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A latitudinal gradient in the biogeographic compositions of rock pool fish assemblages on the Pacific coast of central Japan: an examination of the influence of the Kuroshio Current

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Abstract. To investigate the effect of the Kuroshio Current on the biogeographic composition of coastal fish assemblages, rock pool fishes were quantitatively surveyed at three latitudinally differentiated localities on the Kii Peninsula and in an adjacent area in central Japan: the southern Kii Peninsula in Wakayama Prefecture (the southernmost point, abbreviated as Wakayama); the eastern Kii Peninsula in Mie Prefecture (the midpoint, abbreviated as Mie); and southern Ise Bay in Aichi Prefecture (the northernmost point, abbreviated as Aichi). Ten rock pools were investigated in each location over a 4-month period from September to December, 2013 (Japanese summer to winter). The assemblages included typical rock pool fish species, such as abundant and diverse Gobiidae, Blenniidae, and Pomacentridae. A biogeographic comparison of the species compositions at the three sites showed a latitudinal gradient: the percentage of tropical fish density and the number of tropical species decreased with latitude, and a biogeographic shift in the dominant species was observed, with less tropical species and more cool-temperate species with latitude. Temporal and geographic comparisons of each parameter (fish density, tropical species density, number of species, percentage of tropical species, and diversity index) indicated temporal stability and a higher occurrence of tropical species in Wakayama. These trends in assemblage parameters correspond with the thermal distribution pattern off the eastern Kii Peninsula in 2013, suggesting that the Kuroshio Current has a biogeographic influence on rock pool fish assemblages along the coast of the Kii Peninsula. Further comparisons of biogeographic compositions in terms of the percentages and numbers of species and individuals including results for three other localities from past studies (six sites compared in total) showed that the occurrence of tropical species had a latitudinal tendency, decreasing northward, among five sites along the Kuroshio Current. However, one site (in Kumamoto Prefecture, on the western coast of Kyushu), which is latitudinally below Wakayama but not in the course of the Kuroshio Current, had almost no tropical species. These results indicate that the Kuroshio Current has a greater influence than latitude on local occurrence of tropical fish species.

Key words: intertidal, Kuroshio Current, reef fish, tropical species, warm current

Introduction

Latitudinal gradients in species composition are a topic central to understanding global patterns of biodiversity (Cox & Moore, 2005). In the marine realm, an understanding of the effects of oceanic currents on fauna and flora is also essential to clarifying these patterns. Particularly in Japanese waters, the Kuro-

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shio Current, a strong warm-water current that flows from the Philippines to the Pacific coast of Japan, is one of the fundamental factors structuring assemblages of coastal organisms (Nishimura, 1981, 1992; Fujikura *et al*., 2010). Senou *et al*. (2006) compared and analyzed marine fish fauna, including over 1500 species from 12 sites off the Pacific coast of Japan, and suggested that the Kuroshio Current acts as a southern barrier to warm–temperate species, as well as a transporter of tropical species northward. Murase (2013) investigated the community structure of a rock pool fish assemblage at Yaku-shima Island (hereafter Yaku-shima), which is strongly affected by the Kuroshio Current with maintaining seawater around the island at an average about 20ºC even in midwinter (Naruo, 2000), and revealed the high diversity in the island's rock pools, and year-round stability of diversity in the community. In addition, he compared the biogeographic composition of the island's species with those of other Japanese sites from past studies, and suggested that the fish assemblages at Yaku-shima are more affected by the Kuroshio Current, on the basis of a much higher dominance of tropical species, both in terms of the number of species and the numbers of individuals. However, the three sites compared in his study were at different latitudes, so distinguishing the effects of the Kuroshio Current on the assemblages is difficult.

The southern Kii Peninsula (Wakayama Prefecture, central Japan), which includes the southernmost point of Honshu (the mainland of Japan), has a high diversity of coastal fish fauna from summer to autumn due to an increase in coral reef fish species (Araga & Tanase, 1966; Kuwamura, 1980). In a comparison of the fish fauna of Wakayama Prefecture to those in adjacent regions located farther northward, tropical species accounted for almost 80% in Wakayama Prefecture, while other regions recorded 45–65% tropical species (Ohgaki, 2010). These facts suggest that the distance from the Kuroshio Current affects tropical fish diversity and occurrence. However, as yet, no study has quantitatively investigated and compared the biogeographic compositions of fish assemblages in similar environments around the peninsula in an effort to understand the Kuroshio's effect on coastal fish assemblages. The present study examined the community structures of rock pool fish assemblages at three sites around the eastern coast of the Kii Peninsula, located at different distances from the Kuroshio Current. Here, we investigated variations in the occurrence rates of tropical fish species, in terms of both the number and abundance of species, with respect to the distance from the warm current to elucidate the effects of the Kuroshio Current on coastal fish fauna in Japanese waters. In addition, we performed a biogeographic comparison of the rock pool fish assemblages with those of sites from previous studies to discuss the effects of both latitude and the Kuroshio Current on fish assemblages.

