Converting pests into allies in tea farming -- a case of SEPL in Hualien, Taiwan

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Abstract

Eco-friendly farming, i.e., no insecticide and herbicide application, organic fertilizer application, has been practiced in some tea plantations of Rueisuei Township, Hualien County of Taiwan in order to maintain a viable population of small green leaf hopper, *Jacobiasca formosana.* Tea buds and young leaves "damaged" by small green leaf hoppers can be harvested to make a honey–flavored black tea that is welcomed in the market. To prove that tea plantations with eco-friendly farming practices has a higher biodiversity than those with conventional farming practices, vertebrate (mammals, birds, reptiles, amphibians) diversity, arthropod diversity, soil porosity and soil temperature of 3 sites (tea plantations) with eco-friendly farming practices and 3 sites with conventional farming practices were measured and compared in 2014. A total of 36 soil samples were taken from the 6 sites (6 samples each site) at the beginning of the study to measure the soil density and water content of each site. Vertebrates and arthropods were sampled seasonally (i.e. once every three months and totally 4 sampling events) by Sherman trap, transect count, point count, window traps, pitfall traps, beating and soil core at each site. Soil temperature was measured by HOBO Temperature Data Loggers for 48 hrs at each site in each sampling event. Tea farmers, including owners or managers of the 6 sites, foreman of labors hired by these farmers and the General Secretary of Rueisuei Farmers' Association were interviewed in order to collect information on socio-economic effects of eco-friendly and conventional tea farming. The results showed little difference between sites with two farming practices in terms of soil porosity and water content. Soil temperature of the 3 sites with eco-friendly farming practices is more stable than the 3 sites with conventional farming practices. A total of 56,987 arthropods (mainly insects) were collected from 4 sampling events at 6 sites. Individuals collected at sites with eco-friendly practice (41,793) are nearly four times of those collected at sites with conventional practice (11,194). The number of identified arthropod species collected at sites with eco-friendly practice (390) was 1.7 times of that collected at sites with conventional practice (238). A total of 56 species and 887 individuals of vertebrates, including 7 species and 45 individuals of amphibians, 4 species and 6 individuals of reptiles, 37 species and 794 individuals of birds, 8 species and 42 individuals of mammals, were recorded from the 6 sites. More number of vertebrate, as well as amphibian, reptile, bird and mammal, species and individuals were found at sites with eco-friendly practice. The number of birds found on sites with eco-friendly practice was almost 2.5 times of that on sites with conventional practice. Our data showed that tea plantations with eco-friendly farming practices not only generate higher economic return but also provide higher biodiversity. In addition, more job opportunities were created through the eco-friendly farming practices, based on the result of our social interview. The tea plantations with eco-friendly farming practices and the surrounding farm, forest, stream and communities in Rueisuei, therefore, represent a unique socio-ecological production landscape (SEPL) in Taiwan.

Key words: small green leaf hopper, tea plantation, biodiversity, SEPL, Hualien

Introduction

Small green leaf hopper, *Jacobiasca formosana*, is a common and abundant insect species in tea plantation of Taiwan. With its sucking mouthparts, the insect feeds on phloem sap of the tea foliage, preferably buds and young leaves. The feeding of small green leaf hoppers retards bud growth and causes yellow-green bud curling. The leaf margins turn yellow to brown and eventually fall off. The population of small green leaf hopper usually reaches its peak in the summer and may cause great loss of tea buds and leaves. Therefore, small green leaf hopper has been considered traditionally a serious pest of tea plantation. Many control methods, including chemical and biological control, have been developed to suppress population of small green leaf hoppers and protect tea crop from pest damage.

