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Temporal variation in the density and size composition of a population of the tropical chiton *Stenoplax alata* (Sowerby, 1841) on Ishigaki Island

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ABSTRACT Density and size composition in a population of the tropical chiton *Stenoplax alata* (Sowerby, 1841) were monitored for 4 years on a cobble shore of Ishigaki Island, Okinawa. The density fluctuated between 7 and 32 individuals per m^2, and the sequence was divided into three periods, namely, increasing, higher-level stable, and lower-level stable. Small individuals of less than 4 mm in 5th-valve width were considered to be new recruits. New recruits appeared from November to May with the peak density between February and May, suggesting that the recruitment occurred during this period. The size composition also showed three types, single-mode, double-mode, and triple-mode. A comparison of the patterns of density fluctuation and the size composition suggested that the density fluctuated according to the recruitment density and that the larger mode of the size histogram contained 2- or 3-year classes.

RIASSUNTO E' stata monitorata per 4 anni (da agosto 1997 a luglio 2001) la densità e la distribuzione per taglie di una popolazione del poliplacoforo tropicale *Stenoplax alata* (Sowerby, 1841) su una spiaggia con ciottoli nell'isola di Ishigaki, Okinawa. La densità si è mostrata variare tra 7 e 32 individui per m^2, e la serie e' stata suddivisa in tre periodi, precisamente: crescita, stabilità su alti livelli e stabilità su bassi livelli. Esemplari con larghezza della quinta valva inferiore a 4 mm, sono stati considerati come individui dell'ultima generazione. Questi giovani individui reclutati appaiono da novembre a maggio, con un picco di densità tra febbraio e maggio, il che suggerisce che la comparsa di nuovi individui avvenga in questo periodo. Gli istogrammi che rappresentano la frequenza della larghezza della quinta valva, sono di tre tipi: a distribuzione unimodale (che e' stata osservata da agosto a dicembre 1997 e da luglio a settembre 1999), a distribuzione bimodale (la tipologia più frequente, che appare in tutte le stagioni) e a distribuzione trimodale, che e' stata osservata a gennaio, marzo e maggio 1999 ed a dicembre 2000. Un confronto tra i modelli di fluttuazione di densità e la distribuzione per taglia ha suggerito che le fluttuazioni di densità sono in relazione con la densità di comparsa di nuovi individui e che la moda maggiore degli istogrammi di taglia raggruppa classi di individui di due o tre anni.

KEY WORDS: Cobble shore, Density fluctuation, Long-term monitoring, Size composition, Tropical chiton

INTRODUCTION

Chitons are known to be a major component of the intertidal food web (Paine, 1966) and play a role as herbivores (Dethier & Duggins, 1984; Duggins & Dethier, 1985; Nishihama, 1993; Markel & DeWreede, 1998) and bioeroding agents (Rasmussen & Frankenberg, 1990) in intertidal communities. Several authors have studied various biological and ecological aspects of chitons, for example, distribution patterns (e.g., Kangas & Shepherd, 1984; Nishihama et al., 1986; Otaíza & Santelices, 1985), diet (e.g., Langer, 1983; Nishihama et al., 1986; Piercy, 1987), reproduction (e.g., Pearce, 1979; Yoshioka, 1989), and behavior (e.g., Thorne, 1968; Nishihama & Nojima, 1990; Chelazzi *et al.*, 1990); however, little attention has been paid to their population ecology. Several authors have investigated temperate coast chiton populations (Baxter & Jones, 1978; Otway, 1995; López Gappa & Tablado, 1997; Takada, 1997) and reported the specific traits of individual species. However, other than Glynn's (1970) Caribbean study, basic information on tropical and subtropical chiton population is scarce.

