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Relationship of Abundance of Oceanic Sea Skaters, *Halobates* in the Tropical Pacific Ocean to Surface Biomass and Chlorophyll/Oxygen Concentrations

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Abstract

Relationship of population density of oceanic sea skaters collected from tropical and subtropical zones in the Pacific Ocean was examined to chlorophyll concentration/Dissolved Oxygen concentration and biomass in surface sea water. The four parameters shown above were measured at the site of 12˚N 135˚N during the cruise, MR13-03 cruise, and at the site of 25˚N 160˚E during another cruise KH-14-02. Significant and positive correlation between all biomass (especially invertebrates) and population density of oceanic sea skaters collected with a Neuston-Net trailing during 15 min was shown in overall analysis on the data of the both samplings ($p < 0.001$). Moreover, dissolved oxygen was much lower at 25˚N 160˚E than that at 12˚N 135˚N with similar value of chlorophyll value ($p < 0.001$). These results would suggest that more food resource would be available at 25˚N 160˚E than that at 12˚N 135˚N for keeping high density population of oceanic sea skaters.

Keywords

Oceanic Sea Skaters, Chlorophyll Concentration/Dissolved Oxygen Concentration,

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1. Introduction

Oceanic sea skaters inhabiting tropical and temperature Pacific Ocean

Marine insects have been thought to consist of a few thousand species, and most of them belong to the Coleoptera, Hemiptera and Diptera orders inhabiting various marine environments [1]. However, the insects which inhabit open ocean have been known to be only five species of the oceanic sea skaters as the five species of the genus *Halobates* [2]. Recently, another coastal species, *H. princeps* has been reported to have "open ocean population" in the tropical Pacific Ocean [3]. In the tropical to temperature Pacific Ocean, three species of *Halobates*, *H. micans*, *H. germanus and H. sericeus* are dominant [2] [4] [5]. However, these three species could be seen to inhabit the roughly separated "main-area" there: *H. micas* with biggest body size inhabiting mainly "open" area around equators (15˚N-15˚S), *H. germanus* with middle body size inhabiting the area "near to the islands" of 15˚N-15˚S and *H. sericeus* with smallest body size inhabiting the northern and southern area (15˚N-40˚N, 15˚S- 30˚S) [2] [5] [6].

The combined data of chlorophyll concentration and dissolved oxygen concentration (*DO*) *as an indicator of population density of the oceanic sea skaters.*

A clear positive correlation was shown between the population density of *H. micans* and the combination of "higher chlorophyll concentration" plus "lower dissolved oxygen concentration" in the tropical Indian Ocean suggesting the higher biomass as food resources for the oceanic sea skaters [7]. This relationship would mean that the combination of "higher" chlorophyll concentration and "lower" dissolved oxygen concentration as the indicator of higher population density of the oceanic *Halobates*. However, such clear positive correlation has been shown by only one occasion in the Indian Ocean. Moreover, there has been no example of direct analysis between the *Halobates* population density and sea surface biomass as food resources for the oceanic sea skaters.

This study aims, first, to clarify whether this combined data of higher chlorophyll and lower DO mean an indicator of higher population density of the oceanic sea skaters also in the Pacific Ocean population, and second, to investigate the direct relationship between the population density of the oceanic sea skaters and the biomass in the surface water as the food resources for the sea skaters.

2. Materials and Methods

2.1. Samplings by the Neuston Net during the Cruises

During the two cruises: Cruises No.: MR13-03 by R/V MIRAI [8687t] and cruise No.: KH-14-02 by R/V HAKUHOMARU [3991t], both owned by JAMSTEC [Japan Agency of Marine-earth Science and Technology], samplings were performed in the dark with a Neuston net (an open box-typed frame and inner net with a 1.3 m wide opening and 6 m length of the net), between 1900 h and 0100 h. The net was towed for 15 min each time at the starboard side. Towing was repeated 2 times at each station with the ship cruising at a speed of 2 knots. During the MR13-03 cruise, three toes of Neuston net at one night were performed at a station located at 24˚N 138˚E, and 15 stations located at 12˚N 135˚E. The Neuston net was trailed for the 3 consecutive samplings (each 15 mm × 3 times) on the sea surface to allow us to rescue living sea skaters from the bottom of the net for use in cool coma experiments [8]. The surface area swept by the nets is expressed as a value of the flow meter x the front width of the nets.