On the other hand, a high priced oolong tea with a unique flavor of ripened fruit and honey, Oriental Beauty tea, was accidently made from tea leaves partially fed by small green leaf hoppers nearly a century ago. In the early 2000s, tea makers in Hualien County of eastern Taiwan, specifically Rueisuei Township, collaborated with scientist of Tea Research and Extension Station, were inspired to replicate this process and successfully developed a honey-flavored black tea from oolong tea. The honey-flavored black tea became so popular and its price went so high that tea farmers of Hualien no longer consider the small green leaf hopper a pest but their economic allies. Some, though not all, tea farmers stopped using pesticides in order to keep a healthy population of the small green leaf hoppers in their tea farms so that they can produce and make more honey-flavored black tea.

Conventional tea farming requires the application of herbicide and pesticide to control weeds and insect pests from damaging the crop. However, the application of herbicides and pesticides significantly reduce biodiversity. We identified at least two tea farming families in Rueisuei Township that have completely stopped the use of herbicide and pesticides to “protect” small green leaf hoppers. The purpose of this study is, therefore, to find out if tea plantations with eco-friendly farm practice have higher biodiversity than those with conventional farm practice. We are also keen to know if this eco-friendly tea farming practice benefits the local community. If these are true, tea plantation with this eco-friendly farm practice is qualified to be a socio-ecological production landscape (SEPL) in Taiwan.

Materials and Methods

A. Study site

The tea production landscape we studied was near the Tropic of Cancer Monument, Ruisui Township, Hualien County (Fig. 1). We chose 6 tea plantations for our biodiversity study. The latitude and longitude coordinates of the 4 corners, the elevation, and the approximate area of each site are as following:

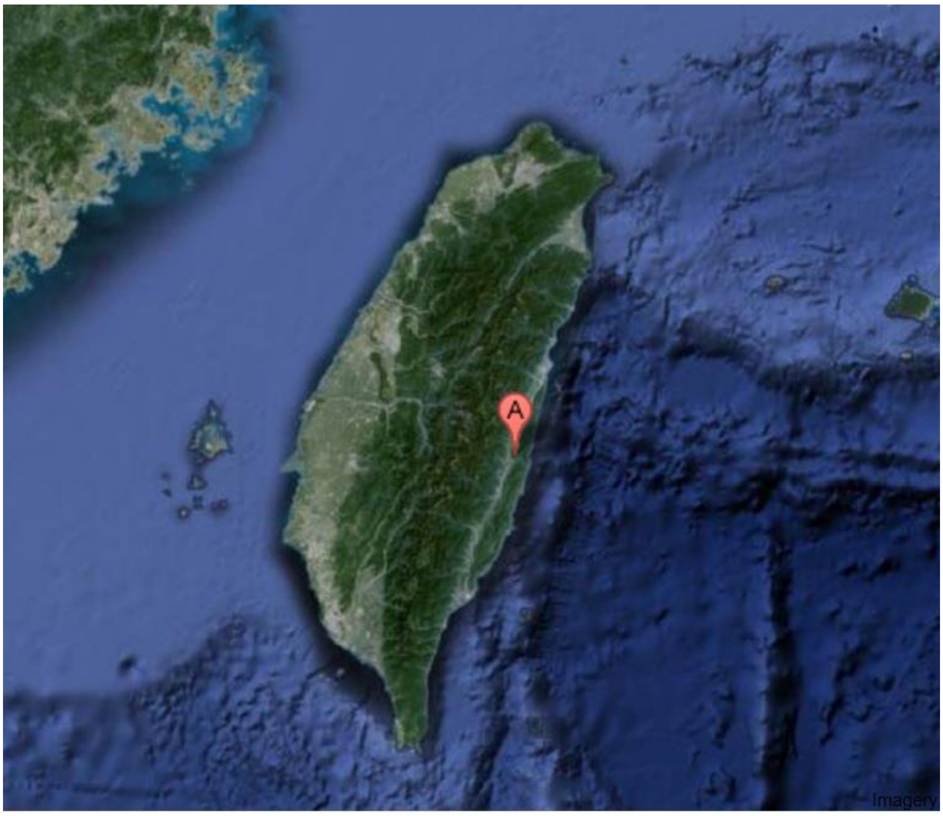

Figure 1. Locality of the present study.