Stenoplax alata (Sowerby, 1841) is a tropical Indo-Pacific species that is widely distributed on southeastern Asian coasts but rarely found on coasts in the Japanese temperate regions. S. alata is a common species along the coasts of the Ryukyu Islands (Okinawa); however, its density is low even in this subtropical region. On a cobble shore of Ishigaki Island, a relatively dense local population of *S. alata* was found and quantitatively monitored for 4 years. Because the spatial range of the population was very small, I assumed that there were some mechanisms, such as stable annual recruitment and low mortality rates, which sustained the population in the limited area. To clarify how these mechanisms sustained the populations, first-hand observations of the population dynamics are indispensable. This paper describes the temporal variations in the density and size composition of the chiton population and their possible causes.

STUDY SITE AND METHODS

The study site was a cobble shore on the west side of Ishigaki Island **(Fig. 1)**, which is moderately sheltered from wave action. Sand accumulates on the shore in winter and disappears from spring to autumn. On the study site, sand accumulates all the year round in the central area of the intertidal zone, but the upper and the lower zones never have been covered with sand. Because Ishigaki Island is surrounded by fringing reef, it is not affected by oceanic swells. During spring tides, the tidal range of the shore is 1.8 m to 2.0 m, and the intertidal zone extends 80 m. The size of stones is 10-20cm, nearly all of which are sedimentary and igneous. The stones that are attached or buried in a sulfide layer of the sediment are blackened on the surface due to a deoxidized substance. On the lower intertidal zone, several species of seagrass grow among the cobbles and form patches of several square meters.

To identify the distribution range of the chiton before routine

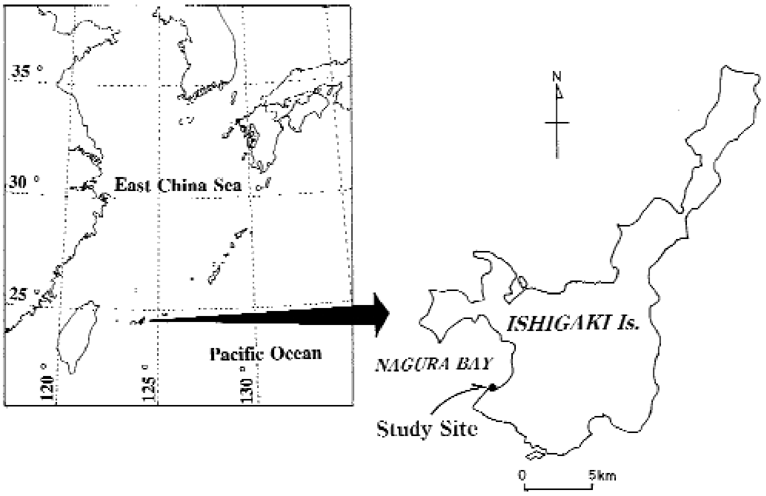


Fig. 1. Location of the study site.
Fig. 1. Mappa della località studiata

sampling, a survey line crossing the chiton habitat was set from the upper shore to the subtidal zone, and the density of molluscs was recorded at 10m intervals using a 50 x 50 cm quadrat. On the lower zone, where the chiton is found, 5m interval grids were set, and the density and the distribution pattern of the chiton were investigated. From August 1997 to July 2001, quantitative sampling was carried out in the chiton habitat monthly to bimonthly to demonstrate the temporal variations in the density and size structure of the chiton. During the low tide of the spring tide, 50 x 50cm quadrats were placed randomly in the chiton habitat. All pebbles and cobbles in the quadrat were turned over, and the 5th-valve width of each chiton was measured using caliper accurate to 0.1 mm. All stones were replaced in their original positions to minimize disturbance of the organisms. The number of quadrats differed with the sampling date according to the chiton density, since the goal was to measure more than 50 individuals per day. No chitons were collected in order to maintain the local population. The data obtained were used to calculate the mean and standard deviation of the chiton density, and size-frequency histograms were constructed.