Materials and methods

Three rocky shore sampling sites at differing distances from the Kuroshio Current, from the southeastern Kii Peninsula to Ise Bay in central Japan, were selected to examine the effects of the warm current on rock pool fish communities (Fig. 1). The southernmost site (33°26'N, 135°46' E) was in Shionomisaki, Kushimoto-cho, at the southern tip of the Kii Peninsula, Wakayama Prefecture (hereafter Wakayama), which contains the southernmost point of Honshu, the main island of Japan. This site was the closest point to the Kuroshio Current and appeared to be the most affected by the warm current. The middle site, on the eastern Kii Peninsula (34°10'N, 136°18'E), was Kaino, Kiinagashima-ku, Kihoku-cho, Kitamuro-gun, Mie Prefecture (hereafter Mie). This site appeared to be less affected by the warm current than Wakayama. The northernmost

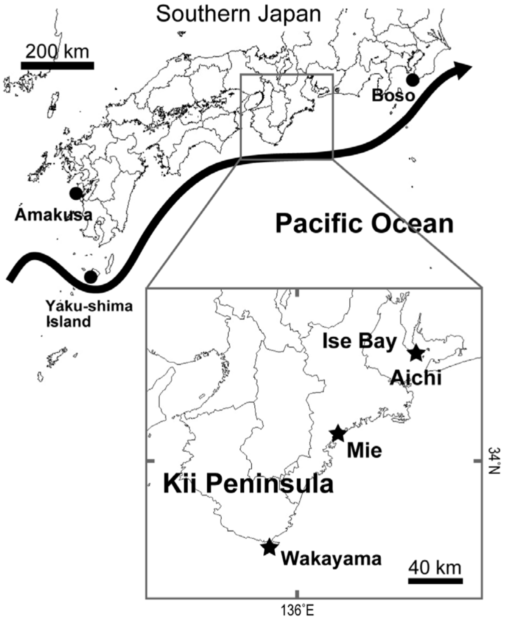

Fig. 1. Map showing the sampling sites of rock pool fish assemblages in the Kii Peninsula and Ise Bay, in central Japan [stars: Wakayama (Shionomisaki, Wakayama Prefecture, southern Kii Peninsula); Mie (Kaino, Mie Prefecture, eastern Kii Peninsula); Aichi (Toyohama, Aichi Prefecture, the Ise Bay)] and comparable sites from past studies in southern Japan (circles: Yaku-shima Island, Amakusa, and Boso). The course of the Kuroshio Current is indicated with a solid arrow.

site (34°42'N, 139°56'E) was Toyohama, Minamichita-cho, Aichi Prefecture (hereafter Aichi), located within the Ise Bay, and appeared to be the least affected by the Kuroshio Current. These sites were selected to be as uniform physical environment (such as wave exposure) as possible.

