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Full Length Research Paper

Response of *Oncomelania* snail distribution on land use in Sichuan, China

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Schistosomiasis is one of the four major infectious diseases that require prevention and control in China. It is mainly distributed along the middle and downstream areas of the Yangtze River and some hilly areas in Sichuan, Yunnan, and so on. Oncomelania snail is the only intermediate parasite in the schistosome life cycle; thus, reducing the number of snails can decrease the incidence of schistosomiasis by limiting its transmission. The number and distribution of snails is closely related to the environment, which is largely influenced by different habitats. To determine the relationship of snail number and spatial distribution with typical habitats, we selected different land use/plant cover types, investigated the snail distribution and analyzed the physical and chemical properties of the soil. The results show that among the different land use types, higher rates of live snail and live snail frame occurred along the riverbanks, wild land and ditches, followed by dry land, paddies, and forest lands. No live snail was found in bamboo stands of *Sinocalmus affinis*. An analysis of the physical and chemical properties of different land use types revealed higher soil pH value (8.41) in bamboo stands, which is beyond the suitable range for snails and possibly the key to inhibiting snails' survival. These results imply that in the land growing bamboo (*Neosinocalmus affinis*) the snail could not propagate owing to soil pH rising. Therefore, the research would provide to some extent, the guidance for snail control through optimizing land use systems.

Key words: Bamboo stand, habitat, Oncomelania snail, *Neosinocalmus affinis*.

INTRODUCTION

Schistosomiasis is one of the four major infectious diseases that require prevention and control in China. It is mainly distributed along the middle and downstream areas of the Yangtze River and some hilly areas at Sichuan, Yunnan, and so on (Peng and Jiang, 1995; Peng, 2005). Oncomelania snail is the only intermediate parasite in the schistosome life cycle; thus, reducing the number of snails can decrease the hazard of schistosomiasis from the aspect of transmission pathway. The number and distribution of snails is closely related to the environment (E-Sawy, 1981; Rug and Ruppel, 2000; Seto et al., 2002; Zhou et al., 2002), which is largely affected by different habitats. According to the environmental conditions and geographical occurrence, the endemic schistosomiasis areas in China can be divided into 3 types: lakes, waterways and hilly areas (Jiang and Peng, 1996). In China, research on the relationship of snail distribution and the environment was focused mostly on Yangtze River beaches, while the comprehensive control methods of snail inhibition were mainly based on the principle of biological control. The measures were available and practicable as well as the effect was ideal (Peng and Jiang, 1995; Peng, 2005; Zhao et al., 2009; Zhong et al., 1995).

The snail distribution in the hilly areas upstream and the lake water network areas downstream of the Yangtze River are highly different. The snails in hilly areas are mainly distributed in stream/river beaches and pond/ reservoir surrounding areas, which is a specific lake type of snail distribution (Goll et al., 1983; Yasuraoka et al.,

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1980; Zhou, 2005). According to statistics, the endemic hilly snails area is about 1.7 billion m^2, accounting for 12.41% of the total snail distribution area in China; the cumulative number of patients was 230 million, accounting for approximately 22.7% of the total patients in the country. The endemic hilly schistosomiasis areas have broad distribution in China and this can be found in Anhui, Jiangsu and 11 other provinces (Peng, 2005; Zhou, 2005). Among these, the endemic schistosomiasis areas in Sichuan, Yunnan, Fujian and Guangxi Provinces are exclusively hilly types. Hilly schistosomiasis is relatively more serious in Sichuan and Yunnan Pro-vinces, and displays an increasing trend.

Until the end of 2003, the five counties and one district in Meishan City, Sichuan, were all schistosomiasis endemic areas, including 139 towns and 1218 villages. The snail area was 17,217,000 m^2, accounting for 26.12% of the snail area in the whole province (Jiang et al., 2006). The population in endemic areas was 1,614,000, with 5.6 million schistosomiasis patients, accounting for 70.71% of the patients in the whole province. The highest infection rate in the endemic villages accounted for 38.5% of the infections in the whole province, comprising 19.31% of the human population and 5,600 cows. The infection rate of cattle was 5.8% in the whole province and 50% in the endemic villages, mainly distributed in Pengshan, Renshou, Dongpo and Danling. These data indicate the urgency of schistosomiasis prevention and control in hilly areas (Peng 2005). However the research on the relationship between snail number and distribution with typical habitats in this region is less and so far few works have been done.