RESULTS

The *Stenoplax alata* population was observed at a point 50 m from the land to the seaward edge of the intertidal zone (**Fig. 2**), where cobbles were spread on a sandy bottom with sparse seagrass vegetation. The chiton habitat was located on the lowest intertidal zone to the uppermost fringe of the subtidal zone. The habitat range of the chiton was about 300 m^2 and included the cobble area and cobble-seagrass mixed area. The chitons were under the cobbles, but they were seldom attached to the deeply buried cobbles or to the deoxidized blackened cobble surfaces. Other invertebrate species were present in numbers in the study site. In the upper half of the intertidal zone, neritid snails (*Nerita squamulata* and *Clithon faba*) were dominant, and, in the lower zone, cerithid (*Clypeomorus subbrevicula*), a cowry (*Cypraea annulus*), another chiton (*Ischnochiton* sp.), tube-building and free-living polychaetes, and sipunculid worms were most common. Many other species of gastropods and bivalves were also noted, especially in the lower zone, though the density of each species was low.

Fig. 3 shows the temporal variation in the density of all *S. alata* from August 1997 to July 2001. The density fluctuation of the small individuals (less than 4 mm in 5th-valve width) that were considered to be new recruits is also given in Fig. 3. The overall mean density of the *S. alata* during the survey was 14.4 individuals per m^2. The mean density on each sampling date increased in the early half of 1998, attained a peak in late May (32.0 individuals /m^2), and then decreased in a short period. In September 1999, the density suddenly decreased by half and then stabilized at around 10 individuals per m^2. The density fluctuation showed neither a seasonal nor annual trend; however, the fluctuation sequence could be divided into three periods; increasing period from the start of the survey to the peak in May 1998, higher-level stable period from August 1998 to August 1999, and lower-level stable period from September 1999 to the end of the survey. During the former stable period, the mean density fluctuated between 14 and 26 individuals per m^2; on the other hand, it ranged from 8 to 13 during the latter stable period. The density of small individuals fluctuated seasonally, increasing from winter to spring and being low in summer and autumn. From 1998 to 2000, the density of small chitons showed a peak between February and May, but in 2001

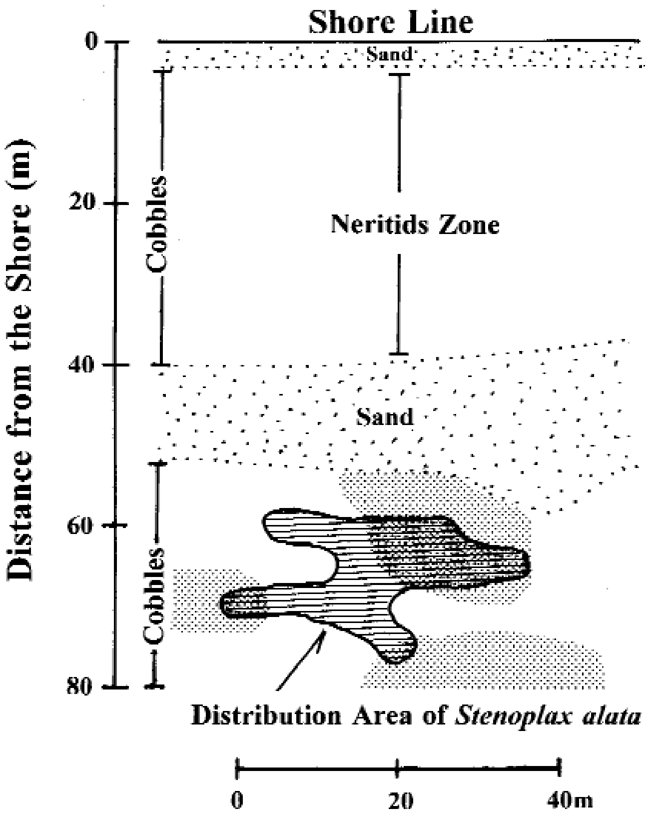


Fig. 2. Scheme of the distribution of the bottom type and the habitat of *Stenoplax alata* at the study site.
Fig. 2. Schema di distribuzione della tipologia di fondale e dell'habitat di *Stenoplax alata* nella località in esame.