Each month, for 4 months, 10 tide pools were investigated at each sampling location. The total number of tide pools investigated during the 4 months differed at each site, as the same pools were not sampled each time; some tide pools were inaccessible on certain sampling occasions due to costal weather conditions, such as high waves, and at these times, another tide pool was selected. Throughout the sampling sites, the tide pools were selected so as to be as close as possible in mean size and elevation, following the methods of Castellanos-Galindo *et al*. (2005) for rock pool measurements and volume estimations. Tide pool volumes ranged from 0.10 to 1.01 m^3 (n = 14, mean ± SD: 0.57 ± 0.33 m^3), 0.06 to 0.62 m^3 (n = 16, 0.25 ± 0.18 m^3), and 0.11 to 2.36 m^3 (n = 18, 0.67 ± 0.66 m^3) in Wakayama, Mie, and Aichi, respectively. Tide pool heights (pool surface height at low tide: see Fig. 1 in Murase *et al*., 2010) ranged from 0.54 to 0.84 m (n = 14, mean ± SD = 0.71 ± 0.10 m), 0.50 to 1.03 m (n = 16, 0.71 ± 0.16 m), and 0.30 to 1.20 m (n = 18, 0.81 ± 0.25 m) in Wakayama, Mie, and Aichi, respectively. Tide pool fish samplings were conducted near spring tide in September, October, November, and December 2013 (Japanese summer to winter) at each site. This period was chosen because as rates of tropical fish occurrences increase in summer and autumn, they are better seasons for comparing the occurrence patterns of tropical species between the sites. Surface water temperatures around the study sites in 2013 varied as follows [data following Fourth Regional Coast Guard Headquaters (2014)]—Wakayama: September, 27–28ºC; October, 25–26ºC; November, 23–25ºC; December, 20ºC; Mie: September, 26ºC; October, 24–25ºC; November, 22–23ºC; December, 19ºC; Aichi: September, 26–27ºC; October, 22–24ºC; November, 20–21ºC; December, 15–18ºC. At each tide pool, two persons collected fish using a dip net until all fish in the pool were captured. Immediately after collection, fishes were identified according to Nakabo (2013) (the scientific names of two gobiid species follow Akihito *et al*., 2013: Table 1), the number of individuals was recorded, and then the fish were immediately released. To ascertain the biogeographic composition of the rock pool fish assemblage at each site, recorded species were divided into three biogeographic categories (tropical species, warm–temperate species, and cool–temperate species) defined by Murase (2013) based on the distributional information of each species in Nakabo (2013). To ascertain differences in community structure between the sites and the sam-

Table 1. List of rock pool fishes captured at three sites in central Japan (Wakayama, Mie, and Aichi) from September to December 2013. Each species is listed in order of family and species abundance.

Species	Biogeographic category	Number of individuals and percent in total assemblage							
		Wakayama		Mie		Aichi		Three site total	
		n	%	*n*	%	*n*	%	*n*	%
Gobiidae									
Bathygobius fuscus	W	182	38.48	89	15.34	51	13.75	322	22.61
Chaenogobius annularis	C	38	8.03	214	36.90	49	13.21	301	21.14
Bathygobius cocosensis	Tr	57	12.05					57	4.00
Chaenogobius gulosus	C			38	6.55	1	0.27	39	2.74
Eviota prasina	Tr	21	4.44					21	1.47
Tridentiger trigonocephalus	C					8	2.16	8	0.56
Luciogobius sp. 6*	W					7	1.89	7	0.49
Bathygobius cyclopterus	Tr					1	0.27	1	0.07
Bathygobius sp.	-	1	0.21					1	0.07
Clariger sp.*	W					1	0.27	1	0.07
Eviota abax	W	1	0.21					1	0.07
Blenniidae									
Istiblennius enosimae	W	47	9.94	171	29.48	12	3.23	230	16.15
Omobranchus elegans	C			9	1.55	112	30.19	121	8.50
Parablennius yatabei	C					77	20.75	77	5.41
Rhabdoblennius nitidus	Tr	17	3.59					17	1.19
Praealticus tanegasimae	Tr	12	2.54					12	0.84
Entomacrodus stellifer stellifer	W	7	1.48	1	0.17			8	0.56
Istiblennius lineatus	Tr	5	1.06					5	0.35
Omobranchus punctatus	W					4	1.08	4	0.28
Istiblennius edentulus	Tr	1	0.21					1	0.07
Omobranchus loxozonus	W	1	0.21					1	0.07
Scartella emarginata	W					1	0.27	1	0.07
Pomacentridae									
Abudefduf sordidus	Tr	33	6.98	26	4.48	3	0.81	62	4.35
Abudefduf notatus	Tr	16	3.38	13	2.24			29	2.04
Abudefduf septemfasciatus	Tr	4	0.85					4	0.28
Abudefduf vaigiensis	Tr	2	0.42			1	0.27	3	0.21
Pomacentrus coelestis	Tr	2	0.42					2	0.14
Abudefduf bangalensis	Tr					1	0.27	1	0.07
Chrysiptera unimaculata	Tr	1	0.21					1	0.07
Plectroglyphidodon leucozonus	Tr			1	0.17			1	0.07
Tripterygiidae									
Enneapterygius etheostomus	W	5	1.06	3	0.52	31	8.36	39	2.74
Labridae									
Stethojulis interrupta terina	W	8	1.69	12	2.07	2	0.54	22	1.54
Thalassoma cupido	W	3	0.63					3	0.21
Thalassoma purpureum	Tr	1	0.21					1	0.07
Gobiesocidae									
Aspasmichthys ciconiae	W	5	1.06					5	0.35
Aspasma minima	W			2	0.34			2	0.14
Sebastidae									
Sebastes cheni	C					4	1.08	4	0.28
Tetrarogidae									
Hypodytes rubripinnis	C					3	0.81	3	0.21
Cottidae									
Furcina osimae	C					2	0.54	2	0.14
Chaetodontidae									
Chaetodon auriga	Tr	1	0.21					1	0.07
Pinguipedidae									
Parapercis snyderi	W	1	0.21					1	0.07
Stichaeidae									
Dictyosoma sp.	C			1	0.17			1	0.07
Syngnathidae									
Micrognathus andersonii	Tr	1	0.21					1	0.07
Total number of individuals		473	100.00	580	100.00	371	100.00	1424	100.00
Total number of species		26		13		20		42	

