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The Distribution of the Oceanic Sea Skaters, *Halobates* inside and outside the *Kuroshio*

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Abstract

The purpose of this study was to clarify the distribution of oceanic *Halobates* in the area of the *Kuroshio* flowing near the southern shore in the direction of 100˚ - 120˚, and also to compare the population density of *Halobates* between the area within or outside the area of the *Kuroshio* and also among seasons. This study was carried out during 8 cruises by R/V TANSEIMARU. The *Kuroshio* area south of the southern Japan coast (30˚00'N - 35˚00'N, 130˚25'E - 141˚04'E) was dominated by *H. sericeus*, and the averaged population-density of this species was significantly higher inside the *Kuroshio* than outside this current. On the *Kuroshio*, *H. sericeus* was dominant with the population density of 16,396.4 km^{-2} ± 66,138.4 [26] (Mean ± SD [n]), whereas the density of *H. germanus* was 8,581.9 km^{-2} ± 24,443.2 [26]. The two oceanic sea skaters, *H. sericeus* and *H. germanus* showed significant seasonal variation in the population density, with significantly higher density in October than other months, whereas there was no such significant October peak in the cosmopolitan oceanic sea skater, *H. micans*. The results of this study may suggest that *H. sericeus* could use the *Kuroshio* as a transportation tool to distribute a wide latitude area of from 10˚N to 40˚N in the western tropical, subtropical and temperate area in the Pacific Ocean.

Keywords

Halobates, Oceanic Sea Skaters, Population Density, Season, The Kuroshio

1. Introduction

Ocean currents take an important role for the transportation of animals inhabiting there. For example, Hernández-León *et al.* [1] showed that the trophic scenario of mesozooplankton could be depicted for the oceanic, upwelling and eddy system in the Canary Current System. Namely, the tremendous increase in production in the coastal area off Northwest Africa, the coupling of this production with the oceanic area through filaments and eddies topographically formed in the coast or shed by the islands promote a continuous transport of organic matter towards the deep ocean in the Canary Current System [1]. Pearce *et al.* [2] performed the application of an individual-based particle tracking model to the migration of tropical fish larvae along the continental shelf between the Houtman Abrolhos Islands and Rottnest Island (Western Australia). This application has shown that there was a potential for the southwards advection of passive particles/larvae in the Leeuwin Current system.

Several animals have been reported to be transferred by the *Kuroshio* which takes important roles for them to make life histories and their distributions, serving several resources for life. For example, the diving behavior of the false killer whale, *Pseudorca crassidens* was recorded using a pop-up archival transmitting (PAT) tag: "The whale reaches the *Kuroshio* front in the morning on one day in October, as indicated by the drastic change in the temperature gradient. The whale frequently performed deep dives exceeding 200 m during the daytime in both the transition and the *Kuroshio* front regions" [3]. The surface waters of the *Kuroshio* are generally regarded as nitrogen-deficient and oligo-trophic region [4]. Many economically important pelagic fish species, however, are abundant in these waters such as the dolphinfish, *Coryphaena hippurus* with annual catches of 9,500 tons by Taiwanese fisheries [5]. In the early and middle larval stages of round herring *Etrumeus teres*, seasonal variation in daily growth rates in Tosa Bay which is strongly influenced by the *Kuroshio* is largely determined by the sea temperatures experienced by hatch-date cohorts in the Pacific coastal waters off southern Japan [6]. Based on monthly samples collected from January 2001 to December 2004, in total, 2558 mesopelagic fish larvae were sampled also in the Tosa Bay [7]. Using the output of a high-resolution ocean general circulation model, particle-tracking experiments were performed to infer the distribution of larvae of the Japanese sardine (*Sardinops melanostictus*) and to detect effects of transport environment on sardine recruitment, and observed data of sardine spawning grounds during 1978-2004. By the 60th day following spawning, 50% of the larvae had been transported to the *Kuroshio* Extension [8].

The only insects that inhabit the open ocean are members of the genus *Halobates*, commonly known as sea skaters. They are included in the family Gerridae (Heteroptera), which also includes common pond skaters or water striders. Only six species have been reported from open oceans among the 47 species included in the *Halobates* genus [9]. The six oceanic species are *Halobates micans* Eschscholtz, 1822, *Halobates germanus* White, 1883, *Halobates sericeus* Eschscholtz, 1822, *Halobates splendens* Witlaczil, 1886, *Halobates sobrinus* White, 1883 [10] and *Halobates princeps* White 1883 [11] which has been reported as a coastal species [12] in most cases. Another *H.* sp. is currently in the process of being described (Harada *et al.* unpublished).