Site 1: East corner: N23°26'45.52", E121°21'17.42", south corner: N23°26'42.31", E121°21'15.92", west corner: N23°26'43.64", E121°21'12.34", north corner: N23°26'46.25", E121°21'15.23", elevation: 194-201 m, area: 1 ha. (Fig. 2)

Site 2: East corner: N23°26'47.35", E121°21'23.91", south corner: N23°26'45.56", E121°21'23.32", west corner: N23°26'46.97", E121°21'18.46", north corner: N23°26'47.73", E121°21'21.44", elevation: 195-203 m, area: ca. 0.7 ha. (Fig. 2)

Site 3: East corner: N23°27'23.52", E121°20'46.39", south corner: N23°27'20.56", E121°20'43.73", west corner: N23°27'22.07", E121°20'42.15", north corner: N23°27'24.09", E121°20'44.71", elevation: 217-227 m, area: ca. 0.5 ha. (Fig. 3)

Site 4: East corner: N23°27'26.62", E121°20'45.93", south corner: N23°27'24.25", E121°20'42.93", west corner: N23°27'24.59", E121°20'41.65", north corner: N23°27'26.69", E121°20'42.93", elevation: 216-224 m, area: ca. 0.6 ha. (Fig. 3)

Site 5: East corner: N23°27'49.45", E121°20'36.45", south corner: N23°27'47.61", E121°20'35.68", west corner: N23°27'48.71", E121°20'31.78", north corner: N23°27'50.70", E121°20'32.34", elevation: 234-237 m, area: ca. 0.72 ha. (Fig. 4)

Site 6: East corner: N23°27'51.81", E121°20'37.58", south corner: N23°27'50.16", E121°20'37.18", west corner: N23°27'51.56", E121°20'32.79", north corner: N23°27'53.18", E121°20'33.27", elevation: 233-236 m, area: ca. 0.6 ha. (Fig. 4)

Figure 2. Site 1 (lined area on the left) and site 2 (lined area on the right).

Figure 3. Site 3 (lined area in the lower part) and site 4 (lined area in the upper part).

Figure 4. Site 5 (lined area in the lower part) and site 6 (lined area in the upper part).

Site 1, site 3, and site 5 are tea plantations managed by eco-friendly farming practices. No herbicide is applied in site 1(Fig. 5), site 3 (Fig. 7) and site 5 (fig. 9), as evidenced by the fact that weeds grow and nourish on these sites and are controlled by frequent pulling and cutting. The soil of these sites stays soft and moist in general. On the contrary, site 2 (Fig. 6), site 4 (Fig. 8) and site 6 (Fig. 10) are tea plantations managed by conventional farming practices. Herbicide is applied, as evidenced by that fact that no or little weeds are observed and the ground always stays clean and compacted. The manager of site 2 uses betel nut leaves as mulch to reduce weed growth and herbicide is only applied to ridges but not to furrows.

In addition, no insecticide was applied to site 1, sit 3 and site 5. By contrast, managers of site 2, site 4 and site 6 do spray insecticides though they claim that they only spray when necessary and always follow the regulation. The main purpose of this study is to compare the biodiversity of tea plantations with eco-friendly farming practice and those with conventional farming practice. Therefore, biodiversity data collected from site 1, site 3 and site 5 was compared with that from site 2, site 4 and site 6.

Figure 5. Site 1 in March 2014. Note the weeds on the ground and vines climbing on tea trees.

Figure 6. Site 2 in March 2014. Note the betel nut leaves are used as mulch.

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Figure 7. Site 3 in March 2014. Note the weeds grow freely.

Figure 8. Site 4 in March 2014. Note the clean ground due to herbicide application.

Figure 9. Site 5 in February 2014. Manually removed grasses are left on the ground as mulch.

Figure 10. Site 6 in February 2014. Note the clean ground due to herbicide application.