Therefore, in order to determine the relationship of snail number and spatial distribution in hilly areas, we selected different land use/plant cover types, investigated the snail distribution and analyzed the physical and chemical properties of the soil. Based on these results, we discussed the effects of different land use/plant cover types on snail number and distribution, especially the relationship of bamboo habitats and snail population distribution. These may provide a scientific basis for the biological inhibition of snails and ecological control of the disease.

MATERIALS AND METHODS

Test area description

The research was conducted in Renshou County, Sichuan Province, which is a mountainous and hilly region. It has a humid subtropical monsoon climate with four distinct seasons and more cold waves. The average annual temperature is 17.4℃; the highest temperature, 26.5℃, is in July, and the lowest temperature, 6.8℃, is in January. The extreme minimal temperature is -3.8℃, and the effective accumulated temperature is 5532.8℃. The frost-free period is 310 days. Rainfall ranges from 765.6 to 1410.2 mm, with an annual average of 1009.4 mm and an inter-annual variation of 644.6 mm. Average annual sunshine is 1196.6 h. Wet and dry seasons are distinct, and the distribution of precipitation within the year is uneven; the precipitation from April to October accounts for 87% of the total precipitation.

More also, regional vegetation is an evergreen broad-leaved forest. Due to the high reclamation coefficient, all of the original vegetation has been replaced with artificial vegetation. The main forests are divided into pine and cedar forests, and in accordance with the species, the region is divided into pine and cedar forest patches with mountain yellow soil and shock yellow/calcareous purple soil, respectively. The total forest land at Renshou is 43977.1 hm^2, accounting for 16.83% of the total land area. The forest coverage is 15.6%, including 40408.2 hm^2 woodland, 879.9 hm^2 sparse woodland, 236.7 hm^2 bush woodland, 1627.7 hm^2 immature woodland, 76.6 hm^2 nursery land and 748 hm^2 sterile woodland. Bamboo land is mainly dominated by *Neosinocalmus affinis* (Rendle) Keng f., which belongs to the family of *Bambusoideae*, *Gramineae*. Growing in clusters, it has axes and it is widely distributed along riverbanks, around fields, houses, roads and hilly areas. The total area of bamboo stand is about 11333.0 hm^2, of which *N. affinis* takes 6933.3 hm^2 in the county.

Field survey methods

The snail density in the different land use types was investigated in March and April, 2009. Different land use types were selected and mechanically sampled, with each 0.11 m^2 frame made of iron wire placed 10 m away from each other. In addition, we searched the 2005 live snail density distribution data in the schistosomiasis control stations at Renshou. Land use types were classified and the surveyed frame number, snail frame number, appearance rate of live snail frame, total number of live snails and live snail density were investigated.

Laboratory analysis

Routine analysis of soil samples was performed following “Soil and Agricultural Chemistry conventional analysis methods.” Soil pH was determined with a pH-3 digital pH meter after water extraction. Total nitrogen of soils was measured via the Kjeldahl method. Effective nitrogen was measured via the alkali diffusion method. Effective phosphorus was measured through the 0.5 M sodium hydrogen phosphate method. Effective potassium was measured using a flame photometer. Organic matter was measured through the potassium dichromate method (Professional Committee of Agricultural Chemistry at Soil Science Society, 1983; Nanjing Agricultural University, 2000).

Data treatment

Analysis of variance was used to determine the significance of the association between snails and the various habitat/soil types investigated. A comparison of multiple data sets was analyzed with SPSS for Windows 11.0. Live snail density and appearance rate of live snail frame were calculated as follows:

$$\text{Live snail density} = \frac{\text{Number of captured living snails}}{\text{Total surveyed frame number}}$$

$$\text{Appearance rate of live snail frame} = \frac{\text{Live snail frame}}{\text{Total surveyed frame number}} \times 100\%$$

Table 1. Snail distribution and number in different land use types in Renshou, Sichuan.