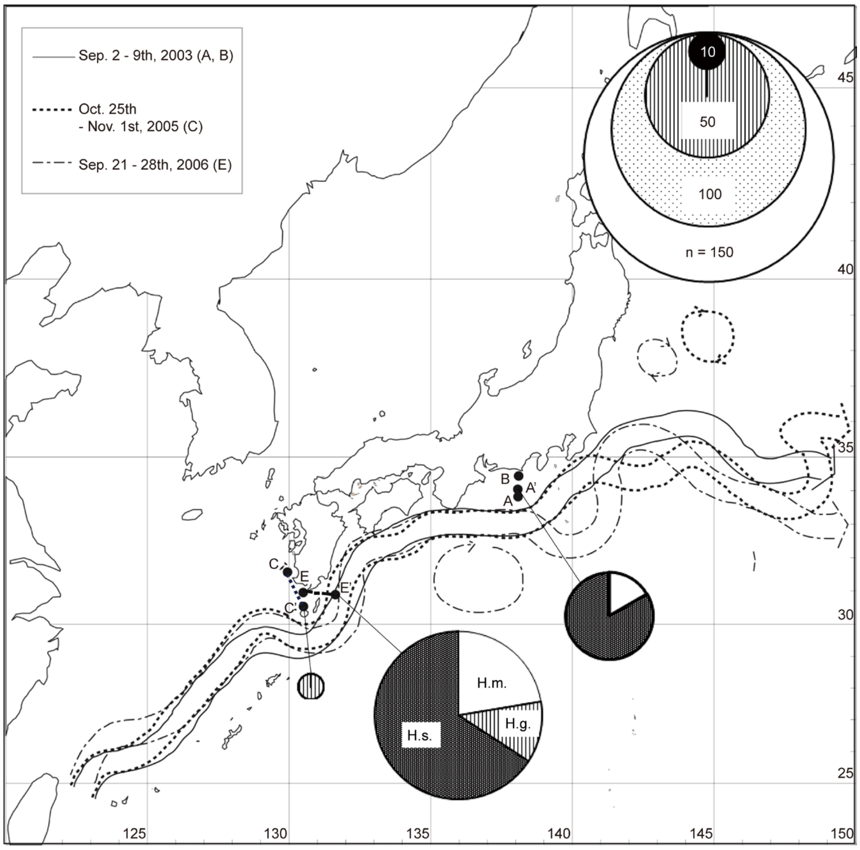
Three species, *H. sericeus*, *H. micans*, and *H. germanus*, dominantly inhabit the tropical and temperate areas of the Pacific Ocean in the northern hemisphere, including the *Kuroshio* (Black Current), the East China Sea, and the Japan Sea [10] [13] [14] [15]. *Halobates micans* is a cosmopolitan oceanic species which is mainly distributed in the latitude range of 20˚N to 20˚S in the Pacific, Indian and Atlantic oceans [16]. This species has also been found up to 32˚N only in the area south of the southern Japanese coast, perhaps being transported there by the *Kuroshio* [12]. The *Kuroshio* might be a transporting agent of oceanic *Halobates*, a point that remains to be studied.

Andersen and Cheng [12] presented a summary of data regarding the population density of oceanic *Halobates*. This review paper [12] shows that *H. micans* has a low population density of 2,000 individuals/km^2 in the eastern tropical Pacific Ocean, even at the low latitude of 10˚ - 20˚N. *Halobates micans* and *H. sericeus* have average population densities of 3,000 and 7,000 individuals/km^2, respectively, in the 13˚ - 20˚N area of the western Pacific Ocean [17]. Harada *et al.* [9] recently reported highly dense populations of *H. micans* of 10,000 individuals or more per km^2 in the Tropical Western Pacific Ocean at 0˚ - 10˚N, 130˚ - 135˚E. However, the eastern region of 147˚ - 156˚E of the Tropical Western Pacific Ocean is less likely to be affected by freshwater flowing down from rivers in the tropical islands. The population density of *H. micans* there was only around 5,000 individuals/km^2, half that at 130˚ - 135˚E [9]. In the area on the *Kuroshio* band of the eastern China Sea, all three species of *H. micans, H. germanus*, and *H. sericeus* have been collected at 7 sampling points from 27˚10'N, 124˚50'E to 29˚00'N, 129˚00'E, while the 127˚00' - 129˚00'E area and the area north of the *Kuroshio* was mainly dominated by *H. sericeus* [15]. However, few studies have been done on the role of the *Kuroshio* flowing near the southern shores of Japan islands for the distribution of *Halobates*.

