Postprint on Population Aggregation Characteristics of *Solenocera crassicornis* in the Northeastern Fujian Waters

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Abstract

Using the negative binomial parameter, mean crowding, and patchiness index as indicators of population distribution pattern intensity, we analyzed the aggregation characteristics of the Solenocera crassicornis population in the northeastern Fujian sea area and investigated the driving factors of these aggregation characteristics. The results showed that the S. crassicornis population exhibited strong aggregation intensity, high mean individual crowding, and was mainly concentrated in a few aggregated patches. The aggregation characteristics varied significantly among seasons. In spring, the population aggregation intensity was strong, mean individual crowding was lowest, and the population consisted mainly of a single aggregated patch. In summer, the aggregation intensity was weak, mean individual crowding was high, and the population consisted mainly of four patches. In autumn, the aggregation intensity was weakest, mean individual crowding was relatively low, and the population consisted mainly of seven patches. In winter, the aggregation intensity was strongest, mean individual crowding was highest, and the population consisted mainly of a single large aggregated patch. As individual growth rate increased, the population showed a dispersal tendency. Food zooplankton biomass and bottom water temperature were the main factors influencing population aggregation intensity.

Full Text

Preamble

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Aggregation Characteristics of *Solenocera crassicornis* Populations in the Sea Area Northeast of Fujian

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Abstract

This study analyzed the aggregation characteristics of *Solenocera crassicornis* populations in the sea area northeast of Fujian using pattern intensity indices including the negative binomial parameter, mean crowding, and poly block index, and investigated the driving factors of population aggregation. The results revealed strong aggregation intensity and high mean crowding, with the population concentrated primarily in a few clustered patches. Seasonal differences in aggregation characteristics were significant. In spring, the population consisted mainly of a single patch with stronger aggregation intensity and the lowest mean crowding compared to other seasons. In summer, the population comprised four patches with weaker aggregation intensity and higher mean crowding. In autumn, the population consisted of seven patches with the weakest aggregation intensity and higher mean crowding. In winter, the population formed a single large patch with the strongest aggregation intensity and the highest mean crowding. The population exhibited a diffusion trend as individual growth rates increased. Zooplankton biomass (as food) and bottom water temperature were identified as the primary factors affecting aggregation intensity.

Keywords: *Solenocera crassicornis*; sea area northeast of Fujian; aggregation properties; population distribution pattern; pattern intensity; negative binomial parameter; mean crowding; poly block index

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Introduction

The aggregation characteristics of marine organisms represent an important attribute of schooling behavior and constitute a primary focus in marine organism aggregation research. Understanding these patterns is fundamental for elucidating migration routes, fishing ground formation mechanisms, and serves as an essential basis for improving fishing efficiency and protecting fishery resources [?, ?]. Marine organism aggregation is a complex behavioral phenomenon that manifests diverse aggregation properties with varied shapes, sizes, and spatial structures. Numerous factors influence marine organism aggregation, creating intricate spatial structures [?].

Primary research methods for marine organism aggregation characteristics include laboratory tank observation, diving observation, ultrasonic image analysis, and mathematical simulation [?, ?]. However, shrimp species typically inhabit muddy or sandy-bottom nearshore waters, making diving observation unsuitable for large-scale studies of shrimp aggregation. The vast natural waters in the sea area northeast of Fujian and current limitations in mathematical simulation methods restrict their application to *Solenocera crassicornis* aggregation studies. While ultrasonic image analysis expands observation range and improves precision [?, ?], *S. crassicornis* inhabits near-bottom waters, which reduces the accuracy of ultrasonic methods and makes species identification difficult, rendering this approach unsuitable for studying aggregation characteristics in this species.

Cai et al. [?] employed school kinetic energy analysis to quantify schooling behavior of *Parargrops edita* in the southern Fujian-Taiwan shallow fishing grounds, providing a simple method for macro-quantification of fish schooling behavior. However, this method only reflects the degree of concentration rather than different aggregation properties such as patch size or individual crowding. Describing different aggregation properties in large-scale natural waters under natural conditions remains a hot topic and challenging problem in marine organism aggregation behavior research, requiring methodological innovation.

Population distribution pattern intensity, commonly used to measure the degree of spatial aggregation in plant populations, has been extensively studied by ecologists. Methods include using the negative binomial parameter to measure aggregation intensity, mean crowding to measure individual crowding levels, and poly block index to reflect patch composition [?]. These methods have been widely applied in plant ecology with significant economic, social, and environmental benefits, but have not been reported for marine organism studies. Given the meaning of population distribution pattern intensity, these indices may be applicable to shrimp aggregation studies. However, shrimp have migratory characteristics fundamentally different from stationary plants, raising questions about the feasibility of applying these plant-based methods. This study explores the application of population distribution pattern intensity to marine organism aggregation research, examining whether these indices have ecological significance for mobile species. Through case studies, this research provides a new perspective for marine organism aggregation studies and offers novel insights into the intrinsic patterns of *S. crassicornis* schooling behavior for targeted fishing.

