 1994). Rutten (1972) discussed about this species based on sediment trap samples collected at approximately 3,000 m depth at Station UM15 in the Bannock basin in the Mediterranean Sea and *A. brasiliensis* was described as a member of calcareous nannoplankton fluxes. Nishida (1979) discussed about this species from the central Pacific Ocean. Manton and Oates (1985) studied morphology of this species in the Galapagos Islands. Manton and Oates (1985) sampled *A. brasiliensis* and *Calciosolenia* aff. *murrayi* from 8 to 19 m depths from Academy Bay, Barrington (Fernandina) Island of the Galapagos Islands. Manton and Oates (1985) discussed fine structures including lath employing LM, SEM and transmission electron microscopy (TEM) and suggested a morphological difference between genus *Anoplosolenia* and genus *Calciosolenia*. Steinmetz (1991) reported about this species in the flux material collected by sediment traps deployed in the equatorial Atlantic, central Pacific and Panama Basin. Nishida et al. (2000) investigated the assemblages and populations of nannoplankton in the central equatorial Pacific Ocean and discussed about this species among other nannoplankton taxa. Ziveri and Thunell (2000) discussed and described this species as a member of coccolithophore flux in sediment trap samples collected from the Gulf of California. Malinverno (2004) observed fine coccolith morphology of *A. brasiliensis* employing an SEM and discussed/classified the results of scapholith morphometrics. The scapholith length of *A. brasiliensis* is 5.8 to 7 μm and the width is 1.9 to 2.3 μm (Malinverno, 2004). In contrast, when *A. brasilieneis* is living in the modern ocean, *A. brasilieneis* has large cell size compared to major calcareous nannoplankton taxa such as genus *Emiliania* and genus *Gephyrocapsa*, but fine details of *A. brasiliensis* size is not well understood. If a population of *A. brasiliensis* were found in a sediment trap sample, it would be possible to predict that the total mass flux of that sample would be very large for the reasons discussed in Discussion section of this paper. Therefore, we discuss about the variations in *A. brasiliensis* population and cell size of living *A. brasiliensis* in the modern ocean.

## 2. Materials and Methods

### *2.1. Sampling logistics*

Seawater samples containing nannoplankton were collected on R/V Mirai of JAMSTEC during Cruise MR99-K07, November to December 1999 in the central equatorial Pacific Ocean (Nishida et al., 2000). The sampled depths were limited down to 200 m and the sample water volumes were approximately two to three liters. The sampled stations are shown (Fig. 1). Cruise MR99-K07 started at 04.2°N/135.6°E as Station 1 and the ship steamed along the equator from 145°E to 170.1°W in the central equatorial Pacific Ocean. Stations 1 to 12 were assigned from the east to west as identification numbers (ID) for the samples. Significantly large populations of *A. brasiliensis* were observed at Stations 7, 8, 9 and 12 and hence the populations of *A. brasiliensis* at the four stations were used for a morphometric analysis. Size variations of this taxon can effectively be measured at the four stations by the following reasons: (1) The populations present are sufficient at the four stations among Stations 1 to 12 with statistically satisfactory numbers. (2) The area of high population density is found at Stations 8 and 9 and Station 7 is located at the margin of the high density. Therefore, the cell size variations of *A. brasiliensis* are set to be measured at the three stations plus Station 12, which provides a fair population density.

The logistics for sampling is given (Table 1). Our study depths for *A. brasiliensis* ranged as follows: 0, 10, 30, 40, 50, 60, 80, 100 and 120 m. This is because that below 120 m depth the population density of this taxon was expected to be nearly zero and thus there was no need of taking additional samples from further down depths. The pertinent environmental data such as water temperature, salinity and nutrients were summarized by Kawano (2000).

The seawater samples were filtered and sieved through 200 μm stainless steel mesh and large-sized plankton particles were excluded: no filtered seawater samples include, for example, copepods and planktonic foraminifers. Finally, the calcareous nannoplankton samples were filtered onto Millipore$^{R}$ HA type membrane filters with a nominal pore size of 0.45 μm. After this process, the filters were dried at room temperature in the shipboard

laboratory.

After the filters were brought back to the shore laboratory, circular subsamples of 6 mm in diameter were cut off. The observation for *A. brasiliensis* was conducted on an SEM. The logistic details of the SEM observation are as follows: JSM-6300PS with the acceleration voltage of 10 to 15 kv; and samples coated with carbon vapor using JFE-400 carbon coater (both made by Japan Electron Optics Laboratory (JEOL)).