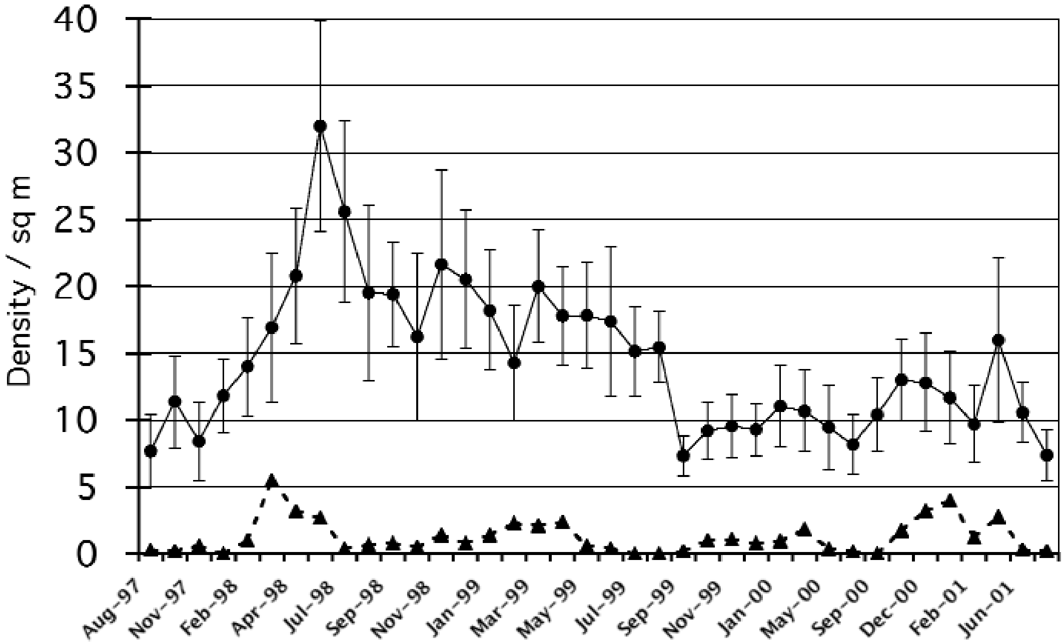


Fig. 3. Temporal variation in the density of *Stenoplax alata*. Solid circles are the mean density of all individuals, and the triangles indicate the mean density of small individuals less than 4 mm in 5th-valve width. Bars indicate the 95% confidence limit of the mean. The confidence limit was omitted in the case of small chitons.

Fig. 3. Variazione temporale nella densità di *Stenoplax alata*. I cerchi pieni esprimono la denistà media di tutti gli individui; i triangoli indicano la densità media degli esemplari con larghezza della quinta valva inferiore a 4 mm. Le barre indicano il limite di confidenza della media corrispondente al 95%. Il limite di confidenza è stato omesso nel caso di esemplari giovanili.

there were two peaks, one in January and another in April.

The patterns of the size-frequency histogram of the chiton could be classified into three types (**Fig.** 4). The most dominant type was the double-mode distribution, which appeared in all seasons. The single-mode type was observed from August to December in 1997 and from July to September in 1999. The third type was the triple-mode distribution, which appeared in January, March, and May, 1999, and December, 2000. In the case of the single-mode type, the chiton mode size was larger than 4 mm in 5th valve width. When the size composition showed a double or triple-mode type, chitons smaller than 4 mm appeared. When the smaller modes first appeared, the range in size varied from 2 to 4 mm and shifted toward the larger size with time. In 1997, small chitons that were assumed to be new recruits were observed from August to November, but they did not form a size group until February 1998. A similar outcome was observed from September 1998 to January 1999, but, in the autumn of 1999, the recruitment density was relatively high, and a smaller mode became obvious in November. In this study, the smallest individual observed was 1.7 mm in 5th-valve width (5 mm in total length). In all types, there was a larger mode between 5.5 and 8.0 mm. Compared to the smaller mode, this larger one was unstable and moved up and down within the range. Observing the movement pattern of these modes, it seemed that the larger mode shifted to the smaller size when the smaller mode approached the larger mode (e.g., October 1998, February and June 1999).