Land use type	Surveyed box number	Number of live snail box	Appearance rate of live snail box (%)	Total number of live snails	Live snail density (number / 0.11 m^2)	
					Average	Standard deviation
Forest lands	87	7	8	16	0.18	0.79
Bamboo lands	5	0	0	0	0	0
Ditches	9	5	55.6	80	8.89	15.87
Dry land	30	3	10.0	45	1.50	4.76
Slopes	55	27	49.1	204	3.71	9.53
Beaches	88	52	59.1	659	7.49	19.32
Paddies	57	40	70.2	488	8.56	12.39
Average	326	134	42.00	1492		5.06

RESULTS

Snail distribution and number at different land use/plant cover types

When investigating the snail distribution and number in different land use types, the wet field was designated as paddies, the wheat field was designated as dry land. The lands were generally classified into 7 types: forest land, bamboo stand, slopes, ditches, dry land, beaches and paddies. During data processing, bamboo stand was not included because its related data was 0 so that the degree of freedom considered was 6. The investigation results for snail distribution and number at different land use types are shown in Table 1.

According to the results in Table 1, snail distribution and number differed in various land use types. Variance analysis revealed different live snail densities at different land use types (F = 5.024, df = 5, $p < 0.0001$). These data show that snail density is evidently higher on river beaches and lower in forest and bamboo stands, with 0 density in bamboo stands; the live snail density on dry lands, slopes, and forest lands was average. Overall, in the various land use types, the surveyed snail box number was 326, 134 of which had live snails and provided a 42% appearance rate in the live snail frame. There were 1462 live snails in total and live snail density was 5.06/0.11 m^2.

The appearance rate of live snails also differed among the various land use types, (F = 4.416, df = 5, $p < 0.003$). A relatively higher appearance rate in the live snail box occurred in paddies, slopes and beaches, followed by ditches and dry land. The lowest level was detected in bamboo stands. Therefore, at various land use types in Renshou, the higher live snail density and appearance rate of live snail box mainly occurred in beaches, slopes and ditches, followed by dry lands and paddies (both reached the average level), whereas the minimum level was detected in forest lands. Although, the spatial distances between bamboo stands and other land use types, such as forest lands, paddies, slopes and beaches were not very far, the appearance rate of living snail was highly different. In the survey, living snails were not discovered in bamboo stands but was found in all other land types. This indicates that bamboo habitats are unique and have inhibitory effects on snail population distribution.

In summary, the live snail density was highly different at various investigated land use types due to the spatial heterogeneity, which can be shown by the high standard deviation among the different land use types in Table 1. Even in the same land use type, snail distribution differed slightly.

The physical and chemical properties of soil in the different land use/plant cover types

Soil is one of the required conditions for the breeding of harmful snail species, but not all types of soil are suitable for snail growth. Snail distribution is related to the physical and chemical properties of soil. To understand the characteristics of different land types, we analyzed the environmental factors and nutrient levels in 7 different land use/plant types, including dry lands, bamboo stands, forest lands, paddies, slopes, beaches and ditches. The results are shown in Tables 2 to 4.

Soil moisture is an important factor in suitable snail growth environment (Eline and Hammou, 2004; Sun and Peng, 1998; Wu et al., 1999). Moisture and porosity are important indicators of the physical properties of soil. Snail number and distribution are heavily affected by soil moisture conditions, and the soil moisture suitable for snail growth is 20 to 60%. With low soil moisture (0 to 20%) snail survival is minimal, while higher soil moisture (20 to 60%), where snail number is high, provides suitable moisture for snail survival. However, higher soil moisture (>60%) inhibits snail growth. As shown in Table 2, bamboo stands had higher soil moisture (28.6%), which was slightly lower than paddies, than other land

Table 2. Soil moisture and pores in different land use types.

Land use type	Moisture (%)	Capillary water (%)	Density (g/cm^3)	Total pore (%)	Capillary porosity (%)	Non-capillary porosity (%)
Forest lands	22.8	38.4	1.206	54.5	46.4	8.1
Bamboo lands	28.6	30.6	1.400	47.2	42.8	4.4
Ditches	16.6	17.5	1.801	32.0	31.6	0.5
Dry lands	14.9	18.7	1.583	40.3	29.6	10.6
Slopes	20.9	31.8	1.283	51.6	40.8	10.8
River lands	24.8	27.2	1.246	53.0	33.9	19.0
Water lands	30.9	35.8	1.330	49.8	47.6	2.2
Average	22.78	28.6	1.407	46.9	38.76	5.4

Table 3. Soil structure and texture.