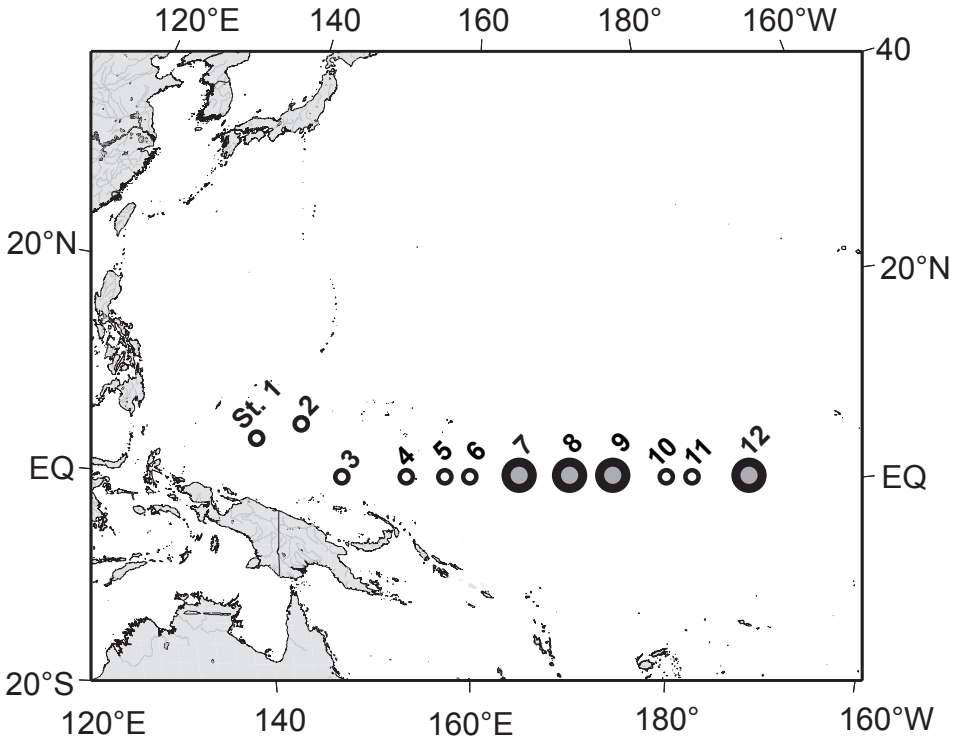


Fig. 1. Map showing the sampled locations

Table 1. Logistics for the sampling.

| Station ID | Longitude (all at the Equartor) | Sampled Date (all 1999) | Sampled Time |
|---|---|---|---|
| St. 7 | 166.3°E | 4 Dec. | 10:33-11:20 |
| 8 | 171.4°E | 5 Dec. | 10:35-11:16 |
| 9 | 174.5°E | 6 Dec. | 11:05-11:43 |
| 12 | 170.1°W | 9 Dec. | 10:30-11:32 |

***2.2. Morphometric technique***

SEM images of *A. brasiliensis* are shown (Fig 2). The morphometric techniques are kept as simplest and fastest as possible in this study. We focused on measuring cell "length", scaling the distance from one tip to the opposite tip. Analogously, "width" represents the widest part of a cell. In practice, *A. brasiliensis* often exhibits a bending feature like an arch. In that case, the length is manually measured with a flexible lead ruler on a TV screen of the SEM. The morphometric concept employed here is illustrated (Fig. 3). Cell volumes can be calculated based on the measurements of length and width, assuming a cell is made of a pair of ideal geometric cones. The numerical formula for a cell volume is also shown (Fig. 3).

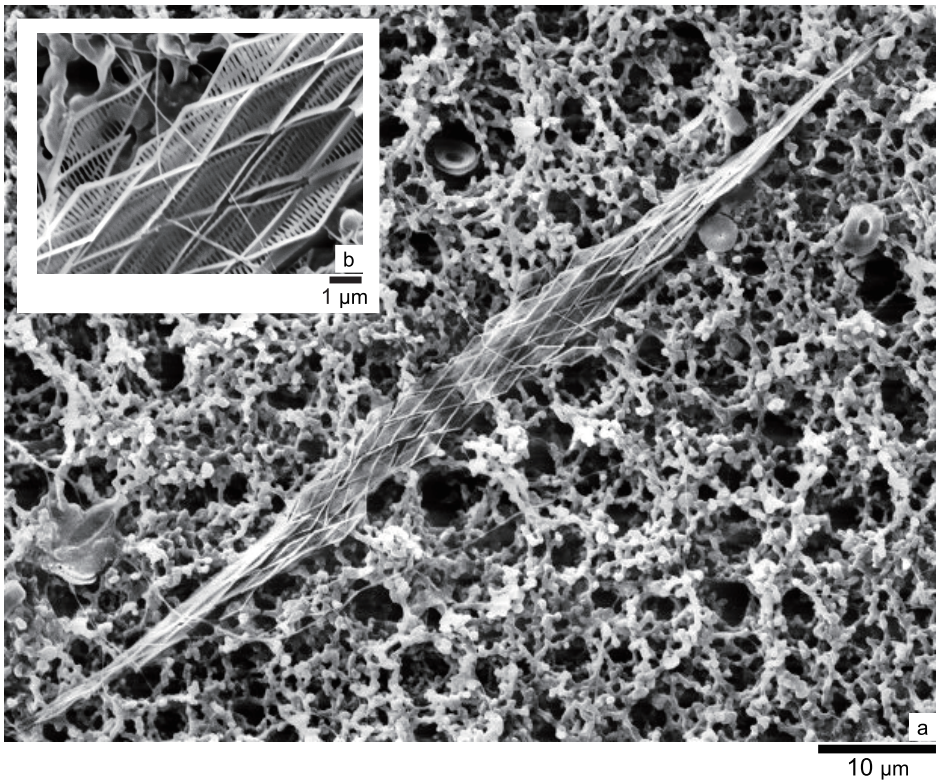


Fig. 2. (a) SEM photograph of *Anoplosolenia brasiliensis* from the equatorial Pacific Ocean (the Equator, 178°05.26W), at 50 m depth at Station 10. (b) An enlarged view of the thickest part of photograph (a).