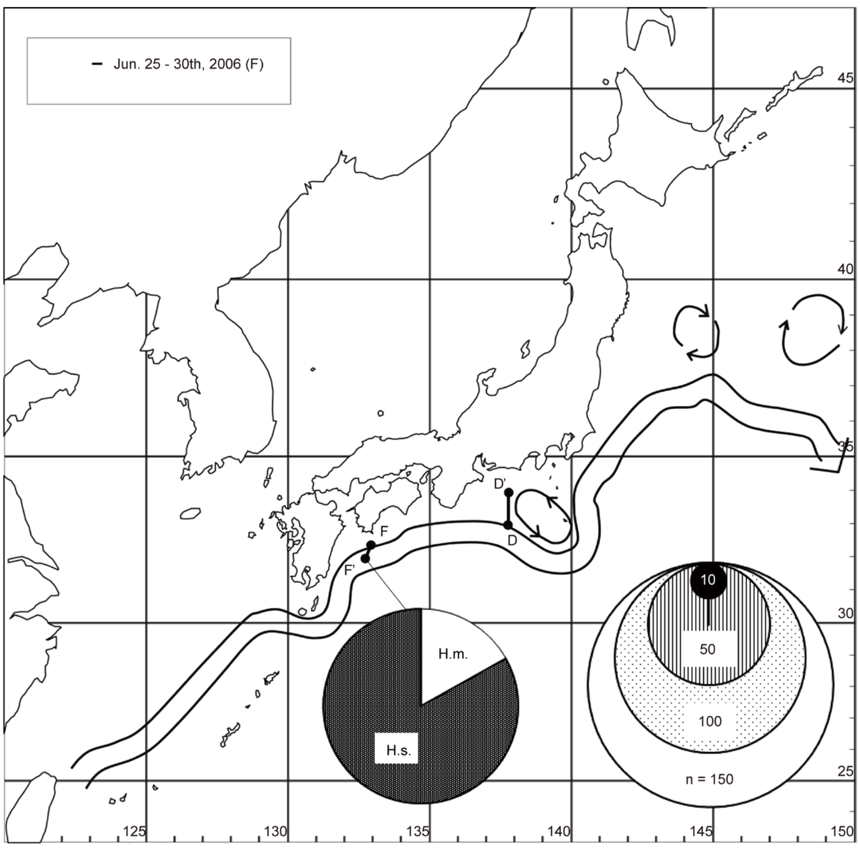
This study aims to examine the population density of oceanic *Halobates* in the area inside and outside of the *Kuroshio* flowing near the southern shore in the direction of 100˚ - 120˚, and to discuss the role of the *Kuroshio* in the distribution of *Halobates*.

2. Materials and Methods

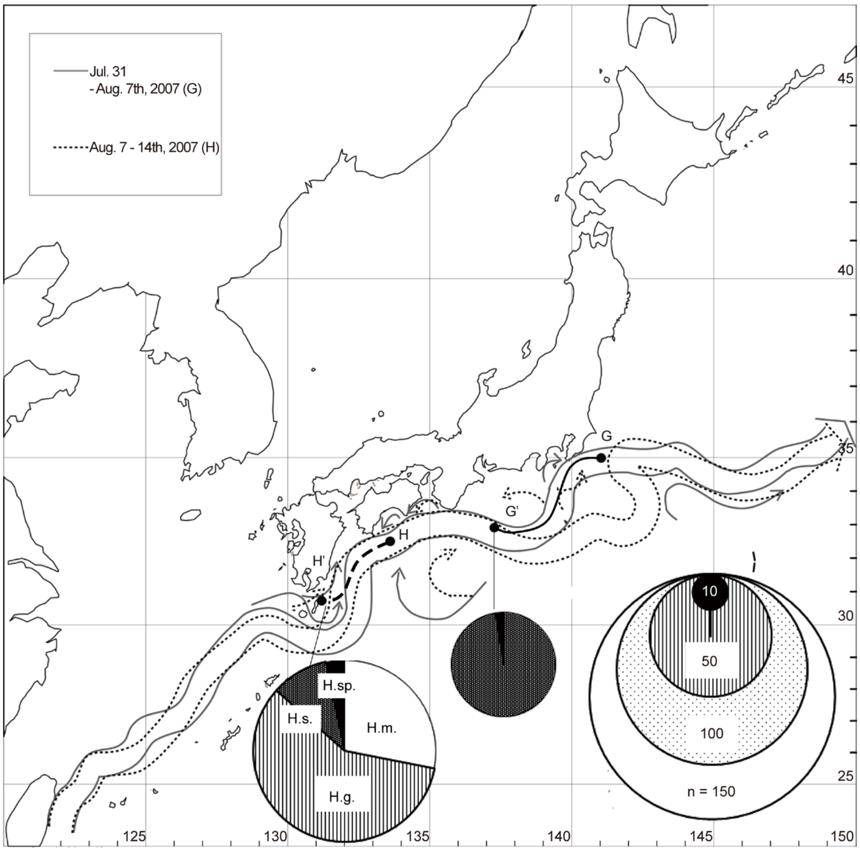
During the eight cruises, samplings were performed with one of two kinds of NEUSTON nets (small net: 0.57 m diameter, large net: 1.3 m diameter) and ORI net (1.5 m in diameter) during the dark, between 19:00 hrs and 05:00 hrs. The net was towed for 15 minutes once at the starboard side of the Research Vessel TANSEIMARU. The towing was replicated 2 to 8 times at each station with the ship moving at a speed of 2 - 2.5 knots. **Figures 1(a)-1(e)** show detailed information about place and season for each of the 8 cruises. The surface area swept by the nets was calculated as an expression: flow-meter value × inner diameter (0.57 m, 1.30 m or 1.50 m) of the nets. Population density of *Halobates* was


