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An Introduction to the Japanese Groundwater Animals with Reference to their Ecology and Hygienic Significance

by

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AN INTRODUCTION TO THE JAPANESE GROUNDWATER ANIMALS

In the first half of this century, little was known of the groundwater animals of Japan. In 1916, Prof. Ijima and Dr. Kaburaki gave a description of a hypogean planarian as the first groundwater animal of Japan. Following this description, eleven species were recorded from wells and caves during the thirty-five years up to 1950. Thus, only twelve species of animals were registered as groundwater animals of Japan in the first four decades of this century.

Since 1950, a number of groundwater animals have been collected and described from caves and wells of Japan, and the present list of the troglobites from the groundwaters of Japan comprises almost two hundred species which are classified in eight phyla, thirteen classes, eighteen orders, forty-seven families, and at least seventy-seven genera.

However, numerous specimens of Oligochaeta, Ostracoda, Cyclopoida, and particularly those of microorganisms such as Protozoa, *Hydra*, Nematoda, and Rotatoria, etc. still remain undescribed. Because sufficient numbers of mature specimens in satisfactory condition are not available for study, some material of Nemertinea, Archiannelida, Turbellaria, Dytiscidae, Phreatodytidae, etc. are also left undescribed.

In recent years, a remarkable decrease in the number of wells available for the collection of material has forced some speleobiologists to divert their activities to the field of the interstitial fauna of rivers and seashores.

Besides the troglobites listed in Table 1, various groups of troglophiles and trogloxenes have been obtained from the groundwaters of Japan. Some of them are significant as a biological indicator of well-water pollution upon which I shall comment later on.

Among the aquatic troglobites of Japan, one of the noteworthy groups may

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Table 1. Troglobites reported from undergroundwaters of Japan

	PROTOZOA	
CILIATA	Suctoria:	*Tokophrya phreaticum*
	Hypotrichida:	1 sp. (undescribed)
	COELENTERATA	
ANTHOZOA	Actiniaria:	1 n.g., n.sp. (undescribed)
	PLATYHELMINTHES	
TURBELLARIA	Tricladida	
	Planariidae:	*Phagocata papillifera*, *Ph. albata*, *Ph. tenella*
	Kenkiidae:	*Speophila* sp. (undescribed)
		Sphalloplana sp. (undescribed)
	NEMERTINEA	
ENOPLA	Hoplonemertinea:	2 spp. (undescribed)
	MOLLUSCA	
GASTROPODA	Caenogastropoda	
	Hydrobiidae:	**Akiyoshia* (s.str.) 2 spp.
		**Akiyoshia* (*Saganoa*) 6 spp.
	ANNELIDA	
ARCHIANNELIDA	Nerillidae:	2 spp. (undescribed)
		Nerilla sp. (undescribed)
OLIGOCHAETA	Neoligochaeta	
	Haplotaxidae:	*Haplotaxis gordioides*, *H. gastrochaetus*
	Lumbriculidae:	*Hrabea ogumai*
HIRUDINEA	Gnathobdellida	
	Erpobdellidae:	*Erpobdella* sp. (undescribed)
ECHIUROIDEA		1 sp. (undescribed)
	ARTHROPODA	
ARACHNIDA	Acarina	
	Hydrovolziidae:	**Stygovolzia uenoi*
	Protziidae:	*Wandesia japonica*
	Torrenticolidae:	*Torrenticola* 2 spp.
	Limnesiidae:	**Kawamuracarus elongatus*
	Hygrobatidae:	*Atractides* 4 spp.
	Unionicolidae:	*Neumania* 3 spp.
	Feltriidae:	*Feltria* 3 spp.
	Axonopsidae:	*Lethaxona* 4 spp., *Axonopsis* 9 spp., *Ljania* 5 spp.
		**Uenaxonopsis nazensis*
		Frontipodopsis reticulatifrons var. *okinawa*
	Aturidae:	*Aturus subterraneus*
	Momoniidae:	*Stygomomonia* 3 spp.
	Midcopsidae:	*Midcopsis* 13 spp.
	*Uchidastygacaridae:	**Uchidastygacarus* 4 spp.
	*Nipponacaridae:	**Nipponacarus matsumotoi*, *N. miurai*, *N. japonicus*
	*Kantacaridae:	**Kantacarus matsumotoi*
	Hungarohydracaridae:	*Bharatohydracarus* 1 sp.
	Arrenuridae:	*Arrenurus* sp.
	Halacaridae:	**Himejacarus morimotoi*
		Parasoldanellonyx typhlops japonicus
		Soldanellonyx 4 spp.