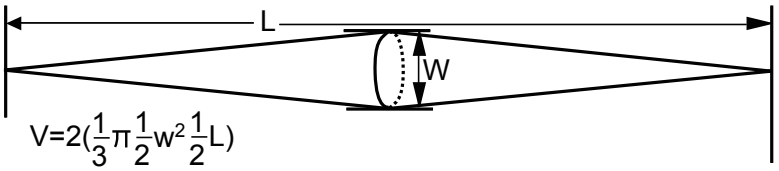


Fig. 3. Graphic representation of the morphometric method. 'V' is a cell volume.

## 3. Results

### *3.1. Population of A. brasiliensis along the equator*

Distribution of *A. brasiliensis* during Cruise MR99-K07 is illustrated (Fig. 4). Among all sampled stations, the maximum population density of calcareous nannoplankton was 3,333 individuals $\ell^{-1}$, and the mean value throughout all stations was 614 individuals $\ell^{-1}$. The depth of the maximum population found was at 40 m at Station 8 (171.4°E). The samples from Station 8 and Station 9 (174.5°E) represented 43% of the specimens of total populations, followed by Station 12 (170.1°W) as the third rank representing 14% of the total. The remaining 43% of the population was represented by those from Stations 1 through 6, 10 and 11 (Fig. 4).

On the other hand, when we pay our attention to vertical distribution, 85% of the population concentrations are located between 0 to 70 m depths (Fig. 4). The highest population density is found at 50 m, contributing 15% of total at all depths. The population contributions at 40 m and 60 m are 12% at both depths. In summary, from the surface to 50 m depth the populations increased gradually, but below 50 m the populations decreased and the populations became very small representing only less than 1% below 100 m.

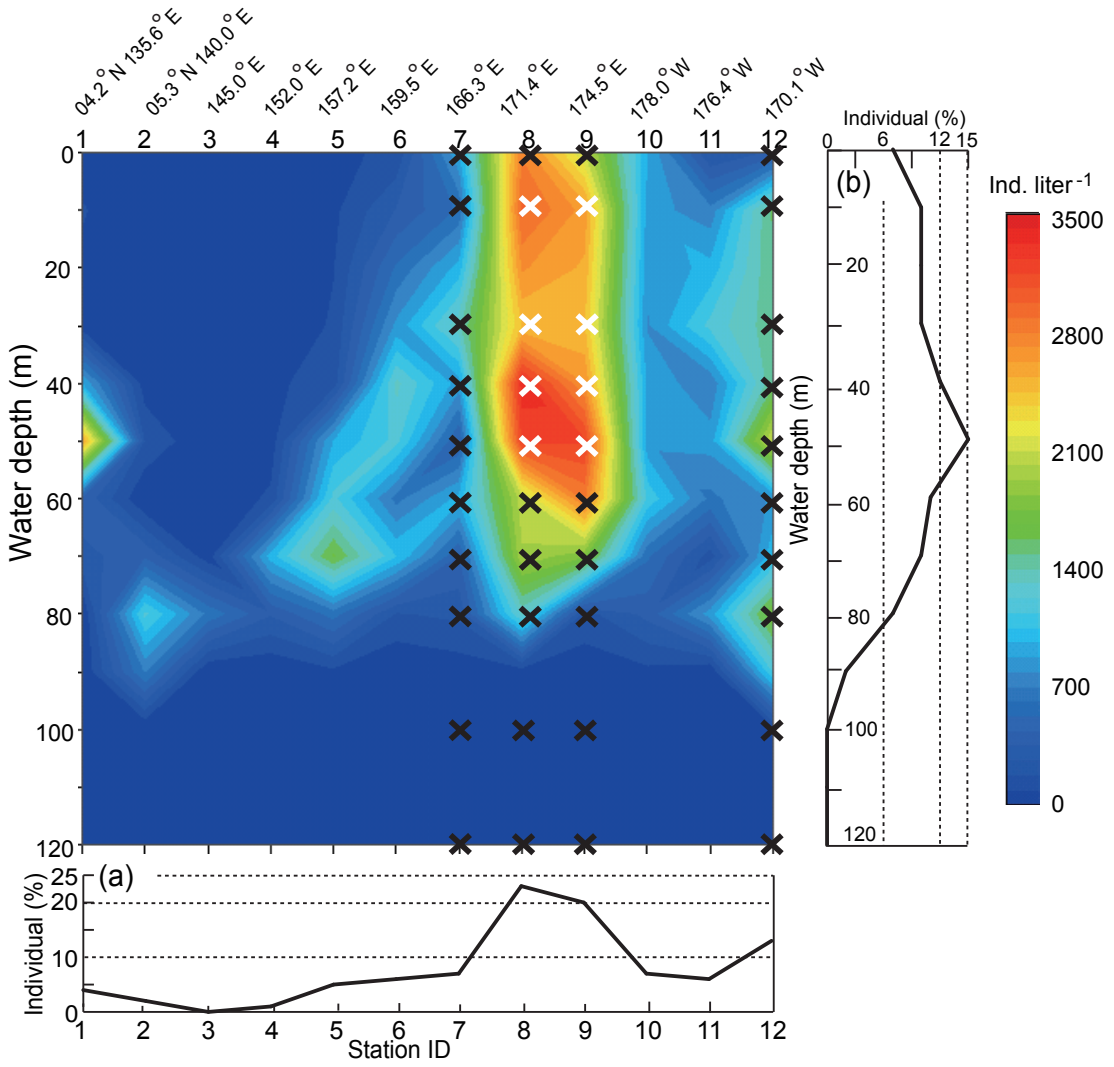


Fig. 4. Distribution of *A. brasiliensis* populations. Crosses represent sampled locations/depths.
Bottom line graph: % contribution by each station in total populations throughout the stations; left line graph: % contribution by each depth in total populations throughout the depths.