Sep. 2 - 9th, 2003 (A, B)
Oct. 25th
- Nov. 1st, 2005 (C)
Sep. 21 - 28th, 2006 (E)
10
50
100
n = 150
B
A'
A
C
E
E'
C'
H.m.
H.g.
H.s.
45
40
35
30
25
125
130
135
140
145
150

(a)

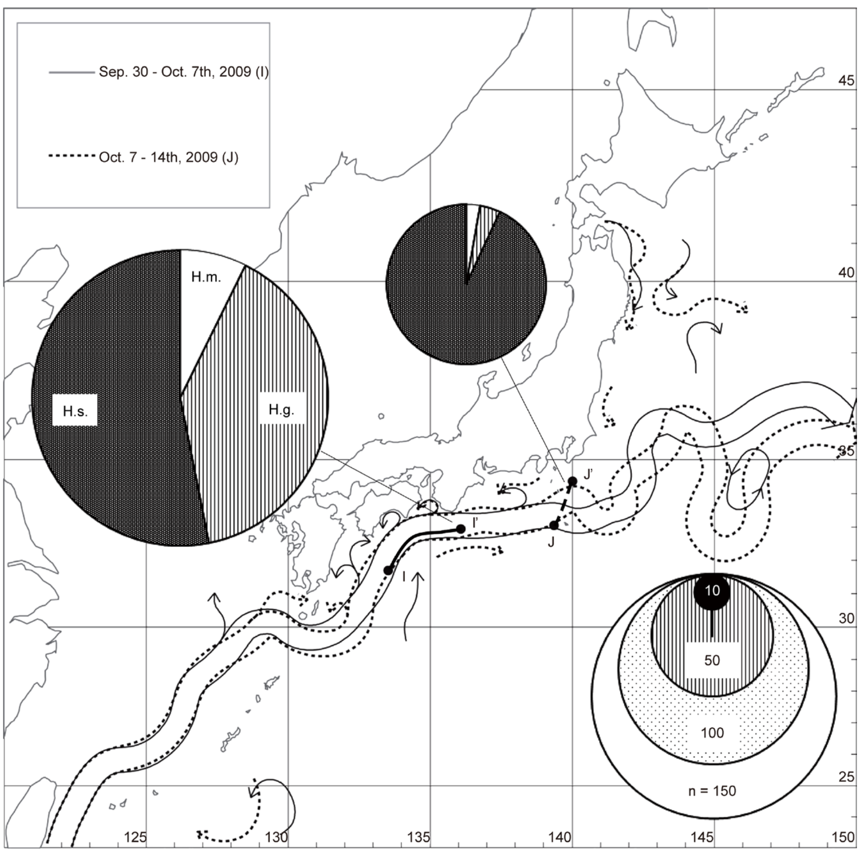

Jun. 25 - 30th, 2006 (F)
D'
D
F
F'
H.m.
H.s.
10
50
100
n = 150
45
40
35
30
25
125
130
135
140
145
150

(b)



