

An Evolutionary Glimpse of the inland-water species of the Genus *Gnorimosphaeroma* (Isopoda, Sphaeromatidae) in Japan

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ABSTRACT In Japan, 15 species of the genus *Gnorimosphaeroma* have hitherto been recorded from various areas of not only seashores but also inland freshwaters. Considering the morphological, ecological and biogeographical data, a preliminary trial on phylogenetic relationship of the group is made.

KEY WORDS *Gnorimosphaeroma* / Isopoda / biogeography / evolution / inland-water / Japan / the Sea of Japan

Introduction

The isopods of the genus *Gnorimosphaeroma* are found very commonly, not only in seawater and brackish water but also in freshwater environments throughout Japan. The latter is rather common in purely freshwater environments along the Sea of Japan side and they show delicate but constant geographical variations, especially in number of setae on oral appendages, number of teeth of oral appendages, number of flagellar segments of both antennae and so on. Therefore, their taxonomy has been left in much inadequate state.

Recently, examining about 1200 specimens from more than 60 localities through Japan, I was confirmed in separating them into 16 species including 8 reported as new ones (Nunomura, 1998, 1999).

Results and Discussion

1. Species of the genus *Gnorimosphaeroma* in Japan

Hitherto, the following 16 species of the genus *Gnorimosphaeroma* have been known as valid in Japan. They are as follows:

① *Gnorimosphaeroma rayi* Hoestlandt, 1969

This species occurs in intertidal and subtidal zones. The distribution of this species is Japan, Korea, Hawaii and California. This species show a notable polychromatism (Hoestlandt, 1975).

② *Gnorimosphaeroma ovatum* (Gurjanova, 1933)

This species occurs in intertidal and subtidal zone. This species is distributed in mainly in northern to central Japan, Korea, and Far-East Russia.

③ *Gnorimosphaeroma hoestlandti* Kim & Kwon, 1985

This species occurs intertidal and subtidal zone. In Japan, this species is distributed in rather wide areas in central and southern Japan: Boso Peninsula, Lake Naka-umi, Shimoda, Amakusa and many shores.

④ *Gnorimosphaeroma hachijoense* Nunomura, 1998

This species was recorded from an intertidal rocky shore of Hachijo-Island, Izu Islands, southern Japan. The distribution of this species has been only the type locality (Nunomura, 1998).

⑤ *Gnorimosphaeroma shikinense* Nunomura, 1998

This species was recorded from a shore of Shikine-Island, Izu islands, eastern Japan. The distribution of this species has been only the type locality (Nunomura, 1998).

⑥ *Gnorimosphaeroma kurilense* Kussakin, 1974

This species was established by Kussakin (1974), and it has been found from deep sea near Shikotan Island and a lake of Itrup, Kurile Islands (Kussakin, 1974).

⑦ *Gnorimosphaeroma chinense* (Tattersall, 1921)

This species was described based on the specimens from China, near the mouth of Yanzhe River. After that, Nunomura (1998) found it from the mouth of Suttu River. Recently this species has been reported from many localities (Fukuhara *et al.*, 2000). The distribution of this species is China, Korea and Japan.

⑧ *Gnorimosphaeroma tondaense* Nunomura, 1999

This species was discovered from the brackish water of the mouth of Tonda River, middle Japan (Nunomura, 1999). The distribution of this species has been known only from the type locality.

⑨ *Gnorimosphaeroma anchialos* Jang & Kwon, 1993

This species was discovered from Korea (Jang and Kwon, 1993) at first. After that, Nunomura (1998) reported this species mouth of Yura River, and Wakayama Prefecture. The distribution of this species is Korea and Japan.

⑩ *Gnorimosphaeroma pulchellum* Nunomura, 1998

Nunomura (1998) described this species from the mouth of Obitsu River, Kisarazu City, Chiba Prefecture, Central Japan. The distribution of this species has been known only from the type locality (Nunomura, 1998).