### *3.2. Morphometric results*

A total of 1,026 of *A. brasiliensis* specimens were initially attempted to measure for size. Some specimens were, however, physically damaged and the seriously damaged specimens were rejected in the analysis, making the number of valid specimens 963 individuals for length and 1,003 for width. The statistical results of the morphometrics are based on total specimens from all depths and they are summarized including the following parameters: minimum, maximum, mean, standard deviation (S.D.), skewness and kurtosis (Table 2). The results in skewness and kurtosis represent good proxies for the measure of normal distribution (Ichikawa and Ohashi, 1987).

The measured cell length ranged from a minimum of 39 µm to a maximum of 165 µm. At Station 8 (171.4°E) cell length showed a wide range of values compared to that from other stations. The mean cell length also showed a wide range compared to other parameters: the mean value was approximately 10 µm; and the S.D. was greater than 15 µm. In contrast, width showed a narrow range compared to length: the measured cell width ranged from a minimum of 1 µm to a maximum of 10 µm. The mean width also showed a narrow range: the mean value was approximately 5 µm; and the S.D. was approximately 1 µm. In summary, the measured length varied significantly greater than that of the width. The cell length and width can be used to calculate cell volume (Table 2). At Station 7 (166.3°E) and Station 9 (174.5°E) the mean cell volume is greater than 700 µm$^3$. On the other hand, the mean

cell volumes at Station 8 and Station 12 (170.1°W) showed both approximately 300 μm³, which was roughly one half of the volume measured at the other two stations. The measured kurtosis values are very large except at Station 9.

Table 2. Summary of the statistical analysis performed.

| Station ID | Longitude | (a) Length | | | | | | | (b) Width | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Min. (μm) | Max. (μm) | Mean (μm) | S.D. (μm) | Skewness | Kurtosis | N | Min. (μm) | Max. (μm) | Mean (μm) | S.D. (μm) | Skewness | Kurtosis |
| Statistics | | 963 | 39 | 165 | 83.1 | 17.4 | 0.62 | 1.02 | 1003 | 1 | 10 | 5.5 | 1.1 | 0.50 | 1.02 |
| St. 7 | 166.3°E | 119 | 55 | 147 | 90.7 | 17.9 | 0.49 | -0.07 | 124 | 3 | 10 | 5.6 | 1.1 | 0.91 | 2.48 |
| St. 8 | 171.4°E | 286 | 42 | 165 | 83.8 | 17.0 | 0.86 | 2.15 | 297 | 2 | 9 | 5.4 | 0.9 | 0.51 | 1.20 |
| St. 9 | 174.5°E | 395 | 39 | 149 | 79.2 | 16.4 | 0.46 | 0.50 | 408 | 3 | 9 | 5.8 | 1.1 | 0.59 | 0.43 |
| St. 12 | 170.1°W | 163 | 46 | 162 | 85.4 | 17.9 | 0.62 | 1.20 | 174 | 1 | 7 | 5.0 | 1.0 | 0.04 | 0.46 |

| | | (c) Length/Width | | | | | | | (d) Cell volume | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | Min. | Max. | Mean | S.D. | Skewness | Kurtosis | N | Min. ($\mu m^3$) | Max. ($\mu m^3$) | Mean ($\mu m^3$) | S.D. ($\mu m^3$) | Skewness | Kurtosis |
| Statistics | | 963 | 6.8 | 37.5 | 15.4 | 3.9 | 0.87 | 1.48 | 963 | 28.3 | 2741.0 | 702.2 | 354.1 | 1.62 | 4.39 |
| St. 7 | 166.3°E | 119 | 9.3 | 25.1 | 16.4 | 3.8 | 0.32 | -0.68 | 119 | 234.8 | 2734.5 | 789.4 | 398.3 | 2.19 | 7.56 |
| St. 8 | 171.4°E | 286 | 7.3 | 28.7 | 15.6 | 3.7 | 0.54 | 0.47 | 286 | 120.6 | 2741.0 | 329.2 | 329.2 | 1.98 | 7.01 |
| St. 9 | 174.5°E | 395 | 7.2 | 28.0 | 13.9 | 3.2 | 0.83 | 1.36 | 395 | 200.9 | 2092.8 | 731.3 | 367.2 | 1.18 | 1.40 |
| St. 12 | 170.1°W | 163 | 6.8 | 37.4 | 17.4 | 4.5 | 1.00 | 2.04 | 163 | 28.3 | 2056.3 | 298.8 | 298.8 | 1.36 | 3.49 |

### *3.3. Relationship between length and width and summarized results for a normal distribution*

The plot for length versus width is illustrated (Fig. 5). The two morphometric parameters did not show any strong correlations each other, but a vague trend can be read along two lines drawn at the upper and lower ends. The morphometric results of *A. brasiliensis* are summarized (Fig. 6). The high kurtosis value for cell length at Station 8 (Table 2) is represented by a sharp peak compared to those at other stations. The frequency distribution curves indicate a dull shape at the top compared to those at other stations, but almost all of the peaks are concentrated between 90 μm and 100 μm in length. In addition, the values for width are concentrated between 5 μm and 6 μm. The peaks for a normal distribution columns are shifted to the left side.