CRUSTACEA	Ostracoda	
	Podocopa:	Podocopa spp. (undescribed)
	Copepoda	
	Cyclopoida	
	Cyclopidae:	*Eucyclops miurai*
		Megacyclops viridis takefuensis
		Acanthocyclops morimotoi
		Diacyclops disjunctus
		D. languidoides japonicus,
		D. languidoides suoensis
		Spreocyclops yezoensis
	Harpacticoida	
	Ectinosomidae:	*Ectinosoma japonica*
	Phyllognathopodidae:	*Phyllognathopus viguieri*
	Laophontidae:	*Onychocamptus mohamed*
	Ameridae:	*Nitocra* 3 spp.
		Nitocrella 4 spp.
	Canthocamptidae:	*Ceuthonectes mirabilis*
		Attheyella 3 spp.
		Bryocamptus 4 spp.
		Paracamptus nakamurai
		Epactophanes richardi
		Elaphoidella 5 spp.
	Parastenocaridae:	*Parastenocaris* 4 spp.
	Malacostraca	
	Bathynellacea	
	Bathynellidae:	*Bathynella* 12 spp., 1 subsp
	Parabathynellidae:	*Eobathynella* 1 sp., 2 subspp.
		Allobathynella 5 spp., 1 subsp.
		* *Nipponbathynella miurai*
	Amphipoda	
	Ingolfiellidae:	*Ingolfiella* spp. (undescribed)
	Pontogeneidae:	*Paramoera relictica, P. izushimana*
		* *Awacaris kawasawai*
	Gammaridae:	*Pseudocrangonyx* 5 spp.
		* *Eocrangonyx japonicus*
		* *Neoniphargus* (*Eoniphargus*) *kojimai*
		Eriopisa sp. (undescribed)
		Bogidiella sp. (undescribed)
	Isopoda	
	Asellidae:	*Asellus* (s.str.) 7 spp.
		* *Asellus* (*Phreatoasellus*) 5 spp.
		* *Uenasellus iyoensis*
		* *Nipponasellus* 5 spp.
	Parasellidae:	*Mackinia* 3 spp.
	Microcerberidae:	*Microcerberus kiiensis, M. fukudai, M. bonnensis*
INSECTA	Coleoptera	
	* Phreatodytidae:	* *Phreatodytes relictus*
		Phreatodytes 2 n. spp. (undescribed)
	Dytiscidae:	* *Morimotoa phreatica*
		Morimotoa 2 n. spp., 1 n. subsp. (undescribed)
	VERTEBRATA	
PISCES	Percida	
	Gobiidae:	*Luciogobius pallidus*
		L. albus

* Families, genera and subgenera endemic to Japan.

be the marine derivatives, such as Actiniaria, Nemertinea, Archiannelida, Echiurida, and Parasellidae, etc. An Actiniaria has been obtained from a slightly saline pool (salinity: 14.89‰) in a lava cave on Isl. Fukue-jima near

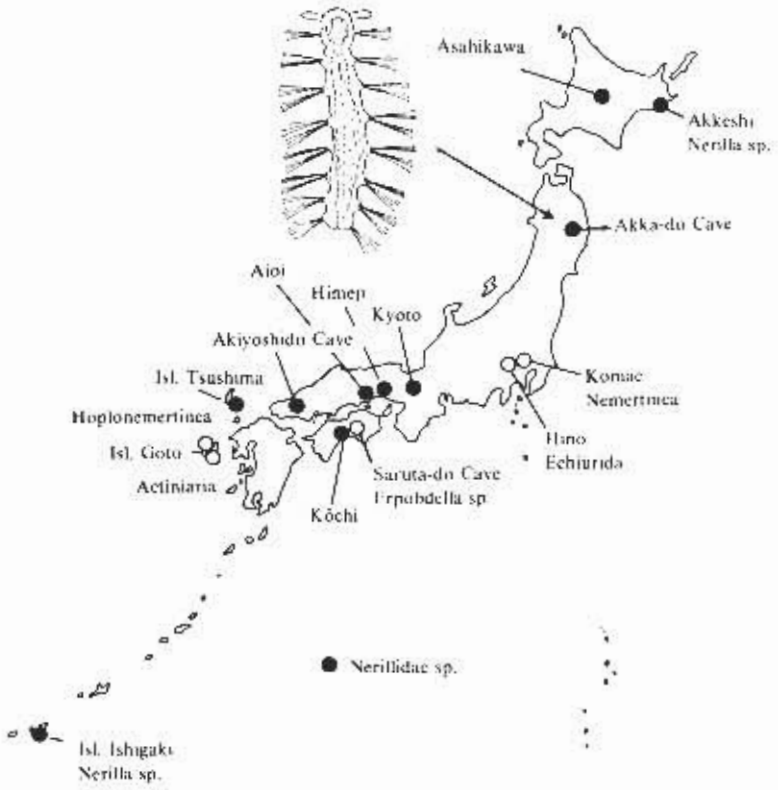

Fig. 1. Distribution of troglobiontic Actiniaria, Nemertinea, Hirudinea, Nerillidae and Echiurida