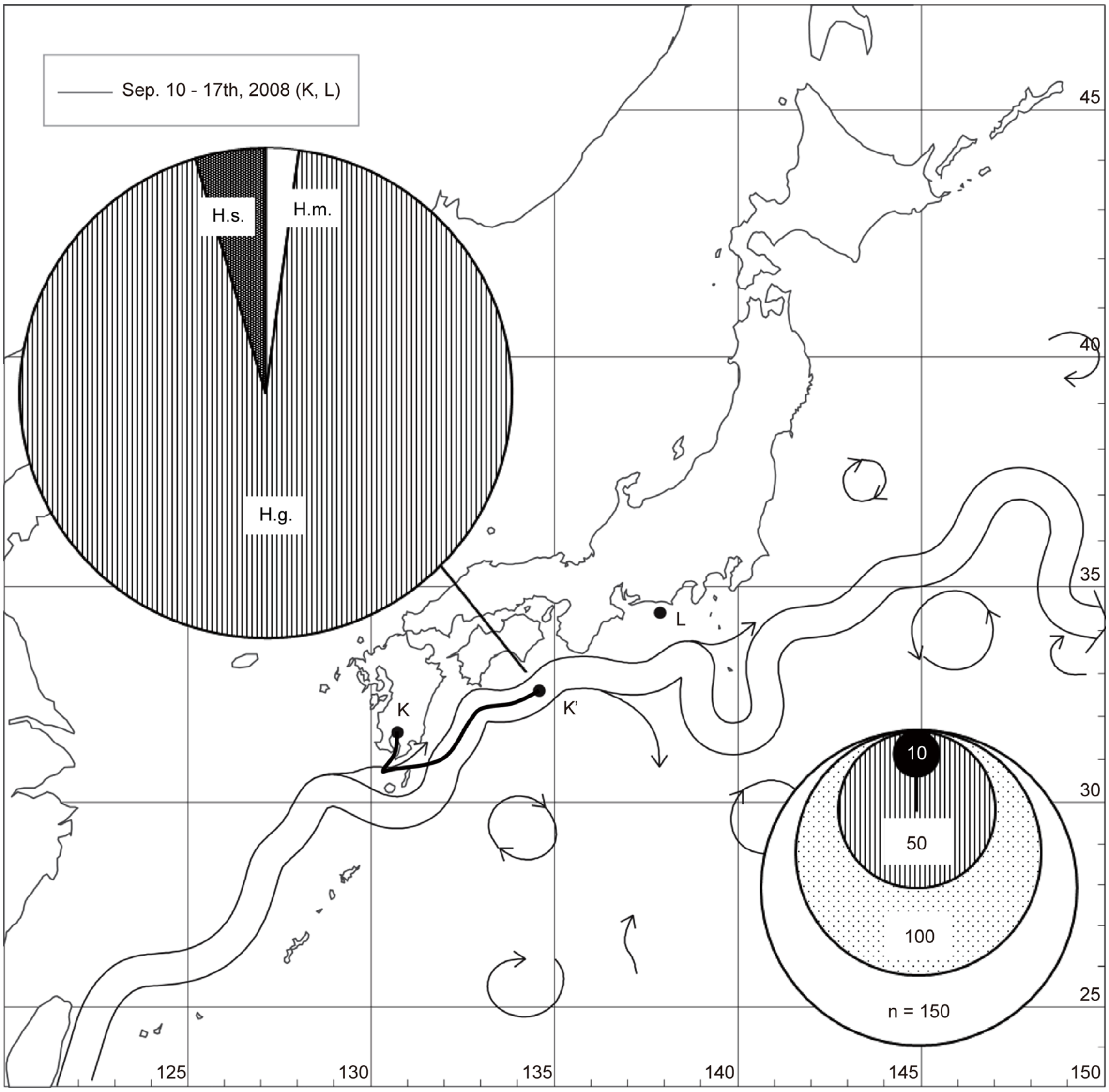
Jul. 31
- Aug. 7th, 2007 (G)
Aug. 7 - 14th, 2007 (H)
G
G'
H
H'
H.sp.
H.s.
H.m.
H.g.
10
50
100
n = 150
45
40
35
30
25
125
130
135
140
145
150

(c)



Sep. 30 - Oct. 7th, 2009 (I)
Oct. 7 - 14th, 2009 (J)
H.m.
H.s.
H.g.
I
I'
J
J'
10
50
100
n = 150
45
40
35
30
25
125
130
135
140
145
150

(d)



(e)

Figure 1. (a) The number of individuals (square of circles) and species ratio in September and October in relation with the current route of the *Kuroshio* at each sampling. Characters A, B, C and E correspond with Table 1(a)-A, B, C and E, respectively, in this manuscript. (b) The number of individuals (square of circles) and species ratio in June in relation with the current route of the *Kuroshio* at each sampling. No sea skaters were collected in D - D' in December. Characters D and F correspond with Table 1(a)-D and F, respectively, in this manuscript. (c) The number of individuals (square of circles) and species ratio in July and August in relation with the current route of the *Kuroshio* at each sampling. Characters G and H correspond with Table 1(b)-G and H, respectively, in this manuscript. (d) The number of individuals (square of circles) and species ratio in September and October in relation with the current route of the *Kuroshio* at each sampling. Characters, I and J correspond with Table 1(b)-I and J, respectively, in this manuscript. (e) The number of individuals (square of circles) and species ratio in September in relation with the current route of the *Kuroshio* at each sampling. Characters K and L correspond with Table 1(b)-K and L, respectively, in this manuscript.

compared between inside and outside (around) the Kuroshio and different seasons.