⑪ *Gnorimosphaeroma naktongense* Kwon & Kim, 1987

This species was reported from brackish water of mouth of Naktong River, South

Korea (Kwon & Kim, 1987). After that, many specimens have been recorded from the various parts in Japan. The distribution of this species is Southern Korea and Japan, the latter contains many freshwater systems (Nunomura, 1998, Fukuhara et al., 2000 and many papers) especially along the Sea of Japan coasts of Japan and some brackish waters (Fukuhara et al., 2000),

⑫ *Gnorimosphaeroma hokurikuense* Nunomura, 1998

This species was first recorded from a small stream, Takaoka City, Toyama Prefecture (Nunomura, 1998). After that, specimens have been found in several streams mainly in the water derived from springs near the type locality. Occurrence of *G. hokurikuense* is restricted to the rivers of the western part of Toyama Prefecture.

⑬ *Gnorimosphaeroma iriei* Nunomura, 1998

This species was recorded from a freshwater lake, Ezu-ko, Kumamoto City, Kumamoto Prefecture (Nunomura, 1998). The distribution of this species is only the type locality.

⑭ *Gnorimosphaeroma tsushimaense* Nunomura, 1998

This species was recorded from the relatively small stream, Asu River, Izuhara, Tsushima Island, Nagasaki Prefecture (Nunomura, 1998). The distribution has been known only from the type locality.

⑮ *Gnorimosphaeroma akanense* Nunomura, 1998

This species was recorded from the freshwater of Akan-gawa, a river from the Oakandake, Hokkaido (Nunomura, 1998). The distribution has been known only from the type locality.

⑯ *Gnorimosphaeroma rebunense* Nunomura, 1998

This species was recorded from Kushu-ko Lake, Rebun Island, Hokkaido. The distribution of this species has been known only from the type locality. Its population density was very high (Nunomura, 1998).

2. Discussion on some tendencies of evolution within the genus *Gnorimosphaeroma*

The genus *Gnorimosphaeroma* was established by Menzies and comparisons with its related genera, *Neosphaeroma*, *Exosphaeroma* and *Pseudosphaeroma* were made (Menzies, 1963). Comparing these genera, the genus *Gnorimosphaeroma* seems to have the most primitive numeric features including the chaetotaxy and number of segments of both antennae.

Before discussing the evolution of Japanese inland-water species of the genus *Gnorimosphaeroma*, it will be necessary to discuss on some tendencies of evolution within the genus *Gnorimosphaeroma*. As a great part of sphaeromatid isopods are marine dweller,

the genus *Gnorimosphaeroma* is considered obviously originally to be a marine dweller, with some species penetrating into brackish or freshwater environments, and therefore, certain primitive features may be conserved in marine species (Table 1).

Considering in relation to the phylogeny of the genus *Gnorimosphaeroma*, the following six general tendencies can be recognizable as "advanced characters".

(1) Simplification of body color

Whereas rocky shores are colorful in general by algae and many sessile animals, the bottom of freshwater is dull, usually uniformly brown or grayish brown. So, dull and uniform coloration in freshwater environments seems to be adaptive as against multiple and polychromatic coloration in rocky seashore.

(2) Reduction in the number of teeth on the maxilla

Numerous teeth of oral appendages are considered to be primitive; in freshwater environments, the amount of organic matter is larger, so less numerous teeth can be considered to be adaptive.

(3) Reduction of setae on appendages

The more numerous setae are considered being more primitive. Because hirsute features are common in many species belonging to marine sphaeromatid isopods.

The following two tendencies are also recognizable in the evolution within this genus. Though they are not closely related to the freshwater environments directly, they are considered to be "advanced features".

(4) Reduction in the number of flagellar articles of both antennae

(5) Reduction in size of exopod of uropods

The fully developed rami of uropods are considered to be more primitive.

(6) Typical marine dwellers have numerous setae on their pereopods, therefore less numerous state of chaetotaxy is considered as "advanced characters".