2.2. Measurements of Chlorophyll Contents and Dissolved Oxygen (DO) during the Two Cruises of MR13-03 and KH-14-02

During the cruise, MR13-03, surface water sensor system was put at the bottom of the research vessel (R/V) MIRAI and consists of sensors to measure water temperatures, conductivity (salinity concentration), chlorophyll contents (can be measured by a fluorescence spectrometer) and dissolved oxygen continuously during the cruise. During the cruise, KH14-02, CTD casting was performed at all the sampling points. The cast was performed to use the Amado-cable more than 500 m long and to measure the conductivity, water temperature, depth, dissolved

oxygen and chlorophyll contents continuously through water surface to 500 m in the depth. Data of dissolved oxygen and chlorophyll at 5 m depth were used for the analysis.

3. Results

3.1. Distribution of Oceanic Sea Skaters in Tropical and Subtropical Areas of the Western Pacific Ocean

As shown in **Table 1**, *Halobates sericeus* mostly exclusively dominated the latitude area of 24˚N-25˚N in the western sub-tropical Pacific Ocean with a relatively high population density of more than 50,000 insects per km^2. On the other hand, *H. micans* and *H. germanus* dominated the lower latitude area of 12˚N. These data match those of other reports by Andersen and Cheng [2] and Harada *et al.* [5].

3.2. Relationship between Population Density and Biomass Collected by Neuston Net

Analysis of the relationship between the population density of oceanic sea skaters and all biomass collected by the Neuston net trailing (Pearson's test: r = 0.605, $p < 0.001$) showed significant and positive correlation (**Figure 1**). Significant positive correlation was also shown between the population density of oceanic sea skaters and biomass excluding fishes (mostly invertebrates like as jelly fishes and copepods) (**Figure 2**). However, there was no correlation between the population density and fish biomass (**Figure 3**).

3.3. Relationship between Population Density and Chlorophyll and Dissolved Oxygen Concentration

The relationship between the dissolved oxygen concentration and chlorophyll concentration in the surface water was shown in **Figure 4**. The oxygen concentration in the areas at 24˚N 160˚E were much lower than that in

Table 1. (a) Population density of oceanic sea skaters, *Halobates* among two areas of open Pacific Oceans. Samplings were performed during the cruise, MR-13-03. *H.m.*: *Halobates micans*; *H.g.*: *H. germanus*; *H.s.*: *H. seriseus*; *H.p.*: *H. princeps*; sp.: *H.* sp.: Density: individual number/km^2; (b) Population density of oceanic seaskaters, *Halobates* among two areas of open Pacific Oceans. Samplings were performed during the cruise, KH-14-02. *H.m.*: *Halobates micans*; *H.g.*: *H. germanus*; *H.s.*: *H. seriseus*; *H.p.*: *H. princeps*; sp.: *H.* sp.: Density: individual number/km^2.

A. 24˚00'N 138˚10'E (Station 1)	(a) MR-13-03: Western Subtropical and Tropical Pacific Ocean						
	Total		Hm	Hg	*Hs*	Hp or sp	AS[#]
	Females	Males					
Number	179	126	6	0	299	0	0031594
Density	56656.5	39881.1	1899.1	0	94638.5	0	-
B. 12˚00'N 135˚00'E (Stations 2 - 10)	Total		*H.m*	*H.g*	*H.s*	*H.p* or sp	AS[#]
	Females	Males					
Number	484	119	276	327	0	0	0.02802519
Density	17270.2	4246.2	9848.3	11688.1	0	0	-

A. Northern Station at 47˚00'N 160˚00'N	(b) KH-14-02 (This cruise; Stations A and B): Western Subtropical and Tropical Pacific Ocean						
	Total		*H.m.*	*Hg*	*Hs*	*Hp* or sp	AS[#]
	Females	Males					
Number	0	0	0	0	0	0	0
Density	0	0	0	0	0	0	0
B: Southern Station at 25˚00'N 160˚00'E	Total		*Hm*	*Hg*	*Hs*	*Hp* or sp	AS[#]
	Female	Males					
Number	593	254	0	0	847	0	0.0162708
Density	36445.7	15610.8	0	0	52056.4	0	-