Nagasaki together with a cave fish, and it is supposed to belong to a new species and new genus. A specimen of Hoplonemertinea has been collected from another lava cave on the same island and one more Nemertinea has been obtained from a driven well in the suburb of Tokyo. Archiannelida have been found from wells and caves in Hokkaido, Honshu, Shikoku, Kyushu, and Isl. Tsushima and comprise, at least, two species of Nerillidae. According to Dr. S. Ueno's note, they are rather related to *Thalassochaetus*, a marine genus from Kiel Bay, than to *Troglochaetus*. Living material of Echiurida from a well near Tokyo unfortunately disintegrated during microscopical observation. Thus, these groups are not yet sufficiently investigated with the exception

of Parasellidae, because of difficulties in fixation of materials and microscopical observation of living ones. As to the Parasellid genus, three species of *Mackinia* have been described from Japan, South Korea, and Far Eastern Siberia

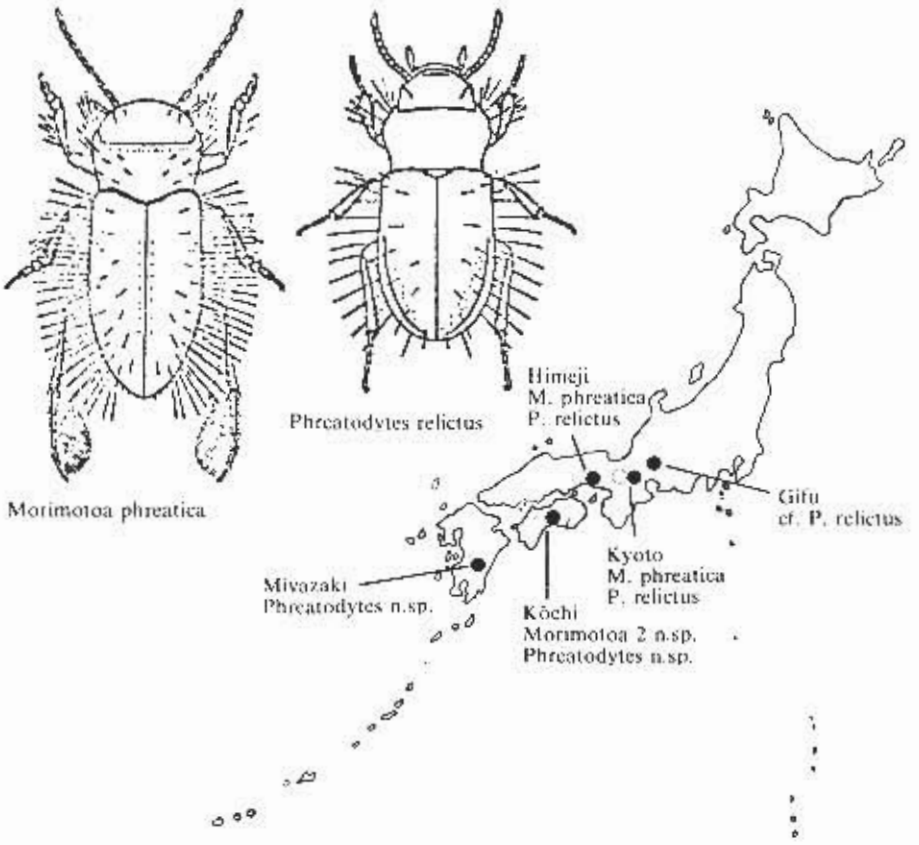

Fig. 2: Distribution of Dytiscidae and Phreatodytidae

near Nahotoka. The other noteworthy groups are the archaic relicts such as Bathynellacea, *Phreatodytes* and *Morimotoa*, etc. The former order is widely distributed throughout Japan and comprises more than nineteen species which are classified in four genera of two families. The latter two genera of aquatic beetles distributed in western Japan are both anophthalmic and depigmented and comprise at least six species. As to the last group, interstitial ancient relicts such as *Ingolfiella* and *Microcerberus* have been recently found in the groundwaters of Japan. Further, the occurrence of the two genera of Kenkiidae, *Speophila* and *Sphalloplana*, though not yet sufficiently investigated, is zoogeo-

graphically interesting, because they are the relatives of the North American cavernicoles.