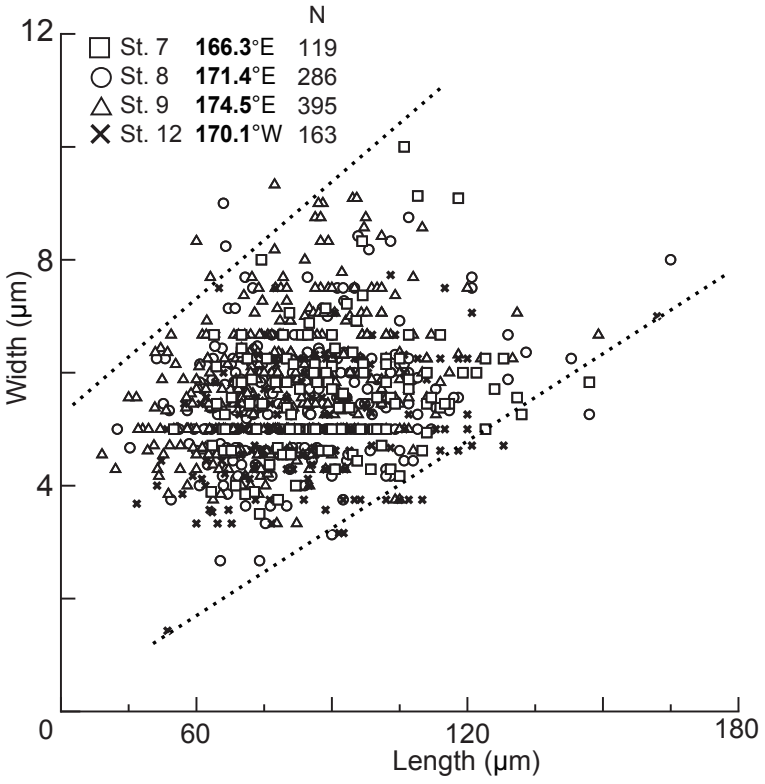


Fig. 5. Plot for length vs. width.

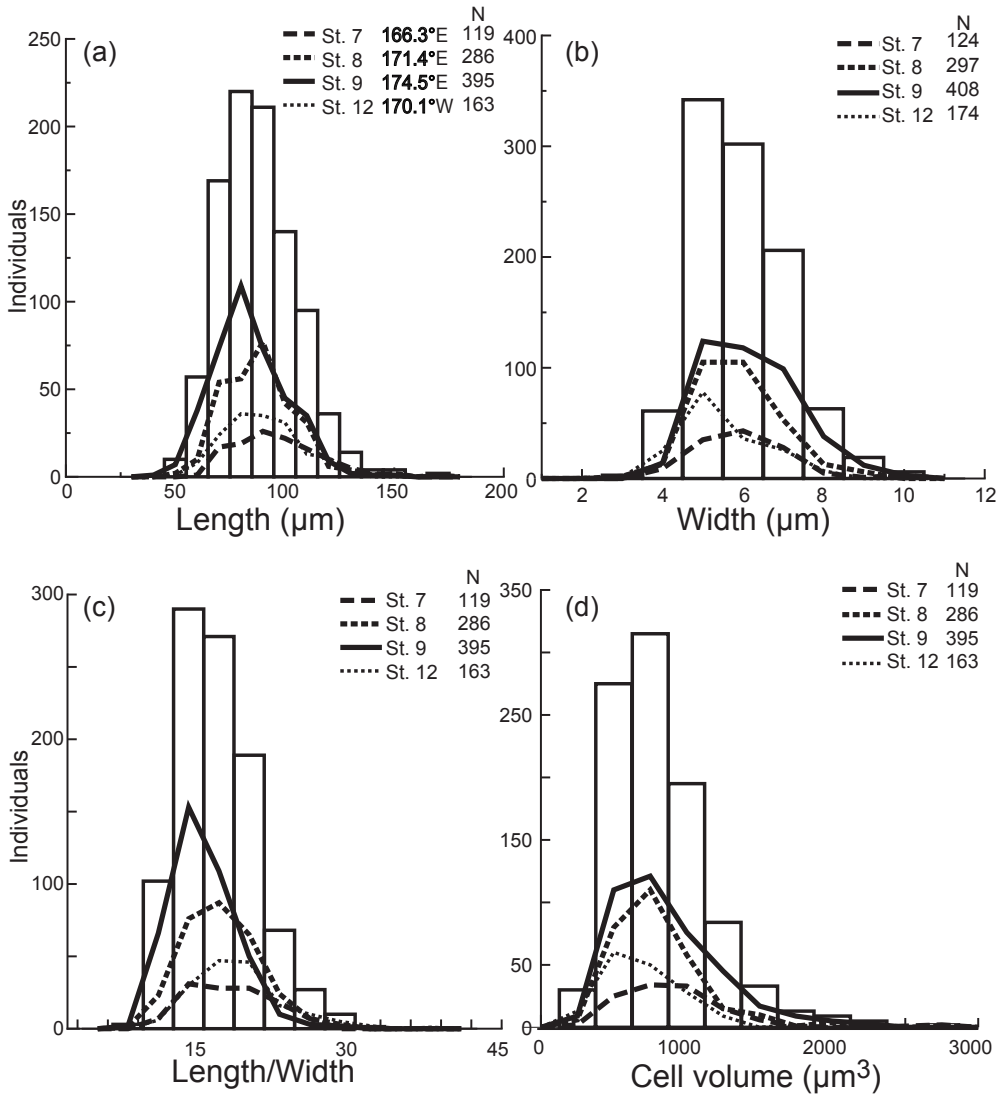


Fig. 6. Histograms for length, width, length/width and cell volume, respectively (columns: sum of the four stations); each of the line graphs represents a histogram curve for a given sampled station.