Aspects of speciation in the genus in Japan will be discussed on the grounds of above-mentioned tendencies.

3. Evolution of marine species and most probable candidate of inland-water species

Hitherto, six marine species, *G. ovatum*, *G. rayi*, *G. hoestlandti*, *G. hachijoense*, *G. shikinense* and *G. kurilense* have been recorded as valid in Japan. Among them, only *G. rayi* has wide distribution from North America to East Asia, Hawaii and California.

Obviously, this genus is essentially marine dweller as some related genera, having many flagellar segments of both antennae, many setae on mouth parts and with many setae on pereopods. Though to judge what is the most primitive stock in the genus *Gnorimosphaeroma* is very difficult to judge, Pacific American species, *G. oregonense* is

Table 1. A comparison of various morphological characters among *Gnorimosphaeroma* species. All the numbers show the maximum value. Many data were taken from the following papers: Gurjanova (1933), Gujanova (1936), Jan and Kwon (1993), Kim and Kwon (1985), Kwon (1990), Kim and Kwon (1993), Kussakin (1994), Menzies (1954), Nunomura (1998), Nunomura (1999), Tattersall (1921), Yun (1982).

Species	Characters									
	1	2	3	4	5	6	7	8	9	10
<i>rayi</i>	12	14	11+11+15	1	2+3+2	6	8	0.76	A>B	M
<i>ovatum</i>	12	15	7+8+9	1	1+3+3	4	2	0.61	A>B	M
<i>hoestlandti</i>	13	12	11+10+15	1	1+2+4	1	8	0.86	A>B	M
<i>hachijoense</i>	10	13	10+10+11	1	1+2+2	1	5	0.8	A=B	M
<i>Shikinense</i>	10	13	4+6+10	1	2+3+1	1	5	0.8	A=B	M
<i>kurilense</i>	7	9	?	1	1+2+3	0	3	0.51	A<B	M,F?
<i>chinense</i>	12	15	3+4+6	1	0+0+1	1	2	0.48	A<B	B
<i>tondaense</i>	10	15	8+8+8	2	2+2+4	1	4	0.55	A=B	B
<i>anchialos</i>	9	13	13+13+11	2	2+4+5	1	5	0.7	A>B	B
<i>pulchellum</i>	11	11	6+3+3	1	0+0+0	1	5	0.42	A>B	B
<i>nacktongense</i>	11	17	9+1+11	2(1)	2+4+5	1	1	0.73	A>B	F
<i>hokurikuense</i>	9	13	14+9+9	1	1+4+4	0	3	0.73	A>B	F
<i>iriei</i>	7	10	12+11+12	1	1+2+2	1	2	0.62	A>B	F
<i>tsushimaense</i>	10	18	12+11+12	1	2+3+2	1	3	0.73	A>B	F
<i>akaenense</i>	7	13	9+10+13	1	1+1+4	1	2	0.75	A=B	F
<i>rebunense</i>	11	10	8+3+14	1	0+2+3	2	4	0.66	A=B	F
<i>oregonense</i>	12	13	11+13+10	1	2+3+2	1	14	0.86	A>B	M
<i>noblei</i>	7	10	3+4+7	1	0+0+1	1	1	0.72	A<B	M

1, Number of flagellar segments of antennule

2, Number of flagellar segments of antenna

3, Number of setae on maxilla (inner lobe + inner ramus of setae on outer margin of maxillipedal palpal segments 2, 3 and 4)

4, Number of coupling hooks on endite of maxilliped

5, Number of setae on outer margin of palpal segments of maxilliped (segment 2 + segment 3 + segment 4)

6, Number of setae on the outer distal angle of basis of pereopod 1

7, Number of setae on the outer distal angle of merus of pereopod 1

8, Ratio of length (exopod length/ endopod length)

9, Length of suture (A, anterior one; B, posterior one, partly calculated from the figures of description)