Most of the species of the Japanese aquatic troglobites are endemic to Ja-

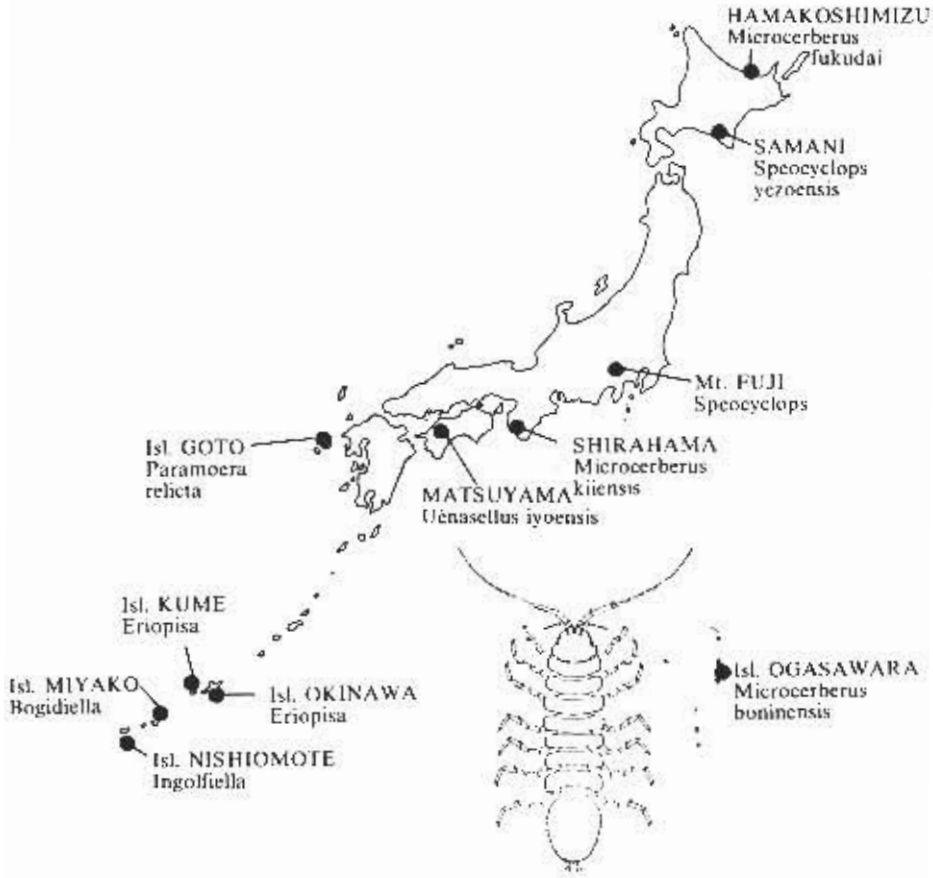

Fig. 3: Distribution of noteworthy troglobiontic Crustacea

pan, and what is more some of their genera and families are also peculiar to Japan. According to Prof. Imamura, three of the seventeen families of the troglobiontic Hydrachnellae: Uchidastygacaridae, Nipponacaridae and Kantacaridae, are endemic to Japan. Further, the troglobiontic Coleopteran family, Phreatodytidae is a peculiar family of Japan. As to the endemic genera, sixteen genera of various animals can be listed: *Luciogobius, Morimotoa, Phreatodytes, Nipponasellus, Uenasellus, Eocrangonyx, Awacaris, Nipponbathynella,*

Himejacarus, Kantacarus, Nipponacarus, Uchidastygacarus, Uenaxonopsis, Kawamuracarus, Stygovolzia, and *Akiyoshia.*