B. Study methods

(A). Soil condition

a. Soil temperature

HOBO Pro v2 External Temperature Data Loggers (Onset Computer Corporation, U.S.A.) were used to measure and record air and soil temperature for each sampling event (Fig. 11). One data logger was set in the center of each site at the beginning of each sampling event. One of the two sensors was inserted into soil at a 5 cm depth and the other sensor was left on the surface of the soil. A single measurement was taken every 30 seconds. The loggers were retrieved at the end of the sampling event. A total of 48 hours recording was run for each data logger.

Figure 11. HOBO Pro v2 External Temperature Data Loggers for measuring air temperature and soil temperature.

b. Soil porosity and water content

Porosity is the open space between soil grains and is used to determine how effectively air and water move through the soil. Large pore spaces allow the water to uptake into the root system of plants without mounding and becoming boggy. Six soil samples were taken at each site by soil core described in section of soil insects. Soil samples were put into sealed plastic bags and brought back to laboratory. Porosity was measured in the laboratory by filling a cylinder with 70 ml of water. One soil sample (with a volume of 100 ml) was poured gradually into a cylinder, stirred and mixed with water slowly and then kept still for 5 minutes. The total volume of soil and water was recorded. The total volume should be smaller than that of the sum of water and soil because air in the pore space is replaced by water. Porosity is calculated as following:

Pore space = volume of soil + volume of water – mixed water and soil

Porosity % = pore space/ volume of soil x 100

In general, a porosity of sandy soil is between 0.43 and 0.36 and a porosity of clay soil is between 0.58 and 0.51.

The water content of the soil (W) is calculated by formula as following:

$$W = (\text{Soil mass at field} - \text{Oven-dry mass}) / \text{Volume of soil core (100 ml)} \times 100$$

(B). Biodiversity study

Species diversity, including insects and other arthropods and vertebrates (i.e. mammals, birds, reptiles, amphibians) in tea plantations managed by eco-friendly versus conventional farming practices were studied and compared.

a. Insects and other arthropods

The following four methods were used to collect insects and other arthropods of the study sites.

(a) Window trap

A window trap comprises a roof, two transparent vanes that intersect vertically and a yellow plastic collecting tray (Figure 12). Window traps are designed to intercept a wide range of flying insects that collide with transparent vanes (the ‘windows’), attracted by the color of the tray or the reflection of the vanes and drop into the collecting tray. One window trap was set at the center of each site. When a trap was set, the collecting tray was filled with 2 liters of water and a few drops of detergent. A total of 6 window traps, i.e. one trap per site, were run for 2 days on each sampling event. After each sampling event the water containing the sample was poured through a sieve, lined with a piece of very fine nylon gauze. The collected sample was then wrapped by the nylon gauze and stored in a pre-labeled plastic bottle filled with 80% ethanol.

Figure 12. Window traps were assembled before trapping.

(b) Pitfall trap

Pitfall traps are used to capture free-living ground dwelling insects. Disposable plastic cups (top diameter 70 mm, height 80 mm, bottom diameter 50 mm, volume 200 ml) were used as pitfall traps in this study. A hole with the size of the plastic cup was first dug to set the trap. The depth of the hole was the height of the plastic cup so that the cup fits snugly without gaps around the outside. A cup was placed in the hole so the top was flush with the surface of the soil (Fig. 13). Four pitfall traps, separated from each other by at least 15 m, were set on each site. A total of 24 pitfall traps were run for 2 days on each sampling event. After each sampling event the water containing the sample was poured through a sieve, lined with a piece of very fine nylon gauze. The collected sample was then wrapped by the nylon gauze and stored in a pre-labeled plastic bottle filled with 80% ethanol.

Figure 13. Pitfall trap set up.