## 4. Discussion

### *4.1. Difference in cell volume at each station*

At this step, the variations in cell volume of *A. brasiliensis* are confirmed by t-test: a statistical difference in length can be evaluated depending on depth and station. The results of t-value are summarized (Table 3). First, the results of t-test suggest that there is a statistical difference between the verge point covered by Station 7 and the dense populations covering Station 8 to Station 9. In contrast, the t-test results between Station 8 and Station 9 shows no statistical difference.

Therefore, concerning the cell volume of *A. barasiliensis* belonging to three discrete sample groups we performed another round of t-test again: Station 7, Station 12 and the group of high population density consisting of Stations 8 and 9. The results are summarized in Table 3. The cell volumes of *A. brasiliensis* appear different depending on the verge point of high population density at Station 7 or the dense population group represented by Stations 8 and 9. Therefore, we performed a third round of t-test of *A. brasiliensis* cell volume in opposite sides: the cell volumes in low and high population density, respectively. The borderline between the low population and high population density appears approximately at 1,000 individuals $\ell^{-1}$. The results of the t-test show a statistical difference in *A. brasiliensis* cell volume between the values less than 1,000 individuals $\ell^{-1}$ and greater than 1,000

individuals $\ell^{-1}$. The relationship between cell length and population density is illustrated (Fig. 6). The density of 1,000 individuals $\ell^{-1}$ appears to represent a reasonable boundary between the following two cases. The case with fewer than 1,000 individuals $\ell^{-1}$ shows a wide range in length from approximately 55 to 110 μm. For the case with greater than 1,000 individuals $\ell^{-1}$, the measured cell length is concentrated at approximately 75 to 100 μm. In summary, the variation in cell length of *A. brasiliensis* can be represented by two separate modes depending on high or low population density.

Table 3. Results of t-test matrix: (a) among four stations; (b) among Station 7, Station 12, and the sum of Stations 8 and 9; and (c) between the population density <1,000 individuals $\ell^{-1}$ and >1,000 individuals $\ell^{-1}$. The results with significant differences are shown in bold face.

(a) among four stations

| Class | St. 8 | St. 9 | St. 12 |
|---|---|---|---|
| St. 7 | **2.72**** | **1.47** | **4.58**** |
| St. 8 | —— | -1.70 | **2.75**** |
| St. 9 | —— | —— | **4.09**** |

(b)

| Class | St. 8+St. 9 |
|---|---|
| St. 7 | **-2.16*** |
| St. 12 | **4.18**** |

(c)

| Class | >1000 ind. liter$^{-1}$ |
|---|---|
| <1000 | **2.58*** |

Prob.: ** (1%), * (5%)

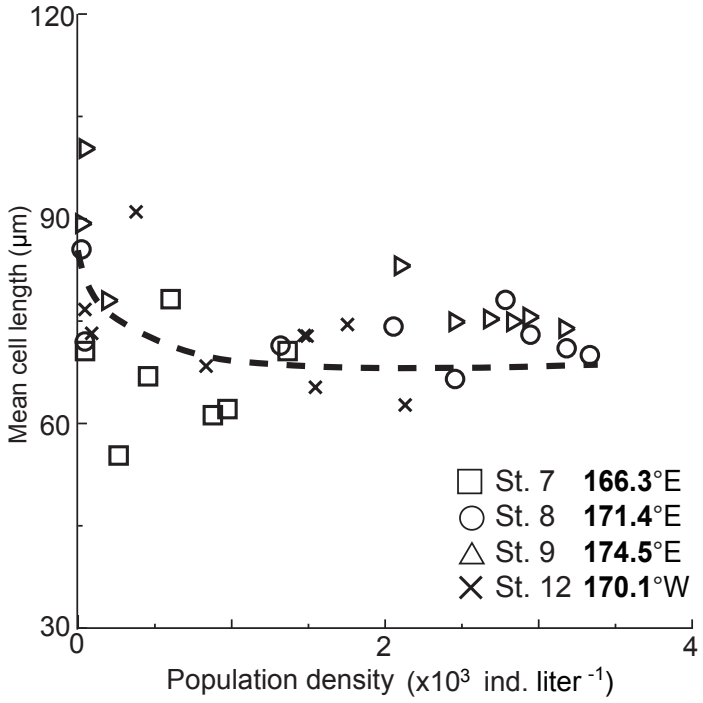


Fig. 7. Relationship between mean cell length and population density. The dashed line is the result of a regression analysis.

***4.2. Environmental conditions as related factors for cell size***

In general, nannoplankton-sized marine life requires metabolic substance from ambient waters such as nutrients for growth. The obtained cell volumes of *A. brasiliensis* at the four stations are compared with the