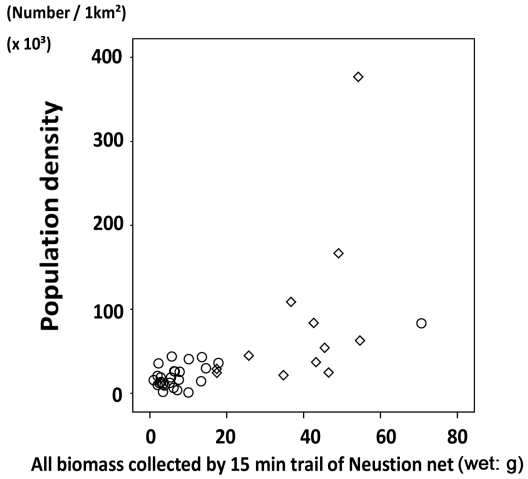

Figure 1. Positive correlation shown between population density of oceanic sea skater and all biomass collected by the Neuston net Trailing (Pearson's test: r = 0.605, $p < 0.001$). Circles: MR13-03; Squares: KH14-02.

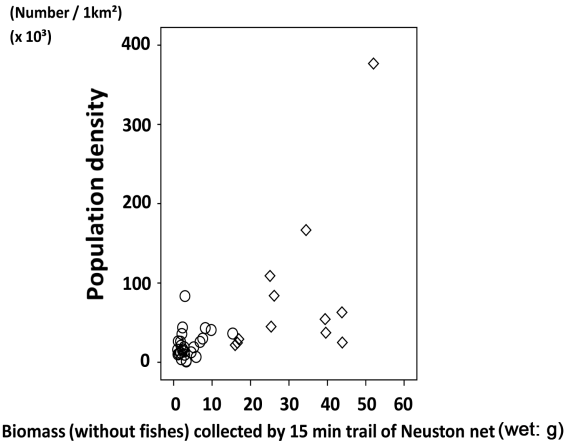

Figure 2. Positive correlation shown between population density of oceanic sea skater and all biomass (excluding fishes) collected by the Neuston net trailing (Pearson's correlation analysis, r = 0.633, $p < 0.001$). Circles: MR13-03; Squares: KH14-02.

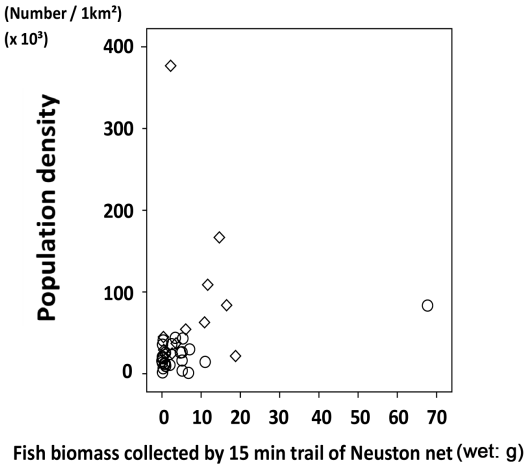

Figure 3. No positive correlation shown between population density of oceanic sea skater and all fishes collected by the Neuston net trailing (Pearson's correlation analysis, r = 0.196, $p = 0.233$). Circles: MR13-03; Squares: KH14-02.

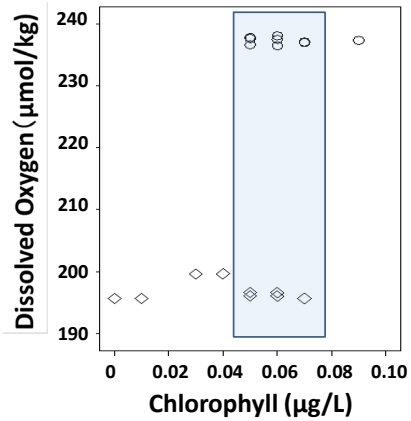

Figure 4. Relationship between dissolved oxygen and chlorophyll in the surface sea water due to CTD casting. Light blue square shows the big difference in dissolved oxygen between MR13-03 with lower population density and KH14-02 with higher population density. The average value of dissolved oxygen was 196.22 (±0.38 micro-mol/kg) in the surface with at 25˚N 160˚E (KH-14-02: diamonds) and significantly much lower than 238.3 (±0.55) at 12˚N 135˚E (MR13-03: circles) (Mann-Whitney U-test: z= −3.985, $p < 0.001$).

those at 12˚N 135˚E, although the range of the chlorophyll concentration in the areas at 24˚N 160˚E was greatly overlapped with that in the areas at 12˚N 135˚E. In the common chlorophyll value range of 0.05 - 0.70 microgram/L, the population density of sea skaters collected at "lower" oxygen dissolved area (24˚N 160˚E) was significantly higher than that collected at "higher" oxygen area (12˚N 135˚E) (**Figure 4** and **Figure 5**).