Materials and Methods

Study Species and Survey Area

Solenocera crassicornis is a eurythermal and euryhaline tropical nearshore species inhabiting muddy or sandy-bottom waters, distributed in India, Indonesia, Japan, and the southern Yellow Sea, East China Sea, and South China Sea of China [**?**]. As a significant economic shrimp resource in the sea area northeast of Fujian, *S. crassicornis* has seen increasing resources in recent years as major fish stocks in the East China Sea have declined, reducing interspecific competition and expanding shrimp survival space [**?**, **?**]. The species has considerable potential for exploitation, with fast monthly growth from May to November and peak reproduction from May to August [**?**].

The study area covered 5, 8, and 11 fishing zones in the sea area northeast of Fujian (26°-28°N, 120°-125°E). The survey vessel was a beam-trawler (Minxia Fishing Vessel) with dimensions of 36 m length and 257 kW power.

Data Collection

The survey followed marine investigation standards (GB/T 12763.6–2007). In each fishing zone, trawling was conducted for 0.8 hours at 15 m depth using a net with 2.7 m height, 32.4 m width, and mesh sizes of 2.5 cm (codend), 6 cm, and 7 cm. The catch per unit effort (CPUE) of *S. crassicornis* in each zone per season was obtained by dividing the catch by trawling duration, serving as the basic data for aggregation analysis .

Analytical Methods

Negative Binomial Parameter. The negative binomial parameter (K) measures aggregation intensity, where smaller K values indicate stronger aggregation. The parameter is calculated based on the variance (S^2) and mean ($\bar{x}$) of CPUE across fishing zones.

Mean Crowding. Lloyd' s mean crowding index (m^*) measures the average crowding degree per individual, representing the average number of neighbors per individual. Larger values indicate higher crowding levels among individuals.

Poly Block Index. The poly block index (PBI) reflects patch composition patterns, calculated as $PBI = 1 + (1/K)$. Larger PBI values indicate that the population consists primarily of a few clustered patches.

Results

Aggregation Intensity

The monthly average negative binomial parameter was 0.18 with a standard deviation of 0.17, ranging from 0.05 to 0.41, indicating relatively strong aggregation intensity in *S. crassicornis* populations with significant seasonal variation. Seasonal patterns showed that aggregation intensity was strongest in winter and spring, and weakest in summer and autumn. In winter, 85.73% of the population (9,061.2 g/h) concentrated in a single zone (C10), while in spring, 77.00% (3,557.0 g/h) concentrated in zone C26. In contrast, summer and autumn showed more dispersed distributions with only 29.16% and 23.34% of populations in single zones, respectively. The negative binomial parameter effectively measured aggregation intensity, with smaller values indicating stronger aggregation. The seasonal ranking of aggregation intensity from strongest to weakest was: winter, spring, summer, autumn.

Mean Crowding

The monthly average mean crowding was 5.82×10^5 with a standard deviation of 2.38×10^5, ranging from 2.81×10^5 to 7.82×10^5, indicating high individual crowding with seasonal variation. In winter, 84.12% of the population concentrated in zone C10 with CPUE of 9,061.2 g/h. In spring, 76.93% concentrated in zone C26 with CPUE of 3,557.0 g/h. Summer and autumn showed more dispersed distributions across multiple zones (C01, C09, C17, C20, C25, C26, C27) with 85.73% and 92.13% of populations, respectively. Mean crowding was highest in winter, followed by summer and autumn, and lowest in spring. This pattern aligns with the analysis of individual crowding levels, where larger values indicate greater crowding among individuals .

Patch Composition

The monthly average poly block index was 18.20 with a standard deviation of 12.73, ranging from 3.82 to 22.20, showing significant seasonal differences. In winter, the largest PBI value (22.20) indicated the population consisted of the fewest patches with the most concentrated distribution. In spring, PBI was also large, with 76.93% of the population in zone C26 (3,557.0 g/h), indicating concentration in a single patch. In summer, smaller PBI values showed the population comprised more patches (C01, C09, C17, C20, C25, C26, C27) with 84.12% distribution, indicating a more dispersed pattern. In autumn, the smallest PBI (3.82) indicated the most patches and most dispersed distribution, with 85.73% of the population across multiple zones. The poly block index thus reflected both patch composition and aggregation intensity.

Discussion

The poly block index reveals patch composition patterns and reflects aggregation intensity. When mean crowding is small, populations are more evenly distributed, variance is smaller, and aggregation intensity is weaker. Conversely, larger variance and smaller negative binomial parameters indicate stronger aggregation. In this study, the average negative binomial parameter in spring was smaller than in autumn and summer, indicating stronger aggregation intensity in spring despite lower population density. This demonstrates that the negative binomial parameter can measure aggregation intensity independent of population density changes, allowing comparison of aggregation intensity across different times or habitats.