Land use type	Content (%) mm							Soil texture classification (U.S. standard)
	2.0 - 1.0	1.0 - 0.5	0.5 - 0.25	0.25 - 0.05	0.05 - 0.02	0.02 - 0.002	<0.002	
Forest lands	0.01	0.09	2.37	36.75	12.40	23.14	25.24	Loam
Bamboo lands	0.50	0.92	1.98	32.02	18.58	24.48	21.52	Loam
Ditches	0.02	0.03	1.37	55.45	6.15	18.86	18.12	Sandy loam
Dry lands	0.03	0.10	0.10	7.76	10.45	44.29	37.27	Powder (sand) clay loam
Slopes	0.01	0.05	0.34	36.32	10.36	26.31	26.61	Loam
River lands	0.03	0.08	0.14	7.89	12.51	39.00	40.35	Powder (sand) clay
Water lands	0.03	0.04	0.29	2.64	12.51	56.69	27.80	Powder (sand) clay loam
Average	0.09	0.187	0.94	25. 547	11.85	33.25	28.13	

types. Changes in capillary water are highly different from soil moisture, and are more similar to capillary porosity. Soil density reflects the tightness of the soil, and the porosity level of soil represents the soil respiration status. They are related to soil texture and organic matter content, and affect the type, number, and living condition of soil microbes. As shown in Table 2, the soil density and porosity in bamboo lands had no significant difference, as compared with other land types and its physical properties were at the ideal state.

If considering soil moisture by itself, bamboo stand is suitable for snail growth and should have snail distribution. However, the actual results (Table 1) contradict this, indicating the uniqueness of the bamboo stand habitat. Therefore, other factors must be analyzed further. Table 3 shows that the soil texture in bamboo stands was loam, in which 0.25 to 0.05 mm of soil particles accounted for the largest proportion (32.02%) of its mechanical composition; this result was similar to that in forest lands, but largely different from the paddies and beaches. For the paddy it was comprised of 0.02 to 0.002 mm of soil particles, its largest proportion, accounting for 56.69% of the area; in beaches, the 0.02 to 0.002 mm soil particles accounted for 39.00% of the area (the soil particles < 0.002 mm accounted for 40.35%). This indicates that the soil in beaches has more clay and higher viscosity. In addition, compared with other land types, coarse-grained soil had a higher proportion in bamboo stand, which was over 10-fold that of other land types, indicating that its soil moisture and respiration were moderate, making it suitable for the survival of soil microbes.

At a certain levels, soil pH reflects the chemical properties of the soil solution and greatly influences soil nutrient status, microbial diversity and quantity. As shown in Table 4, bamboo stands have higher pH (8.41), thus indicating that the soil is alkaline. The lowest pH (5.76) was detected in paddies and this may be related to water quality. While the pH in dry and river beaches were nearly neutral, indicating that the local soil was basically neutral. The low pH in forest lands may be attributed to the returning elements from fallen branches and leaves because a coniferous forest is mostly acidic. Reportedly, the soil pH range suitable for snail survival is 6.8 to 7.5 (E-Sawy, 1981). Thus, bamboo stand is inappropriate for snail survival in terms of soil pH, which may be related to the elemental content and exudates of bamboo leaves. Higher pH values affect the composition changes in soil solution such as the status of some elements, as well as the type and quantity of soil microorganisms. In addition, it may also affect the food and living environment of snails.

Soil organic matter, as well as P and K content represent soil nutrient status. Table 4 shows that the nutrient level of bamboo stand is similar to that of other land types. Forest and dry lands have the highest level of

Table 4. Soil pH and nutrition.

Land use types	pH	Organic matter (g/kg)	Total P (g/kg)	Total K (g/kg)	Total Ca (g/kg)
Forest lands	6.93	31.27	0.34	11.09	3.79
Bamboo lands	8.41	19.71	0.52	15.09	24.50
Ditches	8.41	10.34	0.39	13.95	17.91
Dry lands	7.80	31.49	0.89	22.21	23.30
Slopes	8.25	20.09	0.50	17.26	17.26
River lands	8.07	16.96	0.51	20.65	31.31
Water lands	5.76	16.56	0.32	11.29	1.09
Average	7.66	20.92	0.50	15.93	17.02

organic matter, which were 31.27 and 31.49 g/kg, respectively and this may be related to the tree and crop types, cultivation intensity, and so on. Soil Ca content is related to soil pH and as shown in Table 4, the Ca content of bamboo lands was relatively high at 24.50 g/kg, while the Ca content of water lands was the lowest at 1.09 g/kg. The soil Ca content of different land use types was nearly consistent with soil pH.