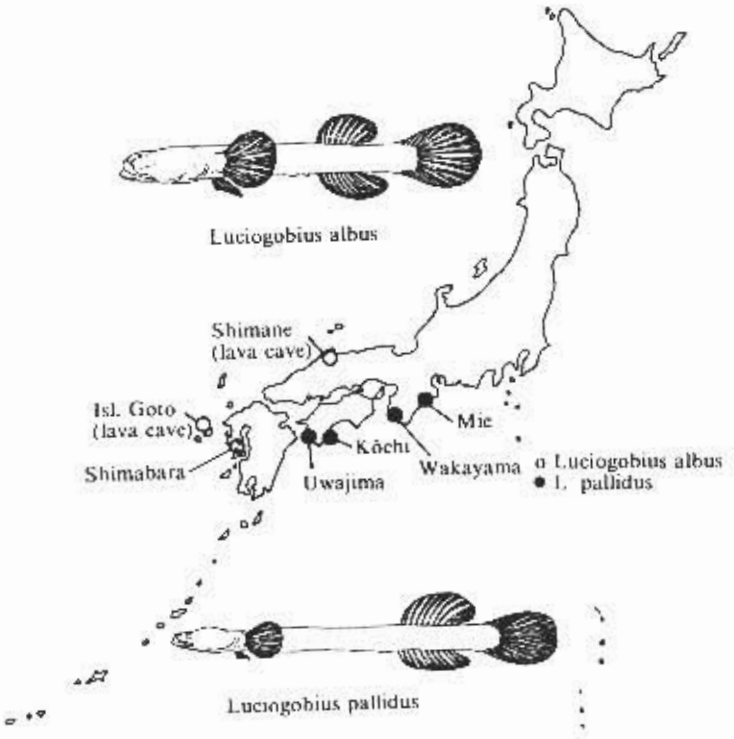

Fig. 4: Distribution of troglobiontic Gobiidae

SOME ACCOUNTS ON THE ECOLOGY OF THE JAPANESE GROUNDWATER ANIMALS

As to the ecology of the groundwater animals of Japan, sufficient material for discussion is not available. Therefore, the writer would like to introduce brief notes on their habitats obtained during the collection of materials and the examination of well-waters. A great majority of the aquatic troglobites of Japan have been obtained from wells and some of them occur also in caves, but only a few have been collected from springs, river-beds, and the bottom of deep lakes. Recently, however, a number of specimens have been collected from interstitial media of rivers and lakes as well as seashores. The general features

of the wells from which the groundwater animals were obtained are summarised as follows:

1) Construction of wells: In Japan, groundwater animals have never been obtained from bored wells deeper than 30 meters. Most of them have been collected from driven wells with a depth of less than 10 meters. Planktonic and nektonic troglobites, such as Cyclopoida, *Mackinia*, and Gammaridae, etc. occur both from driven and dug wells. However, benthic troglobites, such as Gastropoda, Oligochaeta, and Planariidae, etc. are rarely obtained from the pumps of dug wells. *Asellus kawamurai* seems to prefer open dug wells. Generally speaking, groundwater animals available for investigation were rarely obtained from wells with a motor pump.

2) Situation of wells: Groundwater fauna of wells near rivers is much more variable than that of wells further away and from the former various kinds of exogenous animals such as leeches and larvae of aquatic insects, etc. are also obtained occasionally.

3) Bottom materials of wells: Groundwater animals are rare in wells with a rocky bed or sediments of volcanic ashes. Most inhabit wells which have clean sandy sediments mixed with small amounts of organic detritus in alluvial regions. Generally, Hydrachnellae, Ostracoda, Bathynellacea, and *Nipponasellus*, etc. are the representatives of these types. However, Cyclopoida, Oligochaeta, *Asellus* and *Mackinia*, etc. seem to prefer wells with muddy bottoms containing much organic sediment. It is noteworthy that *Asellus kawamurai* seems to prefer open dug wells which have decaying leaves on the bottom. Large types of aquatic Oligochaeta are frequently obtained together with large amounts of their excreta.

4) Water temperature of wells: Water temperature of fifteen riverside wells with depths of 4-5 meters in Hachioji City in Tokyo Pref., where more than thirty species of various groundwater animals were collected, ranged from 21°C to 25°C in August and fell to 9-13°C in January. Most aquatic cavernicoles are known to be cold stenotherms, but the groundwater animals in the Hachioji area were found to be considerably tolerant to thermal fluctuations.

5) Color, turbidity, and odor of well-waters: Most of the groundwater animals preferably inhabit clear, colorless, and odorless water, however, *Mackinia*, Cyclopoida, Amphipoda, and Oligochaeta, etc. have been obtained rarely also from opaquely turbid waters. Further, *A. kawamurai* has been collected in great numbers from unused open dug wells, the water of which has a conspicuous odor of hydrogen sulfide. In many cases, well-waters in which large Oligochaeta live have a fishy smell.

6) pH of well-waters: pH values of all of 521 wells where the groundwater animals were obtained were less than 7.8 and most of them, 455 wells, ranged from 5.7 to 7.0 rather than 7.0-7.8.

7) Chemical properties of well-waters: As to the chemical properties of well-waters in which the groundwater animals occurred, all the results of the examination of chlorine ion, total hardness, $KMnO_4$ consumption, and total residues were within the limits of drinking water criteria except for those of nitrogen compounds and iron. On the whole, more than 20% of the wells, from

which Paludicola, Oligochaeta, Cyclopoida, *Asellus*, *Nipponasellus*, Gammaridae, and even Bathynellacea were obtained, were found to be polluted to the extent of being unfit for drinking.