*Sensu Akihito et al. (2013). Not including Bathygobius sp. as one species.

pling months, the metrics of fish density (number of fish per m^3), tropical fish density, number of species, percent of tropical species, and Simpson's index of diversity (Krebs, 1999) were calculated for each tide pool. Generally, data were compared using one-way analysis of variance (ANOVA), and Tukey's test was used for multiple comparisons. However, if the assumption of homogeneity was violated after Bartlett's test was performed, the assemblage data were $\log_{10}(x + 1.0)$ transformed for statistical comparisons. When the assumption of homogeneity was violated despite $\log_{10}(x + 1.0)$ transformation, Kruskal–Wallis and nonparametric Steel–Dwass tests were performed.

To compare the biogeographic compositions of the rock pool fish assemblages at the study sites to those of other sites on the Pacific coast of Japan, three previous studies were referred to and each species recorded in those studies was biogeographically categorized following the above definitions. The locations of the previous studies (Fig. 1) were Yaku-shima (30°16' N, 130°24' E; Murase, 2013), Amakusa-Shimoshima Island (hereafter Amakusa; 32°31' N, 130°01' E; Arakaki & Tokeshi, 2006), and the southern Boso Peninsula (hereafter Boso; 34°58' N, 139°46' E; Murase *et al*., 2010). Amakusa is the only location that was not located along the course of the Kuroshio Current.

Results

Basic composition of assemblages — In total, 1424 fish individuals belonging to 13 families and 42 species (not including an unidentified *Bathygobius* sp. specimen) were collected from three sites in central Japan over 4 months (Table 1). Gobiidae was the most abundant family (759 individuals, 53.3% of the total) followed by Blenniidae (477, 33.5%), Pomacentridae (103, 7.2%), Tripterygiidae (39, 2.7%), Labridae (26, 1.8%), Gobiesocidae (7, 0.5%), and other families represented by less than five individuals each. In terms of the number of representative species, Blenniidae was the most predominant family with 11 species (42.3% of the total), followed by Gobiidae (10, 38.5%), Pomacentridae (8, 30.8%), Labridae (3, 11.5%), and Gobiesocidae (2, 7.7%), with the remainder represented by one species each. In terms of biogeographic composition, warm–temperate species were the most abundant (647 individuals, accounting for 45.4% of the combined total from all three sites), followed by cool–temperate species (556, 39.0%) and tropical species (220, 15.5%). In terms of the number of species, however, tropical species were the most diverse, with 18 species accounting for 42.9% of the combined total from all three sites, followed by warm–temperate species (15, 35.7%) and cool–temperate species (9, 21.4%).

The rock pool fish assemblages of Wakayama comprised 473 individuals belonging to 26 species from nine families. Gobiidae was the most abundant family (300 individuals, 63.4% of the total assemblage at the site) followed by Blenniidae (90, 19.0%), Pomacentridae (58, 12.3%), Labridae (12, 2.5%), and others representing less than 2.0% each. However, Blenniidae was the most diverse family in terms of the number of species (7 species, 26.9%), followed by Pomacentridae (6, 23.1%), Gobiidae (5, 19.2%), Labridae (3, 11.5%), and others represented by one species each. Biogeographically, in Wakayama, warm–temperate species were the most abundant (260 individuals, 55.0%), followed by tropical species (174, 36.8%) and cool–temperate species (38, 8.0%), although in terms of the number of species, tropical species were the most diverse with 15 recorded species (57.7% of the total), followed by warm–temperate species (10, 38.5%) and cool–temperate species (1, 3.9%).