DISCUSSION

Snail distribution is related to the physical and chemical properties of the soil. In terms of chemical properties, snails prefer fertile soils rich in organic matter, N, P, and Ca. In terms of physical properties, snails find it more difficult to make holes or move through compact soil; snails cannot move in dry soil. Also, sterile soil where temperature changes quickly cannot protect them against harsh sunlight or cold waves. These aforementioned factors are therefore not suitable for snail survival (Archibald, 1933; Liu, 2003; Zhang and Peng, 1999). Our investigation largely confirmed these points. It was observed that the soil conditions in bamboo stands are suitable for snail growth, but no snail was detected. Based on the previous analysis, we preliminarily hypothesized that the high soil pH level in bamboo lands exceeded the suitable range for snails living and propagating and is the key factor for inhibiting snail survival (Sun and Wu, 2001; Xu et al., 1999). Further studies are required to elucidate whether the other factors, such as the type of bamboo leaves or root exudates, had snail-killing effects.

In the Sichuan and Yunnan Provinces of Western China, the endemic schistosomiasis areas are mainly poor mountainous regions with complex natural environments, lagged economic and social development, and underdeveloped economies. The flat dam, hillsides and the bottom of hills are the main habitats for mountain people. Although, the snail areas and patient number in hilly areas do not account for a large ratio in China, the hilly endemic areas have the most widespread distribution, which directly affects the production and livelihood of mountain people and is a major obstacle for the social and economic development of the area. Additionally, snail distribution area is around the hilly regions with its several land distributions, complex terrain, diversified environment, dense ravines, steep slopes and inconvenient traffic; thus, schistosomiasis prevention and control is very difficult. If effective approaches are not promptly implemented to continue the comprehensive management of schistosomiasis, the temporal schistosomiasis prevention accomplished by several generations in the last 50 years will be wasted. Therefore, performing ecological management engineering research on hill-type forest improvement and snail inhibition to control the spread of schistosomiasis and promote social and economic development has become the focus of schistosomiasis studies.

Based on the research, results imply that in the land growing bamboo (*N. affinis*), the snail could not propagate owing to soil pH rising. Thus, this conclusion would provide to some extent the guidance for snail control through optimizing land use systems, although, this is just a primary result with more studies needed for further verification. Meanwhile local people prefer to plant *N.s affinis* as this bamboo has multiple functions such as for paper pulp, traditional Chinese medicine, weaving, etc., hence serving as a good source incomes.

Therefore, with a rational land use plan, large amount of *N. affinis* could be grown, thus changing the environment of snail living, which would helpful for snail control. However, due to the short time of field investigation and only part of environmental factors analysis, the result might not reflect the whole exact fact. In future, more works still need to be done such as biological property of the snail and ecological features of the different land covers, as well as the coupling between the two sides. More also, in terms of biological control and integrated management, schistosomiasis control in these areas should be combined with economic development, and planting more *N. affinis* obviously is an available way. This would not only control the outbreak of the disease, but also increase the income of the locals, which would also serve as a sustainable development strategy.

Conclusion

Overall, in the various land use types, the surveyed snail box number was 326, 134 of which had live snails and provided a 42% appearance rate in the live snail frame. There were 1462 live snails in total, and live snail density was 5.06/0.11 m^2. Through field survey and laboratory analysis, these data show that snail density is evidently higher on river and beaches, and lower in forest and bamboo stands, with 0 density in bamboo stands; the live snail density on dry lands, slopes, and forest lands was average. The appearance rate of live snails also differed among the various land use types. A relatively higher appearance rate in the live snail frame occurred in paddies, slopes and beaches, followed by ditches and dry land, while the lowest level was detected in bamboo stands. Therefore, at various land use types in Renshou, the higher live snail density and appearance rate of live snail frame mainly occurred in beaches, slopes and ditches, followed by dry lands and paddies (both reached the average level), whereas the minimum level was detected in forest lands as well in bamboo stands of *N. affinis*. An analysis of the physical and chemical properties of different land use types revealed higher soil pH value (8.41) in bamboo stands, which is beyond the suitable range for snails and is possibly the key to inhibiting snail living and survival.

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