8) Dissolved oxygen in well-waters: Amounts of dissolved oxygen in thirteen wells in Hachioji City situated on the riverside area ranged from 1.75 ppm. to 10.75 ppm in January, 1960.

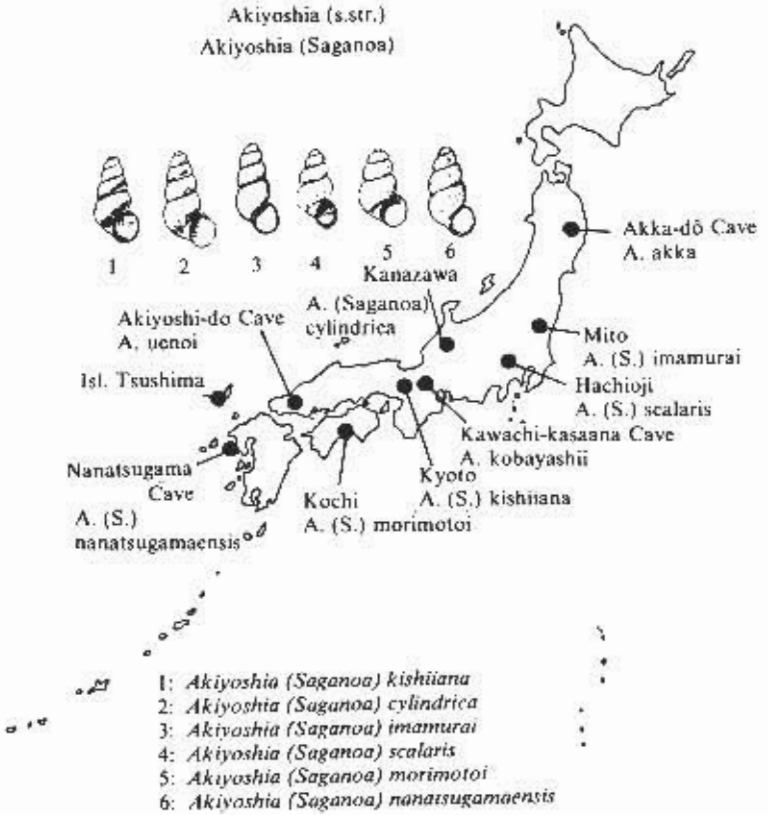

Fig. 5: Distribution of Akiyoshia (Gastropoda, Hydrobiidae)

9) Bacteriological quality of well-waters: Because the bacteriological examination of common drinking waters is much more sensitive for organic water pollution than the chemical examination, groundwater animals were obtained regardless of the bacteriological water quality. As to the results of the Coli-aerogenes group test, most of the groundwater animals were obtained from wells bacteriologically unfit for drinking. Concerning the bacterial counts,

Table 2. Nitrogen Compounds in Well-water and Undergroundwater Animals.

N-Compounds	Numbers of Wells												Total
	NH_3—N				NO_3—N				NO_2—N				
Animals	—	±	+	++	—	±	+	++	—	±	+	++	
Paludicola	10	1	3		1	5	7	1	9	3	1	1	14
Oligochaeta	36	3	10	2	16	13	19	3	36	9	4	2	51
Cyclopoida	65	10	6	2	15	27	35	6	60	13	6	4	83
Harpacticoida	7					5	2		5	2			7
Ostracoda	26	1	2		11	11	6	1	23	4	1	1	29
Mackinia	68	8	6	2	24	29	26	5	63	7	7	2	84
Asellus (s.str.) hilgendorfii	4		1		2	1	1	1	4			1	5
Asellus (s.str.) musashiensis	18	5	1	1	6	7	11	1	19	5	1		25
Asellus (Phr.) kawamurai	2	3			1	1	3		3		2		5
Nipponasellus hubrichti	43	4	4		19	19	11	2	40	4	5	2	51
Gammaridae	70	13	7	4	29	28	31	6	68	12	11	3	94
Bathynellacea	22	5		1	10	5	10	3	19	3	4	2	28
Hydracarina	11		1		9	2		1	11			1	12
Hydrobiidae (Akiyoshia)	10				6	4			10			1	10
Dytiscid	1	1				1	1			2			2
Total Number of Wells examined	393	54	41	12	149	158	163	30	375	64	42	19	500