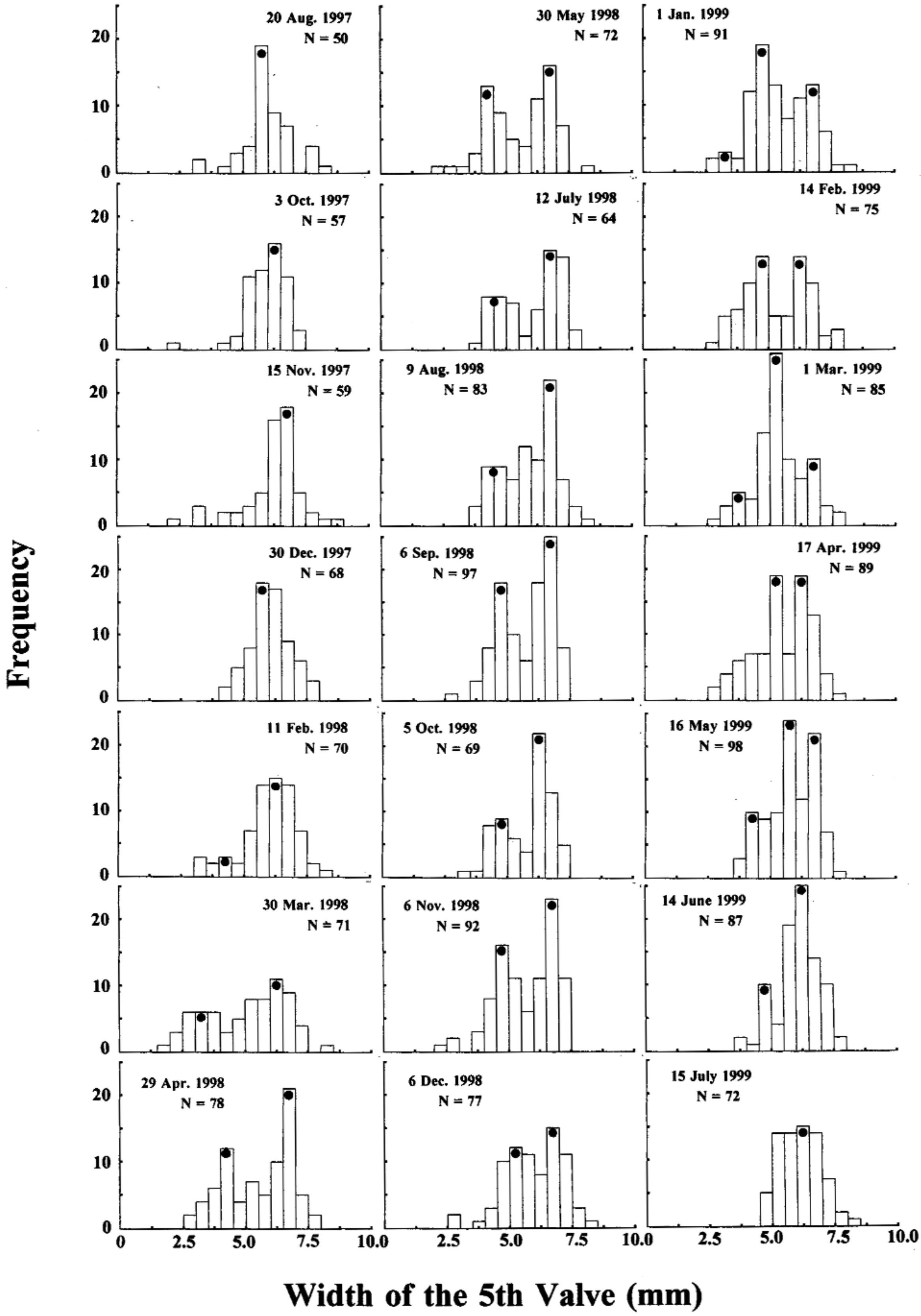
DISCUSSION

In some localities, chitons are extremely dense, densities up to 600 to 1000 individuals per m^2 have been recorded (Langer, 1978; Otaíza & Santelices, 1985; Bode, 1989). Compared with these values, the density of *Stenoplax alata* in this study was low (the overall mean during the survey was 14.4 per m^2, and the maximum, 32 per m^2), but similar to the population densities of several species reported around the world, for example, on the Pacific coast of North America (Piercy, 1987), the Caribbean (Glynn, 1970), Argentina (López Gappa & Tablado, 1997), southern and southeastern Australia (Kangas & Shepherd, 1984; Otway, 1994), and western Japan (Nishihama *et al.*, 1986; Takada, 1997).

The density fluctuation of *S. alata* could be divided into three characteristic periods. During the first period of increase, the size composition of the chiton showed a typical double-mode distribution (from February to July 1998), and small individuals (less than 4 mm in 5th-valve width), assumed to be new recruits made up a certain percentage of the population. In the next higher-level stable period (August 1998 to August 1999), the size