Population density was presented as individuals collected per 1 km^2 which was calculated as an expression: [the number of individuals collected × 1000000/(the surface area swept)].

3. Results

Table 1(a) and Table 1(b) show the number of individuals (total of juveniles and adults) and population density of oceanic sea skaters at 12 sampling points during the 8 cruises (Figures 1(a)-1(e)). Population densities of *Halobates micans, H. germanus, H. sericeus* and *H.* sp range from 0 to 11,327.8, 0 - 49,338.8, 0 - 85,084.2 and 0 - 503.5 ind. km^{-2}, respectively, inside and outside the *Kuroshio* (Table 1(a), Table 1(b)). In the area of the Pacific Ocean south of the southern coast of Japan (30˚00'N - 35˚00'N, 130˚25'E - 141˚04'E), *H. sericeus* dominated 6 of 12 sampling points whereas *H. germanus* and *H. micans* did 3 and 0 of the 12 points, respectively (Table 1(a), Table 1(b)). The average population density of *H. sericeus* was significantly greater inside the *Kuroshio* than outside the *Kuroshio* (Mann-Whitney U-test: $z = -2.557$, $p = 0.011$) (Table 2). Inside the *Kuroshio*, *H. sericeus* was dominant (Kruskal-Wallis test among three species of

Table 1. (a) Total number of individuals (larvae plus adults) and population density of oceanic sea skaters. (b) Total number of individuals (larvae plus adults) and population density of oceanic sea skaters. *H.m.*: *Halobates micans, H. g.*: *H. germanus, H.s.*: *H. sericeus*; *H.* sp.: A proposed new species, N: Number of individuals; ID: Individual density (Number/km^2); SS: Surface area swept by Neuston nets.

(a)

A: 33˚44' - 34˚28'N, 138˚40' - 46'E, 6th Sep, 2003 (SS: 7846.9 m^2)									
In Total		*H.m.*		*H.g.*		*H.s.*		*H.sp.*	
N	ID	N	ID	N	ID	N	ID	N	ID
30	3,823.1	5	637.3	0	0	25	3,186.9	0	0
B: 34.29˚N, 138˚39' - 41'E, 4th Sep, 2003 (SS: 2111.3 m^2)									
Total		*H.m.*		*H.g.*		*H.s.*		*H.sp.*	
N	ID	N	ID	N	ID	N	ID	N	ID
0	0	0	0	0	0	0	0	0	0
C: 31˚40' - 30˚30'N, 129˚56' - 130˚35'E, 30th Oct - 1st Nov, 2005 (SS: 9148.8 m^2)									
Total		*H.m.*		*H.g.*		*H.s.*		*H.sp.*	
N	ID	N	ID	N	ID	N	ID	N	ID
8	874.4	0	0	8	874.4	0	0	0	0
D: 33˚09' - 32˚28'N, 137˚05' - 02'E, 5th Dec, 2001 (SS: 2111.2 m^2)									
Total		*H.m.*		*H.g.*		*H.s.*		*H.sp.*	
N	ID	N	ID	N	ID	N	ID	N	ID
0	0	0	0	0	0	0	0	0	0
E: 31˚05' - 30˚53'N, 130˚25'E - 131˚41'E, 28th - 29th Sep, 2006 (SS: 6023.8 m^2)									
Total		*H.m.*		*H.g.*		*H.s.*		*H.sp.*	
N	ID	N	ID	N	ID	N	ID	N	ID
76	7,031.0	17	2,822.0	9	1,494.0	50	8,300.0	0	0
F: 32˚57' - 32˚00'N, 134˚02' - 132˚30'E, 25th - 30th Jun, 2000 (SS: 14779.1 m^2)									
Total		*H.m.*		*H.g.*		*H.s.*		*H.sp.*	
N	ID	N	ID	N	ID	N	ID	N	ID
69	4,668.8	8	541.3	0	0	61	4,127.5	0	0

(b)