Table 3. Hygienic Grouping of Animals Reported from Well-waters of Japan

Groups	Aquatic animals		Terrestrial animals (exogenous)
	Troglobites	**Troglophiles and Trogloxenes**	
Group 1	*Tokophrya phreaticum* Hypotrichida sp. *Phagocata* 3 spp. *Speophila* sp. *Sphalloplana* sp. Nemertinea sp. *Akiyoshia* 6 spp. Nerillidae 2 spp. *Haplotaxis* 2 spp. *Hrabea ogumai* Echiuroidea sp. Hydrachnella 70 spp. Ostracoda spp. Cyclopoida 7 spp. Harpacticoida 24 spp. Bathynellacea 19 spp. Asellidae 17 spp. *Uenasellus iyoensis* *Mackinia* 3 spp. Gammaridae 10 spp. *Phreatodytes relictus* *Phreatodytes* 2 spp. *Morimotoa phreatica* *Morimotoa* 2 spp. *Luciogobius* 2 spp.	*Hydra* sp. *Craspedacusta iseana* *Dugesia japonica* *Phagocata* 2 spp. *Dendrocoelopsis lacteus* Nematoda spp. *Keratella cochlearis* *Euchlanis* sp. *Lepadella ovalis* *Asplanchna* sp. *Callidina* sp. *Rotaria rotatoria* *Chaetonotus* sp. *Nais* sp. *Aeorosoma hemprichi* *Stylaria lacustris* *Pristina* sp. *Hypsibius augusti* Ostracoda spp. Cyclopoida 11 spp. Harpacticoida 4 spp. *Asellus hilgendorfii* *Rivulogam. nipponensis* *Paramoera ezonis* Chironomidae sp. Culicidae sp.	*Bipalium fuscatum* *B. trilineatum* Plumonata spp. *Eisenia foetida* Lumbricidae spp. Araneida spp. Acarina spp. Oniscoidea spp. Taltridae spp. Diplopoda spp. Chilopoda spp. Collembola 10 spp. Orthoptera spp. Dermaptera spp. Coleoptera spp. Hymenoptera spp. Diptera spp. Anura sp. Sauria sp. Insectivora sp. (hair) Rodentia sp. (hair)
Group 2	Cyclopoida spp. *Asellus miurai* *Asellus musashiensis* *Nipponasellus hubrichti* *Mackinia* spp. *Pseudocrangonyx* spp.		
Group 3	*Asellus kawamurai*	Mastigophora 6 spp. Sarcodina 14 spp. Ciliata 9 spp. *Rotaria rotatoria*	
Group 4 (exogenous)		*Branchitura sowerbyi* Tubificidae spp. Hirudinea 3 spp. *Daphnia pulex* Perlidae sp. Trichoptera sp. *Psychoda* sp. Elmidae sp. *Neonectes natrix* *Zaitzevia* sp. *Luciola* sp.	

Paludicola, Oligochaeta, Cyclopoida, *Mackinia, Asellus*, and *Pseudocrangonyx*, etc. were found to occur also in highly contaminated waters containing more than 5,000 bacteria per 1 ml of water. According to Japanese drinking water criteria, bacterial counts per 1 ml of water is limited to be less than 100 and the Coli-aerogenes group must be negative in 50 ml of water. On the whole, greater numbers of groundwater animals were found to occur in clean well-waters at least within the limits of chemical drinking water criteria, however, from the point of bacteriological safety standards, most of the wells from which groundwater animals were obtained are regarded to be unfit for drinking.

10) Population of groundwater animals: In most cases, the population of the groundwater animals obtained from wells was extremely small. However, the writer has obtained more than three hundred individuals of *Mackinia* from 350 liters of well-water, about one hundred fifty individuals of *Asellus musashiensis* from 300 liters of water, about one hundred individuals of *A. miurai* from 500 liters of water, and about fifty individuals of *A. kawamurai* from 200 liters of water. These large populations of groundwater animals were observed only in polluted wells.

HYGIENIC CONSIDERATION ON THE GROUNDWATER ANIMALS OF JAPAN

As the writer has mentioned, to date, more than 190 species of troglobites and about fifty species of troglophiles have been collected from well-waters of Japan. However, none of them are known to be directly detrimental to human health. In this sense groundwater animals may seem to have little bearing to human health problems. However, a number of trogloxenes and various terrestrial animals have also been found in well-waters and some of them appear to be significant indicators of well-water pollution. Therefore, exact knowledge of their taxonomy and ecology may be necessary to those concerned with the purity of drinking water. All kinds of macroorganisms which occurred in well-waters in Japan have been provisionally classified into four groups and arranged in Table 3. Most of the troglobites listed in Group 1 were collected from well-waters which were clean, at least within the limit of chemical drinking water criteria, and in most cases their populations were extremely small. Therefore, as their occurrence is rare, they themselves are apt to be overlooked. However, smallness of their population size per se does not assure the safety of drinking water quality; this is particularly so as to bacteriological pollution. Further, some of them listed in Group 2 were occasionally observed to multiply to a great number when the well-water was polluted. This phenomenon has been observed in *Asellus, Mackinia, Pseudocrangonyx*, and Cyclopoida. Their multiplication in well-waters may apparently indicate the pollution of water. A minority of troglobites and a majority of troglophilous or trogloxenous microorganisms are listed as Group 3. They were found to prefer naturally eutrophic environments of well-waters with much organic sediment. *Asellus kawamurai* is the representative of this group. Most of the troglophiles and trogloxenes which directly invaded wells from neighbouring surface waters