measured pertinent oceanographic conditions acquired during Cruise MR99-K07 (Fig. 1): temperature and dissolved oxygen (DO) among many parameters available (Kawano, 2000). In the case of temperature, approximately 27°C appears as the most popular level accounting for the majority of the populations that we investigated. Approximately 190 μmol $kg^{-1}$ is the most popular condition for DO (Fig. 8). Temperature is an important factor as a prerequisite, but the relationships with cell volume variations and DO are unknown. Related factors for cell volumes of *A. brasiliensis* are the followings: (1) population density of this own taxon; (2) water temperature; and (3) DO. Nishida et al. (2000) discussed the changes in population density of the major calcareous nannoplankton taxa encountered in the same samples as this study: they are *Umbellosphaera irregularis, Emiliania huxleyi, Florisphaera profunda* and *Thorosphaera flabellate*. The relationship between the populations of *A. brasiliensis* and *E. huxleyi* is of interested and illustrated (Fig. 9). It is quite cleat that these two distinctively different taxa in shape and size were behaving quite differently each other. When the population density of the latter is fairly high (Stations 7, 11-12) that of the former is low. On the contrary to this, the former picks up its populations at Station 8-9 where the latter declines its populations. Such a mirror image trend observed from Stations 12 to 7 may be a hint showing a biological competition for nutrient uptake while it is hard to prove. For example, *Gephyrocapsa oceanica* is one of the major taxa in population besides *E. huxleyi*, but the population of *G. oceanica* decreased from Station 9 to the west towards Station 7 (not shown). The nutrient level of $PO_4$ is the highest at Station 12, which is located within the equatorial upwelling region (Fig. 9). There is a general decreasing trend in nutrient concentrations from Station 12 to the west towards Station 1. However, from Station 9 to the west towards Station 6 significant changes are observed in trend and ranks of nutrient concentrations for $NH_3$ and $NO_2$, especially relative to those of $PO_4$ (Fig. 9). The maximum concentrations for $NH_3$ and $NO_2$, are found at Station 8 and Station 7, respectively. It may be that *A. brasiliensis* expands its population density at the nutrient level somewhat intermediate rather than the highest. Whether the biological competition is important or ambient nutrient concentrations are more influential must be evaluated in light of further data in future studies.

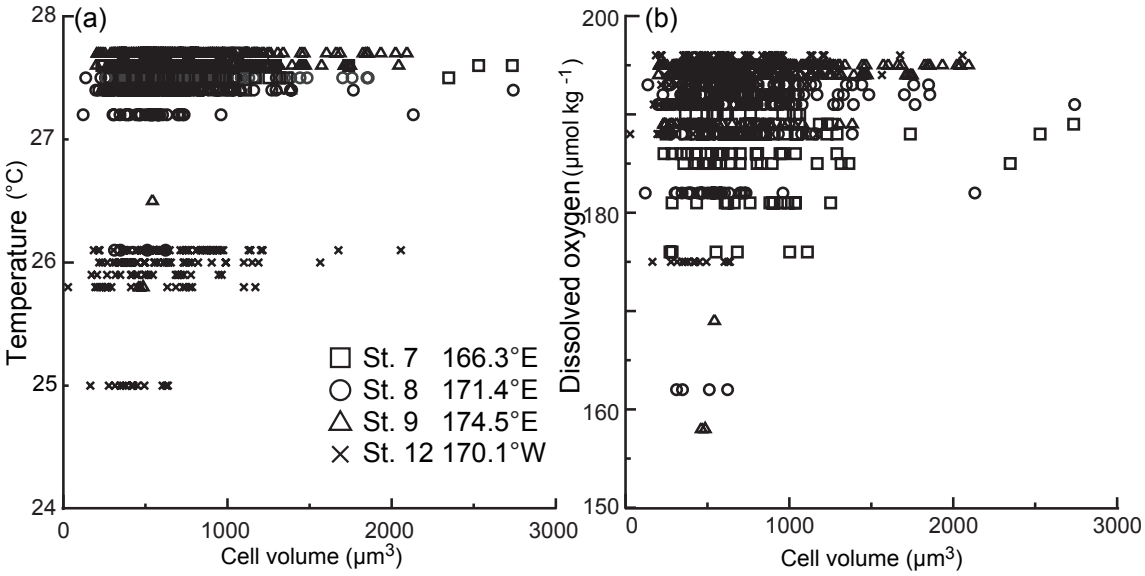


Fig. 8. Relationships between cell volumes and temperature as well as DO as environmental indices.

***4.4. Reproductive strategy of A. brasiliensis***

Organisms are surrounded by environments and thus they are depended on the ambient conditions. *Anoplosolenia brasiliensis,* a coccolithophore taxon, is not an exception for such dependency on environments. *Anoplosolenia brasiliensis* pursues an adaptation strategy called a ”K-strategy”, which is a commonly used term in ecology. The following features, which are encountered in this taxon, fit in a K-strategy: (1) large body size (Table 2, Figs. 5, 6); (2) low population density compared to that of an r-strategy type (low population density shown at Stations 1 through 12, with respect to those of *E. huxleyi* except for at Stations 8-9 (Figs. 4, 9)); (3)