10, Habitat (M, Marine; B, Brackish; F, Freshwater)

considered to be one of the most "primitive" one within the genus, because this species has many setae on many pereopods and other appendages. And other two American species, *luteum* and *insulare* are considered to have evolved from the *oregonense* or *oregonense*-like stoke, considering from their chaetotaxy. As Hoestlandt (1975) stated that *G. rayi* is very similar to the other two American Pacific species, *G. rayi* is closely related to *oregonense* in

having many setae at the sternal margin of basis and merus of pereopod 1, and he also wrote that the polychromatism of *G. rayi* in Japan is more variable than that of *G. rayi* in California.

Among the three Japanese marine species, *rayi* is considered to be the most primitive species, because this species has the following primitive features: (1) numerous setae on the outer margin of merus of pereopod 1, (2) more setae on pereopods, (3) numerous flagellar segments of both antennae and (4) polychromatism of body color not uni-colored.

G. hoestlandti is considered to have evolved from *rayi*-type ancestor, because the two species are very closely allied with any conspicuous difference being the number of setae on the distro-ventral corner of basis of pereopods.

G. ovatum is also considered to have some advanced characters such as less numerous setae. Accordingly *G. hoestlandti* and *G. ovatum* are considered to have derived from the *rayi*-like ancestor, because it has less numerous setae than *rayi*, but both species do not share the same evolutionary relationship. For, the two species has less numerous in different features in chaetotaxy.

Most of marine species known in North America bears more setae than Asian species, and these features can be regarded as primitive. Therefore, the Pan-Pacific species *G. rayi* and its relatives are the most probable candidate of the ancestor for many East Asian species. The speciation of the genus may first have occurred on the west coast of North America, then it might have migrated to Hawaii and East Asia, attaining a wide distribution. And *G. shikinense* and *G. hachijoense* are related each other, but the latter has more advanced features than the form having less numerous setae on maxilla.

It seems reasonable to suppose that *rayi* or its ancestral forms are the most probable candidate of Japanese inland-water species of the genus *Gnорimosphaeroma*.

4. Evolution of freshwater species

The reason for richness of freshwater species occurring in the water systems facing the Sea of Japan is considered as follows: All the Japanese species except *rayi* have relatively less setae on appendages including mouth parts; this is especially conspicuous in the palpal segment of maxilliped, inner distal corner of basis and merus of pereopod 1. As all the freshwater species, *hokurikuense*, *rebunense*, *tsushimaense*, and *naktongense*, around the Sea of Japan are similar to *hoestlandti* and *rayi* and as they all have fewer setae than the latter two species, they are considered to have evolved from the *hoestlandti*-like stock, but the way of reduction seems not to be entirely the same.

But some species show an intermediate state between *hoestlandti* and *rayi* in regard to certain features; nevertheless, the reduction of setae on basis of pereopod 1 in these

species suggests that their ancestor must be relatives of *hoestlandti*, though each species has more teeth than *hoestlandti*.

The occurrences of so many species in the freshwater systems surrounding the Sea of Japan are considered to be related to the glacial events in the Sea of Japan during the Quaternary Period.

The time when speciation of these species had happened is considered to be 10,000–20,000 years ago when the most active phase of glacial period. And the sea level was 130–140 m lower than that of the present time (Iseki, 1976) and the Sea of Japan is considered to have been a closed or semi-closed basin with low salinity. It is considerable to be a freshwater big lake of at least the sea with “low salinity” areas. The ancestor became adaptable to fresh water or very low salinity (Nishimura, 1974). At least, there must have been low salinity along the coasts been some areas almost enclosed areas just as seen on the coast of Toyama Bay at present, where salinity is very low even in the present time.

The speciation of *G. naktongense*, *G. hokurikuense* and *G. tsushimaense* can be explained in this way. It is noteworthy that the recent discovery of *naktongense* (Fukuhara, *et al.*, 2000) from the inland-water of Pacific side, but the possibility of transportation from the Sea of Japan area together with some fishes can not be denied.