The rock pool fish assemblages of Mie comprised 580 individuals belonging to 13 species from seven families. Gobiidae were the most abundant (341

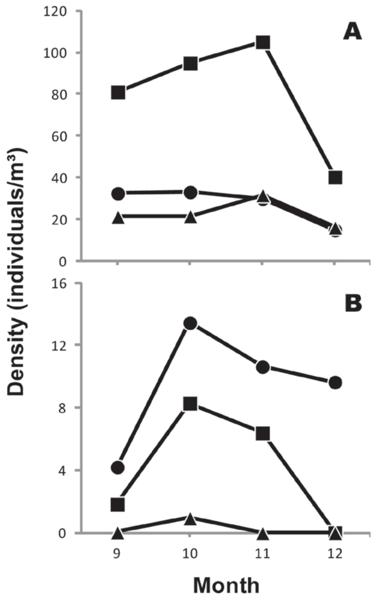

Fig. 2. Mean fish density (A) and mean density of tropical species (B) at each site over 4 months. Circles, squares, and triangles indicate Wakayama, Mie, and Aichi, respectively. Sample size = 10 pools per site per month.

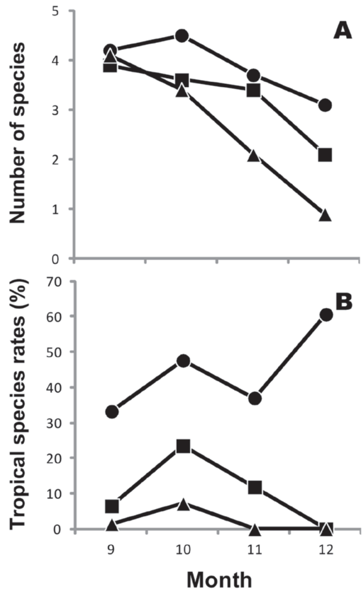

Fig. 3. Mean number of species (A) and percentage of tropical species (B) at each site over 4 months. Circles, squares, and triangles indicate Wakayama, Mie, and Aichi, respectively. Sample size = 10 pools per site per month.

individuals, 58.8% of the site total), followed by Blenniidae (181, 31.2%), Pomacentridae (40, 6.9%), Labridae (12, 2.1%), and others, each representing less than 1.0%. In terms of the number of species, Gobiidae, Blenniidae, and Pomacentridae were the largest families with three species each (23.1% each), with the other families represented by one species each (7.7%). In terms of the biogeographic composition of Mie, warm–temperate species (278 individuals, 47.9%) and cool–temperate species (262, 45.2%) were almost equally abundant, followed by tropical species (40, 6.9%). In terms of the number of species, warm–temperate fishes were the most diverse with six recorded species (46.2% of the site total), followed by cool–temperate fishes (4, 30.8%) and tropical fishes (3, 23.1%).

The rock pool fish assemblages of Aichi comprised 371 individuals belonging to 20 species from eight families. Blenniidae was the most abundant family (206 individuals, 55.5% of the site total), followed by Gobiidae (118, 31.8%), Tripterygiidae (31, 8.4%), Pomacentridae (5, 1.3%), and other families with less than five individuals (1.3%) each. In terms of the number of species, Blenniidae was the most diverse family (7 species, 35.0%), followed by Gobiidae (6, 23.1%), Pomacentridae (3, 15.0%), and others represented by one species each. The biogeographic composition of Aichi was dominated by cool–temperate species (256 individuals, 69.0%), followed by warm–temperate species (109, 29.4%) and tropical species (6, 1.6%). In terms of diversity, both warm– and cool–temperate fishes were represented by eight recorded species (40.0% each), and tropical fishes had four recorded species (20.0%).

Table 2 shows the five most abundant species at each site, accounting for more than 75.0% of total fish individuals. Wakayama and Mie had two and one abundant tropical species, respectively, while Aichi had no abundant tropical species. On the other hand, Aichi and Mie had three and two abundant

Table 2. The most abundant fish species at three sites in central Japan. Letters in parentheses indicate biogeographic categories (C, cool–temperate; Tr, tropical; W, warm–temperate). Abundance rates indicate the percentage of the site total number of individual fish.