4. Discussion

4.1. Distribution of Oceanic Sea Skaters in Tropical and Subtropical Areas of the Western Pacific Ocean

Andersen and Cheng [2] showed the distributions of the three species of oceanic sea skaters inhabiting Pacific Ocean were roughly separated: the biggest species, *Halobates micans* was distributed mainly open area around the equator in the latitudes of 15˚N to 15˚S, the middle sized species *H. germanus* was mainly near to the islands in the latitudes of 20˚N to 20˚S, and the smallest species *H. sericeus* was mainly distributed to the northern area of 15˚N-40˚N. The results of this study match the previous knowledge that *H. germanus* and *H. micans* were dominant at 12˚N 135˚E and the *H. sericeus* was dominant at 24˚N 138˚E and 25˚N 160˚E. The critical line for the dominant occupation by the bigger two species or smallest species could be located between 12˚N and 24˚N in the Pacific Ocean. What is the mechanism of the separated distribution? It could be speculated that the difference in the temperature preference (the smallest species prefers lower temperature area: Nakajo *et al.* [6], Furuki *et al.*, [8]) would lead to the higher latitude difference in the distribution. Another hypothesis could be cannibalism: adults of *H. micans* are very active to do cannibalism into the smaller species based on the accumulated observations during the rearing sea skaters during several cruises (Harada, unpublished).

4.2. Relationship between Population Density and Biomass Collected by Neuston Net

A clear positive correlation was seen between the abundance of individuals and the whole biomass or biomass excluding fishes collected by the Neuston net in this study. This would mean that the main foods for the oceanic sea skaters could be speculated to be not the dead bodies of fishes but zooplanktons. Cheng [9] reviewed that one experiment ensured the simulation of the relative composition of several kinds of atoms in the liquid inside the stomach of oceanic sea skaters into another composition of atoms of zooplanktons. This study matches this report that zooplanktons could be major of the foods of the oceanic sea skaters.

4.3. Relationship between Population Density and Chlorophyll and Dissolved Oxygen Concentrations

The sampling areas at 25˚N 160˚E and at 12˚N 135˚E had common areas showing the surface water chlorophyll

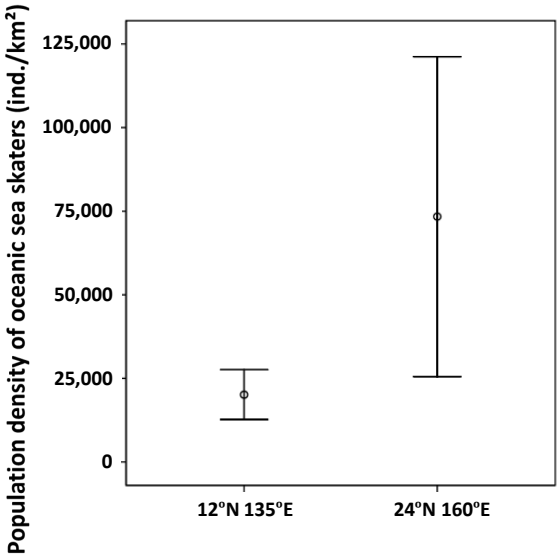

Figure 5. Comparison of population density of oceanic sea skaters at 12N 135E to that at 24N 160E. Sampling stations were limited to the sites where surface chlorophyll value was common and ranged 0.05 - 0.07 micro-gram/L (range shown by blue square in **Figure 4**). (Mann-Whitney U-test: z = −3.212, p = 0.001).

value of 0.05 - 0.07 microgram/L. In the common areas, the area of 25˚N 160˚E showed higher sea skater population and lower dissolved oxygen value than the area of 12˚N 135˚E. This relationship would mean that the area of 25˚N 160˚E could be speculated to have more zooplanktons as foods of oceanic sea skaters than the area of 12˚N 135˚E. The clear positive correlation was shown between the population density of *H. micans* and the combination of "higher chlorophyll concentration" plus "lower dissolved oxygen concentration" in the tropical Indian Ocean suggesting the higher biomass as food resources for the oceanic sea skaters [7]. This relationship would mean that the combination of "higher" chlorophyll concentration and "lower" dissolved oxygen concentration means the indicator of higher population density of the oceanic *Halobates*. Such clear relationship was also shown by tropical and subtropical populations in the Pacific Ocean. Moreover, direct and positive relationship is shown by this study between the *Halobates* population density and sea surface biomass as food resources for the oceanic sea skaters as something new to science.

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