such as rivers, ponds, and ditches, etc. are listed in Group 4. Their occurrence may suggest the presence of permeable passways through which they could reach the well and indicate a heavily contaminated condition of well-waters. Some of the Tubificidae, Hirudinea and aquatic insects are listed as members of this group.

Furthermore, most of the terrestrial animals shown in the table are commonly distributed in country districts and suburban areas. They live around or inside dug wells and occasionally fall into the water. Therefore, remains or parts of their bodies are occasionally pumped out from wells. Of course, their accidental presence in the well-water has no relation to the water quality. However, they themselves will be an undesirable origin of contamination, and they may imply an unhealthy state and an incomplete construction of wells. Earthworms, snails, slugs and *Bipalium*, etc. occur in wells situated in low and wet environments. Terrestrial arthropods are often found in crowded circumstances and sometimes invade wells during cold seasons seeking warmer wintering refuges. Furthermore, some species of Collembola, such as *Onychiurus folsoni*, are frequently found to swarm on the surface of well-waters.

Thus, a little ecological and taxonomical knowledge of the animals found in well-waters makes it at times possible to detect well-water pollution and to point to its origin.

Microorganisms, such as Algae, Protozoa, and Aschelminthes, etc., may be the most significant and sensitive indicator organisms for water pollution. Unfortunately, knowledge of these is extremely limited in Japan. Only the following is certain. The chlorophilous organisms are originally exogenous to groundwater environments and their presence is indicative of well-water pollution. This fact was carefully investigated by T. Koriyama (1952), who demonstrated that most of the well-waters which contained Chlorophyceae and chlorophilous Protozoa were not bacteriologically fit for drinking.

SUMMARY

1) Nearly two hundred species of troglobites are known from the groundwaters of Japan. Most of these troglobiontic species, sixteen of seventy-seven genera, and what is more, four of forty-seven families are endemic to Japan. Uchidastygacaridae, Nipponacaridae, and Kantacaridae are endemic acaridan families of Japan. The coleopterous family, Phreatodytidae, is also endemic to Japan.

2) Though studies on Protozoa, Turbellaria, Annelida, Aschelminthes, and Ostracoda, etc. remain sparse, the interstitial fauna is actively investigated recently and many specimens of Bathynellacea, *Ingolfiella*, *Bogidiella*, *Microcerberus*, *Pseudovermis* (Opisthobranchia), and Nerillidae, etc. have been collected from freshwater and marine environments.

3) None of the troglobites is known to be directly detrimental to human health and most of them have been collected from well-waters which are regarded as chemically clean in many cases, but they have also been obtained occasionally from bacteriologically contaminated well-waters.

4) Ecological and taxonomic knowledge, of even the limited amount which we possess at present, has enabled us to utilize various animals which occur in well-waters as biological indicators of well-water pollution and to have some insight as to the origin of the pollution.

ZUSAMMENFASSUNG

Beinahe zweihundert Arten Grundwassertiere sind aus den japanischen unterirdischen Gewässern bekannt. Die meisten von ihnen sind in Japan endemisch; an Gattungen sind sechzehn und an Familien sind vier, d.h. Nipponacaridae, Kantacaridae, Uchidastygacaridae, und Phreatodytidae, heimisch. Während Protozoa, Turbellaria, Annelida, Aschelminthes, Ostracoda, usw. wenig erforscht sind, werden in letzter Zeit die interstitiellen Grundwassertiere aktiv untersucht. Keines der genannten Grundwassertiere ist, soweit bisher bekannt, für die Menschen direkt gesundheitschädlich. Das Brunnenwasser, aus dem die meisten von ihnen entnommen worden sind, ist zwar in chemikalischer Hinsicht als klar anzusehen. Aber es kommt manchmal auch vor, daß sie im bakteriologisch verseuchten Brunnenwasser ermittelt werden. Verschiedene Tiere, die im Brunnenwasser gefunden werden, können als biologische Anzeiger für die Verseuchung des Brunnenwassers gebraucht werden und verhelfen uns zu weiterer Einsicht in die Ursprünge der Verschmutzung.

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