Ranking	Wakayama	Mie	Aichi
1	*Bathygobius fuscus* (W, 38.5)	*Chaenogobius annularis* (C, 36.9)	*Omobranchus elegans* (C, 30.2)
2	*Bathygobius cocosensis* (Tr, 12.1)	*Istiblennius enosimae* (W, 29.5)	*Parablennius yatabei (C, 20.8)*
3	*Istiblennius enosimae* (W, 9.9)	*Bathygobius fuscus* (W, 15.3)	*Bathygobius fuscus* (W, 13.8)
4	*Chaenogobius annularis* (C, 8.0)	*Chaenogobius gulosus* (C, 6.6)	*Chaenogobius annularis* (C, 13.2)
5	*Abudefduf sordidus* (Tr, 7.0)	*Abudefduf sordidus* (Tr, 4.5)	*Enneapterygius etheostomus* (W, 8.4)

Table 3. Results of statistical comparisons (ANOVA or Kruskal–Wallis test) among the 4 months at each site, and among the three sites in each month.

	Among the months			Among the sites			
	Wakayama	Mie	Aichi	September	October	November	December
Results of statistics							
Fish density	$F = 1.78$; $p = 0.17$	$\chi2 = 6.21$; $p = 0.10$	$F = 0.49$; $p = 0.69$	$F = 13.52$; $p < 0.001$	$F = 8.34$; $p < 0.01$	$\chi2 = 7.13$; $p < 0.05$	$F = 2.83$; $p = 0.08$
Tropical fish density	$F = 1.85$; $p = 0.16$	$\chi2 = 11.97$; $p < 0.01$	$\chi2 = 6.81$; $p = 0.08$	$\chi2 = 9.51$; $p < 0.01$	$F = 4.56$; $p < 0.05$	$\chi2 = 9.40$; $p < 0.01$	$\chi2 = 23.85$; $p < 0.001$
Number of species	$F = 1.63$; $p = 0.20$	F = 5.09; $p < 0.01$	$F = 8.11$; $p < 0.001$	$\chi2 = 0.01$; $p = 0.99$	$F = 1.38$; $p = 0.27$	$F = 5.85$; $p < 0.01$	$F = 8.05$; $p < 0.01$
% of number of tropical species	$F = 2.26$; $p = 0.09$	$\chi2 = 12.55$; $p < 0.01$	$\chi2 = 6.59$; $p = 0.09$	$F = 7.86$; $p < 0.01$	$F = 16.28$; $p < 0.001$	$\chi2 = 12.10$; $p < 0.01$	$\chi2 = 23.94$; $p < 0.001$
Diversity index	$\chi2 = 4.91$; $p = 0.18$	F = 0.72; $p = 0.55$	$F = 5.39$; $p < 0.01$	$\chi2 = 1.53$; $p = 0.47$	$\chi2 = 4.42$; $p = 0.11$	$\chi2 = 9.09$; $p < 0.05$	$F = 7.50$; $p < 0.01$
Results of multiple comparisons							
Fish density	-	-	-	w < m, a < m	a < m	-	-
Tropical fish density	-	Dec < Oct	-	a < w	a < w	a < w, a < m	a < w, m < w
Number of species	-	Dec < Sep, Dec < Oct	Dec < Sep, Dec < Oct	-	-	a < w, a < m	a < w
% of number of tropical species	-	Dec < Oct	-	a < w, m < w	a < w, m < w	a < w, a < m	a < w, m < w
Diversity index	-	-	Dec < Sep, Dec < Oct	-	-	a < w	a < w, a < m

Abbreviations as follows: Sep, September; Oct, October; Nov, November; Dec, December; a, Aichi ; m, Mie; w, Wakayama.

cool–temperate species, respectively, while Wakayama had only one abundant cool–temperate species. Two warm–temperate species were included among the most abundant species at each site.

Temporal and geographic variation of assemblages — Mean fish densities at each site tended to be stable, with no significant differences, but fish densities in Mie tended to decrease in December, and were higher than the other two sites throughout the sampling period (Fig. 2A, Table 3). On the other hand, mean tropical fish densities tended to be higher in October at all three sites (statistically significant in Mie only), and Wakayama tended to have higher tropical fish densities than the other two sites throughout the sampling period (Fig. 2B, Table 3). Mean numbers of species at each site tended to decrease toward December, at which time they were significantly lower than in September and October in Mie and Aichi; Wakayama tended to have higher diversity than the other two sites, especially in November and December (Fig. 3A, Table 3). Mean percentages of tropical species did not vary significantly in Wakayama and Aichi, but in Mie, the percentage of tropical species was significantly higher in October than in December; Wakayama tended to have higher percentages of tropical fishes than the other two sites for all 4 months (Fig. 3B, Table 3). Mean diversity indices did not significantly vary in Wakayama or Mie, while in Aichi, diversity decreased significantly in December; Aichi was significantly less diverse than the other two sites (Fig. 4, Table 3).