G. rebunense is rather different from the above-mentioned three species, for it has more setae on basis and merus of pereopod 1. Therefore it is considered to have evolved from the common ancestor to *rayi* or still unknown stock.

On the other hands, the existence of freshwater species of the Pacific side of Hokkaido and Kyushu must be explained by different ways. Perhaps, the speciation of the “Pacific species” differs from those of the Sea of Japan species. They must have been evolved from the marine stock independently, and speciation may have occurred in estuarine environments.

The occurrence of *G. iriei* can not be explained by the same speciation-mechanism, because the freshwater system where *G. iriei* occurs is not facing to the Sea of Japan, but to the East China Sea, a part of the Pacific Ocean.

G. iriei is considered to have evolved from *hoestlandti*-like ancestors, as surmised on because the setae formula, especially that of maxillipedal palp, number of teeth on maxilla and the number of seta on basis and merus of pereopod 1. But the possibility that it may have derived from *ovatum*-like ancestor can not be excluded.

Though almost all the freshwater species in Japan have been recorded only from the Sea of Japan side this species is distributed from Kumamoto Prefecture,

The speciation of *iriei* was considered to be 5000–6000 years ago, so-called “Jōmon transgression”. Sea level was about 0–5m higher than the present time (Iseki, 1976). The

similar situations may have been possible in many places in Japan such as Kanto Plain, Osaka Plain and much low altitude plain area. And the possibility of the similar phenomena on much area is can not be denied, but most of them are considered to have diminished by huge effects of human activities.

Freshwater species of Pacific sides at least the case of *iriei* are considered to be related to the post-glacial transgression. After the transgression, the bay became land and the innermost part became freshwater environments and the ancestor living there may have acquired freshwater acclimatization.

G. akanense may also have been evolved from the *hoestlandti*-like ancestor according to the setae formula, but *iriei* and *akanense* are different in the way of reduction of setae.

Adding this, there are some records which some fishes had been brought from several brackish lakes of Hokkaido (Motoda, 1950). Therefore, two possibilities of the origin of *akanense*: one of them is a similar way of *iriei*, and another one is the transportation together with other organisms from other brackish lakes or sea. As the possibility of transportation from the other lakes can not be denied, the origin of *akanense* can not be determined at the present time.

5. Brackish species

Generally the genus *Gnorimosphaeroma* seems to have ability for strong tolerance to low-salinity environments. According to my observations, three marine species, *G. hoestlandti*, *G. ovatum* and *G. rayi*, are often found in the relatively low salinity water including the mouth of rivers.

Apart from the above-mentioned tendency, at least four exclusively brackish-water species have been reported in Japanese water.

G. chinensis and *G. pulchellum*, have been recorded from brackish waters. The both species have much reduced exopod of uropod (Nunomura, 1998) and considered to be the related species.

The other two brackish species, *G. anchialos* and *G. tondaense* also morphologically resemble each other, and had derived from *hoestlandti*-like or *rayi*-like ancestors judging from the chaetotaxy, especially their less numerous setae on maxilla.

In conclusion, the species of the genus *Gnorimophseroma* in Japan are considered to have evolved from plural ancestors, and thus may not be monophyletic. The evolution of these species seems to be complicated.