composition showed all three types, and new recruits were rare. During the third lower-level stable period, the major type of size composition was, relatively clearly, the double-mode type, though new recruits were not abundant.

These relationships suggested that annual variation in recruitment density occurred, governing the variation in the size composition and the density of *S. alata* at the study site. To verify this assumption, it will be necessary to quantify the recruitment density and its annual variation.

Because the size histogram had a maximum of three modes, it was suggested that there were year-classes of 2 and more. In the smaller mode, the individuals that were less than 4 mm in 5th-valve


20 Aug. 1997
N = 50
30 May 1998
N = 72
1 Jan. 1999
N = 91
3 Oct. 1997
N = 57
12 July 1998
N = 64
14 Feb. 1999
N = 75
15 Nov. 1997
N = 59
9 Aug. 1998
N = 83
1 Mar. 1999
N = 85
30 Dec. 1997
N = 68
6 Sep. 1998
N = 97
17 Apr. 1999
N = 89
11 Feb. 1998
N = 70
5 Oct. 1998
N = 69
16 May 1999
N = 98
30 Mar. 1998
N ≐ 71
6 Nov. 1998
N = 92
14 June 1999
N = 87
29 Apr. 1998
N = 78
6 Dec. 1998
N = 77
15 July 1999
N = 72
Frequency
0
10
20
0
2.5
5.0
7.5
10.0
Width of the 5th Valve (mm)