G: 35˚00' - 33˚01'N, 141˚04' - 137˚10'E, 1st - 7th August, 2007 (SS: 32,862.7 m²)									
In Total		*H.m.*		*H.g.*		*H.s.*		*H.sp.*	
N	ID	N	ID	N	ID	N	ID	N	ID
38	1,156.3	14	426.1	0	0	23	699.9	1	30.4
H: 32˚45' - 30˚56'N, 133˚45' - 131˚03'E, 9th - 12th August, 2007 (SS: 20738.1 m²)									
Total		*H.m.*		*H.g.*		*H.s.*		*H.sp.*	
N	ID	N	ID	N	ID	N	ID	N	ID
89	4,291.6	25	1,205.5	52	2,507.5	9	434.0	3	144.7
I: 30˚10' - 50'N, 129˚33' - 40'E, 3 - 5th October, 2009 (SS: 11917.6 m²)									
Total		*H.m.*		*H.g.*		*H.s.*		*H.sp.*	
N	ID	N	ID	N	ID	N	ID	N	ID
1743	146,254.3	135	11,327.8	588	49,338.8	1014	85,084.2	6	503.5
J: 31˚51' - 34˚27'N, 133˚30' - 140˚00'E, 9th - 12th October, 2009 (SS: 26543.9 m²)									
Total		*H.m.*		*H.g.*		*H.s.*		*H.sp.*	
N	ID	N	ID	N	ID	N	ID	N	ID
264	9,945.8	16	602.8	79	2,976.2	169	6,366.8	0	0
K: 30˚50' - 33˚02'N, 130˚53' - 133˚48'E,14th - 17th Sep, 2008(SS: 13370.4 m²)									
Total		*H.m.*		*H.g.*		*H.s.*		*H.sp.*	
N	ID	N	ID	N	ID	N	ID	N	ID
324	24,232.6	7	523.5	302	22,587.2	15	1,121.9	0	0
L: 34.48˚N, 138˚30'E, 17th Sep, 2008 (SS: 4692.6 m²)									
Total		*H.m.*		*H.g.*		*H.s.*		*H.sp.*	
N	ID	N	ID	N	N	ID	N	ID	N
0	0	0	0	0	0	0	0	0	0

Table 2. Population density (Mean ± SD [n], individual number/1 km²) inside and around the *Kuroshio* current. *H.m.*: *Halobates micans*; *H.g.*: *H. germanus*; *H. s.*: *H. sericeus*; *H.* sp.: A proposed new species. When a sampling site has a current surface water speed more than 1 knot, this site was estimated as "inside the *Kuroshio*, when it does less than 1 knot, estimated as "around the *Kurosio*.

	Population density				
	H.m.	*H.g.*	*H.s.*	*H.*sp.	K-W test※
Inside the *Kuroshio*	2,202.6 ± 8,815.4 [26]	8,581.9 ± 24,443.2 [26]	16,396.4 ± 66,138.4 [26]	75.3 ± 306.2 [26]	6.442, 2, 0.040
Around the *Kuroshio*	1,362.5 ± 2,704.9 [19]	5,079.0 ± 9,501.2 [19]	2,223.8 ± 5,839.9 [19]	33.6 ± 146.6 [19]	0.805, 2, 0.669
Mann-Whitney U-test z & p values	−0.770 & 0.441	−0.074 & 0.941	−2.557 & 0.011	−0.698 & 0.485	

※*Kruskal-Wallis test among three species of Halobates micans, H. germanus and H. sericeus*: χ^2*-value, df, p.*

H. micans, H. germanus and *H. sericeus*, χ^2-value = 6.442, df = 2, $p = 0.04$) with a population density of 16,396.4 ind. km^{-2}, whereas the density of *H. germanus* was 8,581.9 ind. km^{-2} which did not differ from the population density outside the Kuroshio (5,079.0 ind. km^{-2}) (Mann-Whitney U-test: $z = -0.074$, $p = 0.941$) (**Table 2**).

The population densities of *H. sericeus* and *H. germanus* were significantly higher and more than 15,000 ind. km^{-2} in October inside and around the *Kuroshio* (Mann-Whitney U-test: *H. sericeus*, $z = -2.328$, p =0.020; *H. germanus*, $z = -2.483$, $p = 0.013$) than the other seasons, whereas there was no significant seasonal differences in population density of *H. micans* ($z = -0.770$, $p = 0.441$ between October and the other months) (**Table 3**). In total, the population density inside the *Kuroshio* was 27,234.5 ind. km^{-2} (±71,486.7 [26]) (Mean ± SD [n]) on average and tended to be higher than the population density in the area outside the *Kuroshio* (8,661.6 individuals km^{-2}) (±13,343.1 [19]) (Mann-Whitney U-test: $z = -1.763$, $p = 0.078$). At the beginning of December (**Table 1(d)**), no oceanic *Halobates* were collected even in the the *Kuroshio* where the sea surface temperature was 25˚C.