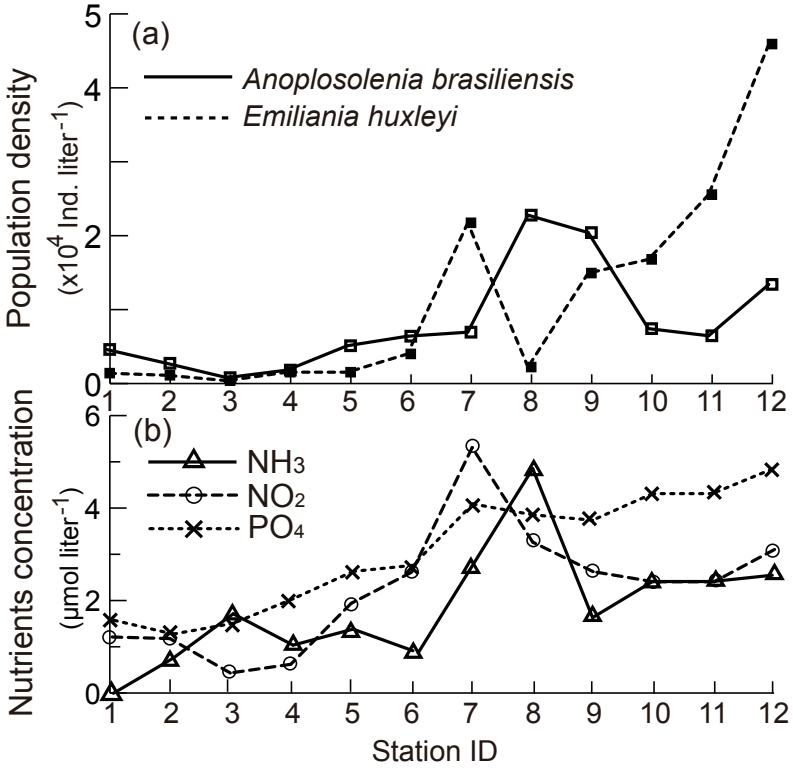


Fig. 9. (a) Changes in population density of *A. brasiliensis* and *E. huxleyi* for Cruise MR99-K07. (b) Also potted are nutrients concentrations for $NH_3$, $NO_2$, and $PO_4$ obtained during Cruise MR99-K07 (Kawano, 2000).

possessing a monomorphic stage; and (4) responsive to low nutrient concentrations (e.g., Foster, 1964; MacArthur and Wilson, 1967; Kimoto, 1979; Tuomi, 1980; Iwasa, 1981; Young et al., 2003; Malinverno, 2004 and Litchman et al., 2007). Young et al. (2003) and Malinverno (2004) described this taxon as possessing a haploid, and this taxon did not show any positive response for specific nutrients (Fig. 9). The above four features represent as evidence for a K-strategy. In addition to a K-strategy, MacArthur and Wilson (1967) proposed another way of life adaptation as an ”r-strategy”. With an r-strategy in stable environments organisms adapt opposite features and characteristics with respect to those of a K-strategy such as high fecundity, small body size, early maturity, and short generation time. A K-strategy can also be seen in other coccolithophore taxa than *A. brasiliensis*. For example, it is known that *Coccolithus braarudi* represents two different ecological niches depending on environmental conditions, representing a haploid stage when nutrient concentrations are low and a diploid stage when nutrient concentrations are high (Houdan et al., 2006).

However, at Stations 8 and 9 *A. brasiliensis* showed remarkably large populations compared to that of other stations (Fig. 4). When the population density of *A. brasiliensis* is greater than 1,000 individuals $\ell^{-1}$, cell length decrease ca. 25% from low to high population density groups along the regressions line (Fig. 7). When the population density of *A. brasiliensis* is greater than 1,000 individuals $\ell^{-1}$, this taxon appears to have modified growth strategy for adaptation. In other word, the greater the population density becomes, smaller the variance of cell length becomes. We interpret that this taxon has adapted an r-strategy in the situation with relatively high population density. Such a trend can also be observed in body size and litter size of mammals (Tuomi, 1980). Moreover, it is known that major phytoplankton groups and size classes use skillful tactics for nutrient utilization along nutrient availability gradients (Litchman et al., 2007). When the major species of coccolithophores such as *A. brasiliensis* and *E. huxleyi* swapped their population maxima between Stations 8 and 9, *A. brasiliensis* appeared to have won the competition against *E. huxleyi*. Therefore, *A. brasiliensis* fundamentally pursues a K-strategy, but this taxon is also pursuing an r-strategy when the situations become appropriate such as in the above case. According to Lewis (1985), natural selection in phytoplankton could optimize the utilization and storage of nitrogen and phosphorus, and render an advantage to haploid organisms with lower requirements of

these elements in ambient environmental conditions. Margalef (1978) and Houdan et al. (2006) strongly recommended needs for observations on nutrient response in r-strategy and K-strategy in phytoplankton.

## 5. Summary

The maximum population density of *Anopsolenia brasiliensis* was 3,333 individuals $\ell^{-1}$ located at 40 m depth at Station 8. A total of 963 individuals were measured for size analysis. The measured cell length ranged from the minimum of 39 μm to the maximum of 165 μm; width from the minimum of 1 μm to the maximum of 10 μm; and cell volume from the minimum of 28 $\mu m^3$ to the maximum of 2,741 $\mu m^3$. The length/width ratios showed the minimum of seven to the maximum of thirty-seven. One of the related factors for cell length of *A. brasiliensis* appears to be own population density. When the population density is less than 1,000 individuals $\ell^{-1}$ the measured cell length ranged from 55 to 110 μm. In contrast, when the population density is greater than 1,000 individuals $\ell^{-1}$, the values for cell length are clustered in the range of 75 to 100 μm. As other related factors attributing to such a large cell size, the following hydrographic conditions appear important enough to report among many parameters available: water temperature is ca. 27°C; and DO is ca. 190 μmol $kg^{-1}$. The cell volume variations in *A. brasiliensis* may be negatively influenced by the presence of *E. huxleyi* populations. Intricate nutrient levels with a balance among nutrient species must be considered as one of the factors contributing in high population density of *A. brasiliensis* encountered at Stations 8 and 9. Fundamentally, *A. brasiliensis* pursues a K-strategy for survival because that this taxon presents: (1) large cell size; (2) low population density compared to that of *E. huxleyi*; and (3) responsive to low nutrient conditions. Nevertheless, this taxon is also pursuing an r-strategy when ambient situation becomes appropriate.

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