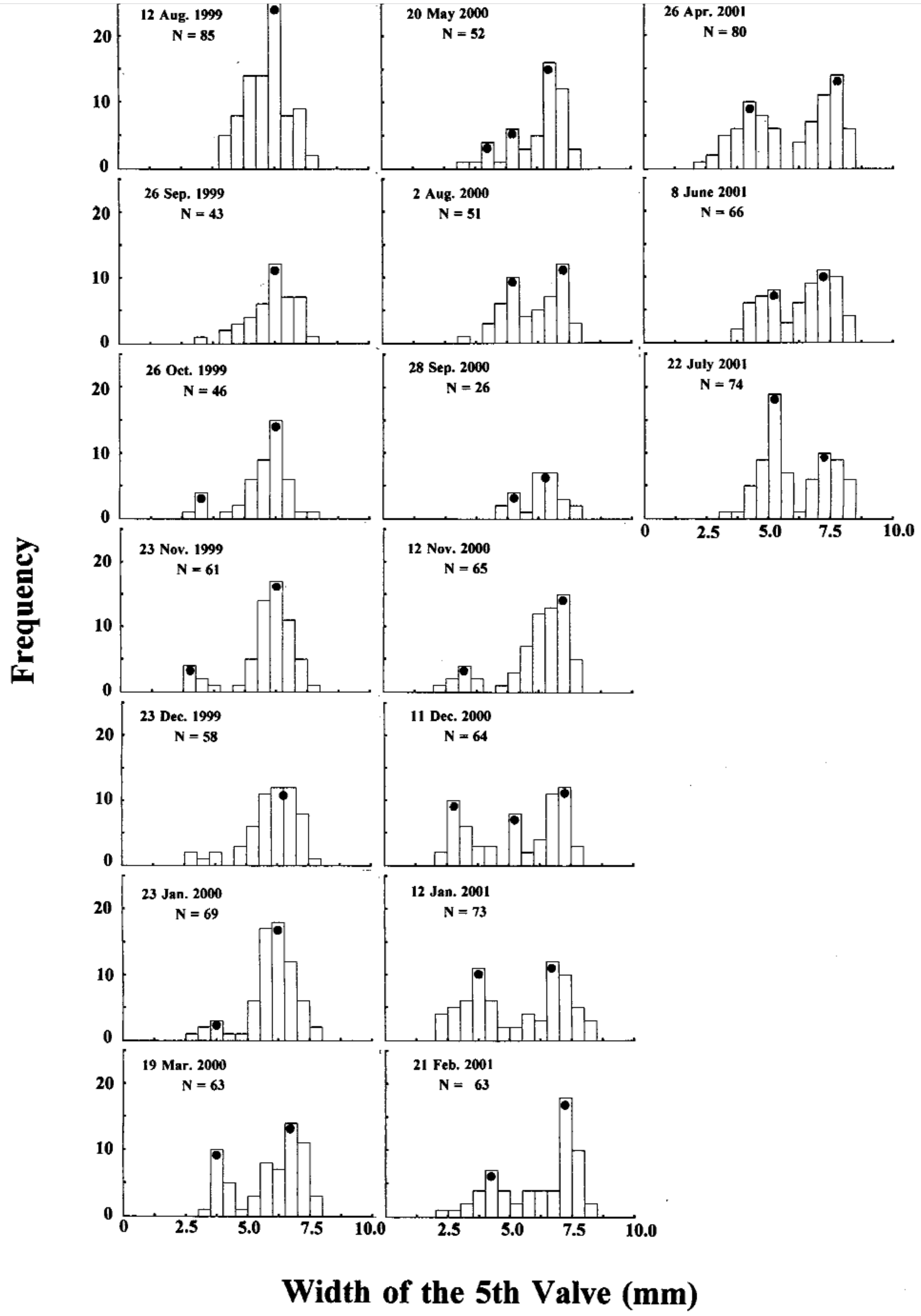


Fig. 4. Temporal variation in the size composition of *Stenoplax alata*. Solid circles indicate the mode size.

Fig. 4. Variazione temporale nella distribuzione per taglie di *Stenoplax alata*. I cerchi pieni indicano la taglia modale.

width were considered to be new recruits. Although some individuals in this size range appeared from August to October (e.g., 1997, 1999), most appear later, forming a size group from November onward and showing a peak between February and May (Fig. 3). While this pattern suggests that the main recruitment season is from November to May, post-settlement juvenile chitons are generally less than 1 mm in total length (e.g., Christiansen, 1954; Okuda, 1947; Yoshioka, 1988), so the new recruits of *S. alata* at this site must have settled earlier than we first record them. As the smaller mode shifted to a larger size, it fused with the larger mode and became indistinguishable; therefore, the larger mode contains at least 2 year-classes. To divide the fused larger mode into year classes, more information on the growth of the chiton is needed.

The mobility of adult chitons generally is quite limited, and only larvae are dispersed over a wide area. If a local population of chitons is small and isolated, it is not sustainable unless the larval supply continues. In this study, the adult *S. alata* did not seem to immigrate into or emigrate from the habitat because neither the chiton nor a suitable habitat for it could be found outside of this small area on the coast of Ishigaki Island (personal observation). Larval duration in the plankton and triggers for larval settlement for this species are still unknown, as is the larval source for recruits into this population. If some catastrophic event, such as heavy sedimentation or reclamation, were to destroy the habitat or stop the larval supply, this local population would become extinct. Further investigation of this local population could provide a model for the conservation biology of marine molluscs.

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