Biogeographic comparison with other sites — In the biogeographic comparison of six sites within Japanese waters, tropical species occurrences, in terms of both the numbers of individuals and numbers of species, tended to decrease with latitude, with the exception of Amakusa, which had almost no tropical

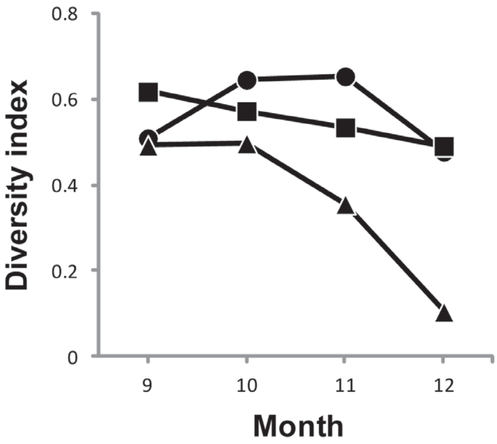

Fig. 4. Mean diversity indices at each site over 4 months. Circles, squares, and triangles indicate Wakayama, Mie, and Aichi, respectively. Sample size = 10 pools per site per month.

species in terms of number of individuals (<0.5% of the total assemblage) despite being located at a lower latitude than Wakayama (Fig. 5). No notable tendencies were observed for warm– or cool–temperate species occurrences in relation to latitude.

Discussion

Our results indicate that rock pool fish assemblages in the region ranging from the Kii Peninsula to Ise Bay comprise the typical members at the family level (e.g., Gobiidae, Blenniidae, Pomacentridae, and Labridae), similar to other warm–temperate tropical zones of the Indo-West Pacific region (Gibson & Yoshiyama, 1999; Beckly, 2000; Griffiths, 2003; Cox *et al*., 2011; Murase, 2013). In addition, at the three separate sites in this study, the predominant families at each site were Gobiidae, Blenniidae, and Pomacentridae (with the exception of the third most abundant family in Mie, which was Tripterygiidae), following the global pattern. Murase *et al*. (2010) reviewed rock pool fish fauna in temperate Japanese waters and noted that three gobiid species, *Chaenogobius annularis*, *Chaenogobius gulosus*, and *Bathygobius fuscus*, represent rock pool fish fauna in this zone. Similarly, in this study, *C. annularis* and *B. fuscus* were included in the top five species in terms of abundance at every site (Table 2), supporting the findings of Murase *et al*. (2010). In addition to these gobiids, a blenniid, *Istiblennius enosimae*, occurred at all three sites and was included in the top five species at both Wakayama and Mie (Table 2). *Istiblennius enosimae* has also been recorded in other regions of temperate Japanese waters (Nakamura, 1970; Shiogaki & Dotsu, 1972; Ueda & Hagiwara, 1992; Murase *et al*., 2010) and appears to be another representative species of the warm–temperate rock pool fish communities on the Pacific coast of Japan. In Aichi, another two blenniids were more abundant than the gobies (Table 2); *Omobranchus elegans* and *Parablennius yatabei* have been recorded in the rock pools of other temperate regions, but they are not abundant on some Japanese coasts (Ueda & Hagiwara, 1992; Murase *et al*., 2010). The habitat characteristics of each location may affect fish occurrence patterns, and further detailed studies of factors such as habitat preference would be necessary to reveal the factors influencing each individual species.