4. Discussion

Results of this study suggest that *Halobates sericeus* may be the dominant rider of the *Kuroshio* among the oceanic sea skaters studied. Andersen & Cheng [12] reported that the distribution of this species was limited to 13˚ - 45˚N in the Pacific Ocean. However, estimated suggest was a moderate population density of 2,010 - 7,100 individuals/km^2 in the tropical area from 0˚ - 10˚N (including the area around the equator) in the Western Tropical Pacific Ocean (Harada *et al.* 2010) [9]. This species may have been actively transferred by several currents, including the *Kuroshio*, the North Equator Current, the

Table 3. Population density (Mean ± SD [n], individual number/1 km^2) in several months inside and around the *Kuroshio. H.m.*: *Halobates micans*; *H.g.*: *H. germanus*; *H. s*: *H. sericeus*; *H.* sp.: A proposed new species.

	Population density				
	H.m.	*H.g.*	*H.s.*	*H.*sp.	In Total
June	947.3 ± 792.5 [6]	0.0 ± 0.0 [6]	4,318.9 ± 5,413.6 [6]	0.0 ± 0.0 [6]	5,170.6 ± 5,809.4 [6]
August	1,612.7 ± 792.6 [9]	2,078.9 ± 3,684.6 [9]	594.3 ± 711.4 [9]	79.1 ± 211.2 [9]	4,365.1 ± 5,934.2 [9]
September	1,141.6 ± 14852.0 [10]	7,007.1 ± 12007.4 [10]	3,611.7 ± 7329.4 [10]	0.0 ± 0.0 [10]	11,760.3 ± 14,852.0 [10]
October	3,436.0 ± 1,1631.0 [15]	15,058.4 ± 31,172.9 [15]	26,745.1 ± 86,786.1 [15]	125.6 ± 400.8 [15]	45,318.8 ± 91,296.7 [15]
November	0.0 ± 0.0 [3]	1,657.8 ± 2871.3 [3]	0.0 ± 0.0 [3]	0.0 ± 0.0 [3]	1,657.8 ± 2,871.3 [3]
December	0.0 ± 0.0 [2]	0.0 ± 0.0 [2]	0.0 ± 0.0 [2]	0.0 ± 0.0 [2]	0.0 ± 0.0 [2]
In Total	1,847.8 ± 6,879.2 [45]	7,102.9 ± 19,479.8 [45]	10,412.3 ± 50,492.1 [45]	57.7 ± 249.9 [45]	19,392.6 ± 55,339.9 [45]
# U-test					
z & p values	−0.857, 0.391	−2.483, 0.013	−2.328, 0.020	−0.780, 0.435	−1.483, 0.138

#Mann-Whitney U-test between population density in October and that in the other months.

Mindanao Current and the North Equator Counter Current, widely throughout the Western Pacific Ocean. The *Kuroshio* may be transporting a relatively large number of *H. sericeus* individuals (with a density of 1,1721.6 individuals/km^2) in the relatively northern area south of the Japanese archipelago.

Harada *et al.* (2010) [9] estimated a high population density of 13,000 to 60,000 *H. germanus* individuals/km^2 throughout the wide longitudinal area from 130˚ - 156˚E (0˚ - 10˚N) in the Western Tropical Pacific Ocean. In this study, a moderate population density of around 6,000 individuals/km^2 of *H. germanus* was estimated both inside and outside the *Kuroshio* in the northern Pacific Ocean area south of the southern coast of Japan. The genetic variation of the populations of *H. germanus* living outside several currents flowing in the wide range of latitudes from the equator to 35˚N might lead to the result of a lack of genetic crossing, because, for example, there are no opportunities for the population north of the *Kuroshio* to mate with the other populations north of the North Equator Counter Current, for example, excluding the special occasion of the transportation by typhoons moving south to north in the Pacific Ocean.

The species ratio of *H. micans* decreases greatly in October and November. This phenomenon suggests that *H. micans* populations that are transported from low latitude areas may show low reproductive activity under low air temperature conditions in the fall, and suggests that this species is actually a tropical species.

For the future study, the interaction between populations inside and outside the *Kuroshio* and that between populations inhabiting the two currents of the *Kuroshio* and the North Equator Current should be tested by examining genes such as mtDNA of the individuals from the two populations. If it would be possible, the "catch, mark and release" project would be exciting, releasing many adult sea skaters which have been collected, marked with color paints and released on the North Equator Current and then, catching them on the *Kuroshio*, for example.

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