(c) Beating method

Insects feed and/or rest on or in the tea trees can be easily collected by beating the plants with stick while holding a beating sheet under the area being beaten. We used a 71 cm square heavy duty Canvas Beating Sheet (BioQuip, U.S.A.) stretched across two diagonal pieces of wood joined at the center. When collecting insects with this method, the beat sheet was held in one hand while the tea plant was hit 20 times with a stick (Fig. 14). Originally we used aspirators to suck up the bugs but later found some active insects escaped in this way. Therefore, a piece of nylon mesh the same size of beat sheet was placed and fixed on top of the sheet. After each beating, nylon mesh together with the fallen litters and insects were quickly wrapped and put into a killing jar containing ethyl acetate for 5- 10 minutes. The wrapped nylon mesh were then taken out and spread on top of a piece of white paper. The killed insects were picked up from litter and debris and poured into a pre-labeled, plastic bottle filled with 80% ethanol and taken back to laboratory. Four samples by beating were collected at each site. Sampled insects were counted and sorted under dissecting microscope in the laboratory.

Figure 14. Beating the tea plant with a stick and collecting fallen insects with a beat sheet.

(d) Soil insects

Soil insects play important roles in decomposition and soil formation. We sampled soil insects by taking 4 soil cores (each with a size of 25 cm^2 x 4 cm depth giving a volume of 100 ml) per site (Fig. 15). A total of 24 soil samples were taken on each sampling event. Soil samples were put into a sealed plastic bag and taken back to laboratory. Soil insects of each soil sample were extracted by a Tüllgren funnel in the laboratory. Extraction took 7 days during which time a 40 w light bulb was on continually over each funnel. Insects moving away from the heat of the light bulb pass sown the course mesh disk at the stem of the funnel and were collected in a vial of 80% ethanol attached to its base. Insects collected from extraction were counted and sorted under dissecting microscope.

(d) Specimen deposit

All voucher specimens collected by the above methods are deposited in Forest Arthropod Collection of Taiwan (TACT), Taiwan forestry Research Institute, 53 Nanhai Road, Taipei, Taiwan.

Figure 15. A soil sample was taken with a soil core.

b. Vertebrates

(a) Amphibians and reptiles

The number and species of amphibians and reptiles sighted or calls heard were recorded by walking along the edge of each site. This transect sampling took twice a day, one during the day (from 0900 hr to 1500 hr) the other during the night (from 1900 hr to 2300 hr), per site. A total of 24 transect sampling were run for each sampling event.

(b) Birds

(1) Point count

The number, species and distance (< 25 m, 25-50m, 50-100m, >100m) of birds seen or heard were recorded by standing at the center of each site for 6 minutes within 4 hours after sunrise. In general, birds were sampled in the spring (breeding season) and autumn (migration season). In this study, additional sampling was done in the summer. A total of 12 point count bird sampling were run on each sampling event.

The bird population density (number/ha) D is estimated by formula

$$D = (N \times 10000) / (\pi \times r^2 \times c)$$

where N is the total number of birds detected within the specific basal radius, π equals to 3.1416, r is the specific basal radius (m) and c is the number of survey times (Reynolds et al., 1980), and in our case c equals to 2.

(2) Transect

A transect was established along the edge of each site. The number and species of birds seen or heard in a 3m width band along transect were recorded. Each site was visited once in the morning of a day. All 6 transect walks must be finished within 4 hours after sunrise. A total of 12 transect recording were run for each sampling event.

(c) Mammals

(1) Camera trap

An infrared trail monitoring equipment (Reconyx HC500, RECONYX, Inc., U. S. A., Fig. 16) was tied on a wooden stick which was inserted into the soil. The infrared trail monitoring equipment was set lower than the tea trees to record animals that pass through the tea trees. One camera trap was set on each site. The camera was run for 2 consecutive days for each sampling event. Images recorded were checked in the laboratory. One of our cameras was lost for unknown reason during the second sampling event in May 2014. Because each camera trap costs 450 USD, to avoid further loss of such expensive equipment, we decided to give up this method after the second sampling event.