The biogeographic compositions at each site exhibited a latitudinal gradient. Specifically, the relative abundance of tropical fishes decreased with increasing latitude (i.e., from south to north, 36.8% in Wakayama, 6.9% in Mie, and 1.6% in Aichi), and the percentage of tropical species was also lower at higher latitude sites (57.7% in Wakayama, 23.1% in Mie, and 20.0% in Aichi). In addition, regarding the most abundant species at each site (Table 2), the number of dominant tropical species varied inversely with latitude (two species in Wakayama, one in Mie, and none in Aichi), whereas cool–temperate species varied directly with latitude (one species in Wakayama, two in Mie, and three in Aichi). The temporal and geographic variation in all rock pool fish assemblage metrics indicated temporal stability and higher trop-

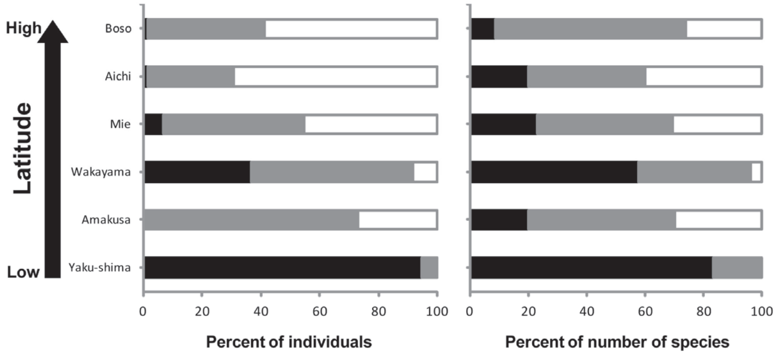

Fig. 5. Biogeographic compositions of rock pool fish assemblages at six sites in Japanese waters based on relative abundances of individual fishes (left) and species (right). The black, gray, and white areas indicate tropical species, warm–temperate species, and cool– temperate species, respectively. Note that Amakusa, which faces the East China Sea, in not located along the course of the Kuroshio Current.

ical species occurrences in Wakayama. Specifically, all metrics in Wakayama were stable throughout the study period, while some metrics at the other two sites were significantly lower in December; although total fish density was higher in Mie, tropical species density tended to be higher in Wakayama than at the other sites for all 4 months; the mean number of species in Wakayama tended to be higher than at the other two sites in November and December, and the mean percentage of tropical species was significantly higher in Wakayama than at the other sites through the entire study period; and diversity indices were stable for all 4 months in Wakayama and Mie. No environmental data were recorded during the present study, but it is the case that the latitudinal gradient in the biogeographic composition of rock pool fish in this study corresponded with the thermal distribution pattern around the southern Kii Peninsula during September–December 2013, which had a tendency of increasing temperatures southward along the eastern coast of the peninsula (this tendency was particularly conspicuous in December; Hydrographic and Oceanographic Department, 2014).

Furthermore, the biogeographic comparison of the compositions of rock pool fish assemblages including other Japanese waters (Fig. 5) revealed a latitudinal pattern in tropical fish dominance and a clear difference between Amakusa and Wakayama. Specifically, Amakusa, which is not located on the course of the Kuroshio Current, possessed almost no tropical fishes in its rock pool fish assemblages, while Wakayama showed a relatively greater dominance of tropical species than the other sites (except for Yaku-shima), despite its location at a higher latitude than Amakusa. This fact emphasizes the influence of the Kuroshio Current on coastal fish fauna, particularly its role in transporting tropical fish species northward. On the other hand, Boso did not show rich tropical fish fauna despite its position on the course of the Kuroshio Current. As mentioned in Matsuura (2012), tropical fish species visiting at Pacific coast of the southern Japan in summer and autumn disappear in winter due to a fall in water temperature. On the winter surface temperature, the thermal distribution pattern of Naruo (2000) and the mean temperature information of Fujimoto & Tomosada (1980) in Pacific coast of Japan on the course of the Kuroshio Current showed clear lower tendency around the Boso Peninsula than the southern Kii Peninsula. This may be one of the main factors for the differences in rockpool fish fauna between Wakayama and Boso. Although the cause of this thermal gap between two regions is unknown, the extent of Kuroshio's effect may differ between the sites. However, using the data comparing the six sites, with differences in sampling duration and year, we are still unable to discern a relationship between the seasonal occurrence patterns of rock pool fish assemblages and the Kuroshio Current. Nevertheless, basically, our results quantitatively support the findings of Nishimura (1992), who concluded that water movements that determine thermal distributions directly function as key players in transporting biological assemblages in the ocean.

Our findings from this study fill in a gap in the biogeographic knowledge of rocky intertidal fish communities from the Boso Peninsula (Murase *et al*., 2010) to Yaku-shima (Murase, 2013), covering a distance of almost 800 km. Further studies of fish assemblages in Japanese waters on various temporal and spatial scales will be necessary to elucidate the patterns of community formation and the factors affecting them.

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