Aggregation intensity is a fundamental component of population distribution patterns, relevant to various aspects of fishery resources including fishing ground formation mechanisms and fishery forecasting. The negative binomial parameter shows potential application value in fisheries resource research. Mean crowding represents the average number of other individuals per individual in a sample plot—a relative index of individual aggregation. However, as it is based on averages across all sample plots, it is strongly influenced by zero-count plots, which can provide biased information when intraspecific competition is intense. In contrast, mean crowding depends on existing individuals rather than plot averages, making it an individual-based rather than plot-based metric that can more accurately reflect true crowding levels and intraspecific competition, providing more reliable information for aggregation studies.

The poly block index, defined as the ratio of mean crowding to mean density, also measures aggregation intensity. When mean crowding is small, populations are evenly distributed across many patches; when large, populations concentrate in few patches. Thus, PBI reflects spatial pattern properties—two populations may show similar PBI values despite different mean densities, or different PBI values with similar densities.

Population aggregation characteristics are determined by habitat conditions, biological characteristics, and their interactions [**?**]. Environmental factors, particularly water temperature and food availability, are most important. In the study area, zooplankton biomass was higher in summer and autumn but lower in spring and winter [**?**, **?**]. The relationship between zooplankton biomass (E, mg/m^3) and negative binomial parameter (K) was:

$$K = 0.004 \times E$$

with correlation coefficient $R = 0.893$ and $F = 11.870 > F_{\alpha=0.05}$, indicating significant linear correlation. High zooplankton biomass corresponded to weak aggregation intensity, suggesting *S. crassicornis* exhibits dispersed foraging behavior. With large individual size and substantial population numbers, most sea areas provide sufficient zooplankton to meet dietary needs, allowing wide distribution and resulting in weak aggregation intensity during high-biomass seasons.

Bottom water temperature also significantly affected aggregation intensity. The relationship between average bottom temperature (T, °C) and K was:

$$K = -2.105 + 0.124 \times T$$

with $R = 0.873$ and $F = 9.398 > F_{\alpha=0.10}$, showing significant linear correlation. Lower bottom temperatures limited survival space, causing aggregation intensity to increase as temperature decreased. *S. crassicornis* appears adapted to higher bottom temperatures.

Individual developmental stage and physiological condition are primary biological factors affecting aggregation. The poly block index can analyze population diffusion trends: decreasing PBI indicates diffusion, while increasing PBI indicates aggregation. From May to November, individual growth rates increased monthly [**?**], and PBI showed a decreasing trend from winter to autumn, indicating diffusion with increasing growth rates. During rapid growth, individuals require substantial nutrition, increasing demand for food resources. By expanding distribution range, populations reduce intraspecific competition, increase feeding opportunities, and enhance competitive ability and survival. Therefore, as individual growth rates increase, population distribution range expands, showing a diffusion trend.

Population distribution pattern intensity provides an effective method for studying different aggregation properties in marine organisms, opening a new approach for large-scale spatial quantification of schooling behavior. Different indices have different emphases: negative binomial parameter focuses on aggregation intensity, poly block index on patch composition, and mean crowding on true individual crowding levels reflecting intraspecific competition. Using multiple indices can yield seemingly inconsistent results—for example, mean crowding was higher in autumn than spring while aggregation intensity was weaker in autumn—but this multi-angle approach more accurately reflects aggregation characteristics at finer scales, identifies key driving factors and mechanisms, and reveals meaningful distribution patterns with direct guidance for fisheries production.

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Figures

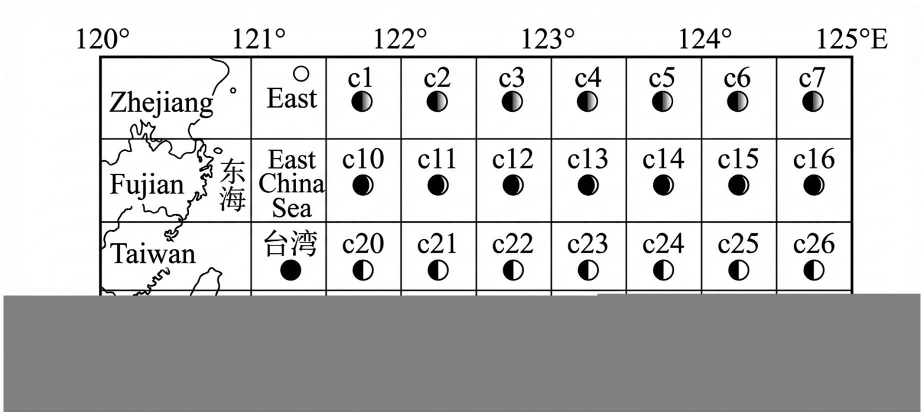

Figure 1: Figure 1

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