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References

- Abe, M and H. Fukuhara. 1996. Protogynous Hermaphroditism in the Brackish and Freshwater Isopod, *Gnorimosphaeroma* (Crustacea, Isopoda, Sphaeromatidae). *Zool. Sci.* 13 (2): 325–329.
- Fukuhara, F., N. Kimura and A. Furukawa. 2000. Study on the distribution of *Gnorimosphaeroma naktongense* and *G. chinense*. (in Japanese)
- Gurjanova, E. 1933. Contribution to the Isopoda fauna of the Pacific Ocean. I. New species of Valvifera and Flabellifera. *Expl. Mers d' U. R. S. S.* 17: 87–106. (in Russian).
- Gurjanova, E. 1936. Beiträge zur Kenntniss der Isopodenfauna des Pazifischen Oceans IX. Neue Isopodenarten aus dem japanischen und Bering Meer. *Zool. Anz.* 114: 250–265.
- Iseki, H. 1976. Eustatic Changes in Holocene. In (ed.) Japan Association for Quaternary Research). The Quaternary Period: Recent Studies in Japan. University Tokyo of Press. pp. 89–97.
- Jan and Heon. 1993. A new Species of the Genus *Gnorimosphaeroma* (Crustacea, Isopoda Sphaeromatidae) from a Brackishwater Lake in Korea. *Korean J. Zool.* 36: 402–407.
- Hoestlandt, H. 1975 Occurrence of the Isopoda Flabellifera, *Gnorimosphaeroma rayi* Hoestlandt on the coast of Japan Eastern Siberia and Hawaii, with a brief note on its generic polychromatism. *Publ. Seto Mar. Biol. Lab.* 22 (4): 31–46.
- Kim, H. S. and D. H. Kwon. 1985. The systematic study of the family Sphaeromatidae (Crustacea, Isopoda, Flabellifera) from Korea. *Inje J.* 1(2): 143–165.
- Kim, H. S. and D. H. Kwon. 1988. Marine Isopod Crustaceans from Cheju Island, Korea. *Inje J.* 4(1): 195–220.
- Kwon, D. H. 1990. A systematic study on the Korean marine isopod crustaceans. Flabellifera, Part 2. Family Sphaeromatidae. *Inje J.* 6: 151–192.
- Kwon, J. and D. H. Kwon, 1993. A new Species of the Genus *Gnorimosphaeroma* (Crustacea, Isopoda, Sphaeromatidae) from a Brackish water lake in Korea. *Korean J. Zool.* 36: 402–407.
- Kwon, D. H. and H. S. Kim 1987. A New species of the Genus *Gnorimosphaeroma* (Crustacea, Isopoda, Sphaeromatidae) from the Naktong River, with a key to the Korean Species of the genus. *Korean J. Syst. Zool.* 3(1): 51–56.

- Menzies, R. J. 1954. A review of the Systematics and Ecology of the Genus "Exosphaeroma," with the Description of a New Genus, a New Species and a New Subspecies (Crustacea, Isopoda, Sphaeromatidae). *Amer. Mus. Novi.* 1968: 124
- Motoda, S. 1950. Hokkaido Kosho-shi, Hokkaido lakes Fishery Report. *Hokkaido Pref. Fish Hatchery Rep.* 5(1): 1-96.
- Nishimura, S. 1974. Formation of the Japan Sea: An Approach from Biogeography, 227 pp. Tsukiji-shokan, Tokyo. (in Japanese)
- Nunomura N. 1998. On the Genus *Gnorimosphaeroma* (Crustacea, Isopoda, Sphaeromatidae) in Japan with description of Six New Species. *Bull. Toyama Sci. Mus.* 21: 23-54.
- Nunomura, N. 1998. [Abundance of species reveals their history—on the genus *Gnorimosphaeroma* in Japan.] *Journal Umiushi-Tsushin, Suisan-musekitsui Doubutsu Kenkyusho (Research Institute of Marine Invertebrates)* 19: 5-7 (in Japanese).
- Nunomura, N. 1999. Sea Shore Isopod Crustaceans Collected from Izu Islands, Middle Japan. *Bull. Toyama Sci. Mus.* 22: 7-38.
- Tattersall, 1921. Mysidacea, Tanaidacea, and Isopoda (Zoological results of a tour in the Far East). *Mem. Asiatic Soc. Bengal* 6, 87: 403-433, Pl. 15-17.
- Yun, S. H. 1982. Five Species of Sphaeromatid Isopod (Flabellifera) from Southern Coast of Korea. *Bull. Nat. Fish Univ. Busan* 22(2): 1-23.