Figure 16. Setting a camera trap in the field (left) and an image of Chinese hare recorded by camera at site 2 (right)

(2) Sherman trap

Sherman live traps were used to capture small mammals such as rodents and shrews. Starting from the first row of tea plantation, one Sherman trap was set every 10 rows (Fig. 17). A total of 10 traps were laid out under the tea trees, 15 steps from the end each row on each site. All traps were baited with sweet potato smeared with peanut butter for 2 consecutive trapping nights. Traps were checked the next morning of each trapping night. The species, weight, sex and maturity of the captured animal were recorded and the animal was released back to the field (Fig. 18).

Figure 17. Resetting a Sherman trap and weighing the captured animal.

Figure 18. Captured shrews and rodents are released on site after measuring.

(3) Transect

A transect was established along the edge of each site. Mammals seen or heard, tracks, feces, or signs found along transect were recorded. One transect walk was run for each site per day and a total of 12 transect walks were run for each sampling event.

(C). Social Interview

Tea farmers, including owners or managers of the 6 sites (NIEN A-Duan of sites 1, 3, and 5, LEE Chao-Yi of site 2, WANG Shien-Chao and LIU Fu-Chun of site 4, HUANG Wu-Hsiung of site 6) and key tea farmers in Rueisuei Township (Wife of YEH Fa-Shan of Fu-Yuan Tea Corp., HSU Yi-Cheng of Chi-Lin Tea Farm), foreman of labors hired by these farmers (Mei-Huei), and the General Secretary of Rueisuei Farmers' Association (WEI Ching-Ho) were interviewed in order to collect information on history, cultivation, production, ecological and socio-economic effects of eco-friendly and conventional tea farming. Key questions asked in the interviews are listed in Appendix I.

Results

A. Soil condition

(A) Soil temperature

Patterns of soil and air temperature measured during each sampling event in March, May, August and November of 2014 are shown in Fig. 19-22. Two HOBO sensors went out of order in the first sampling event in February and we re-sampled in March. In March, air temperature was in general lower than that of soil temperature (Fig. 19). In May, air temperature coincided with soil temperature at night but was higher than that of soil temperature during the day (Fig. 20). Sensor for measuring air temperature at site 4 malfunctioned and the sensor for measuring soil temperature at site 5 was taken out accidentally by a labor mowing grass that day (Fig. 21) and the temperature data of these two sites were excluded for further analysis. Temperature patterns in August were similar to those of May except the difference between air temperature and soil temperature at night was larger in August (Fig. 22). Temperature patterns in November were similar to those of August but all temperature dropped down several degrees (Fig. 22).

Difference of soil and air temperatures, in terms of mean temperature, maximum temperature and minimum temperature, of tea plantation with eco-friendly farming practice (1+3+5) were all greater than those of sites with conventional farming practices (2+4+6) (Table 1). This also holds true for mean temperature range except the March record (Table 1). It seems that eco-friendly farming practice offered a more stable temperature environment than that of conventional farming practices.

Table 1. Comparison of difference of soil and air temperatures between 3 sites of tea plantation with eco-friendly farming practice (1+3+5) and 3 sites with conventional farming practices (2+4+6) in Rueisuei Township, Hualien County, Taiwan, 2014. *One measurement was deleted due to malfunction of data loggers

Date (sites)	Mean soil temperature - Mean air temperature	Maximum soil temperature - Maximum air temperature	Minimum soil temperature - Minimum air temperature	Mean soil temperature range - Mean air temperature range
20140313-5 (1+3+5)	2.13	0.40	2.70	-2.30
20140313-5 (2+4+6)	1.87	0.20	2.41	-2.21
20140511-3 (1+3)*	-1.43	-10.02	1.90	-11.92
20140511-3 (2+6)*	-2.34	-21.89	1.87	-23.76

20140806-8 (1+3+5)	0.03	-9.64	3.25	-12.89
20140806-8 (2+4+6)	-1.55	-20.27	0.26	-20.27
20141103-5 (1+3+5)	1.75	-9.12	4.91	-14.04
20141103-5 (2+4+6)	1.02	-11.36	3.63	-14.98

Figure 19. Soil temperature (solid line) and air temperature (dotted line) at 6 sites measured from March 13 to 15, 2014.

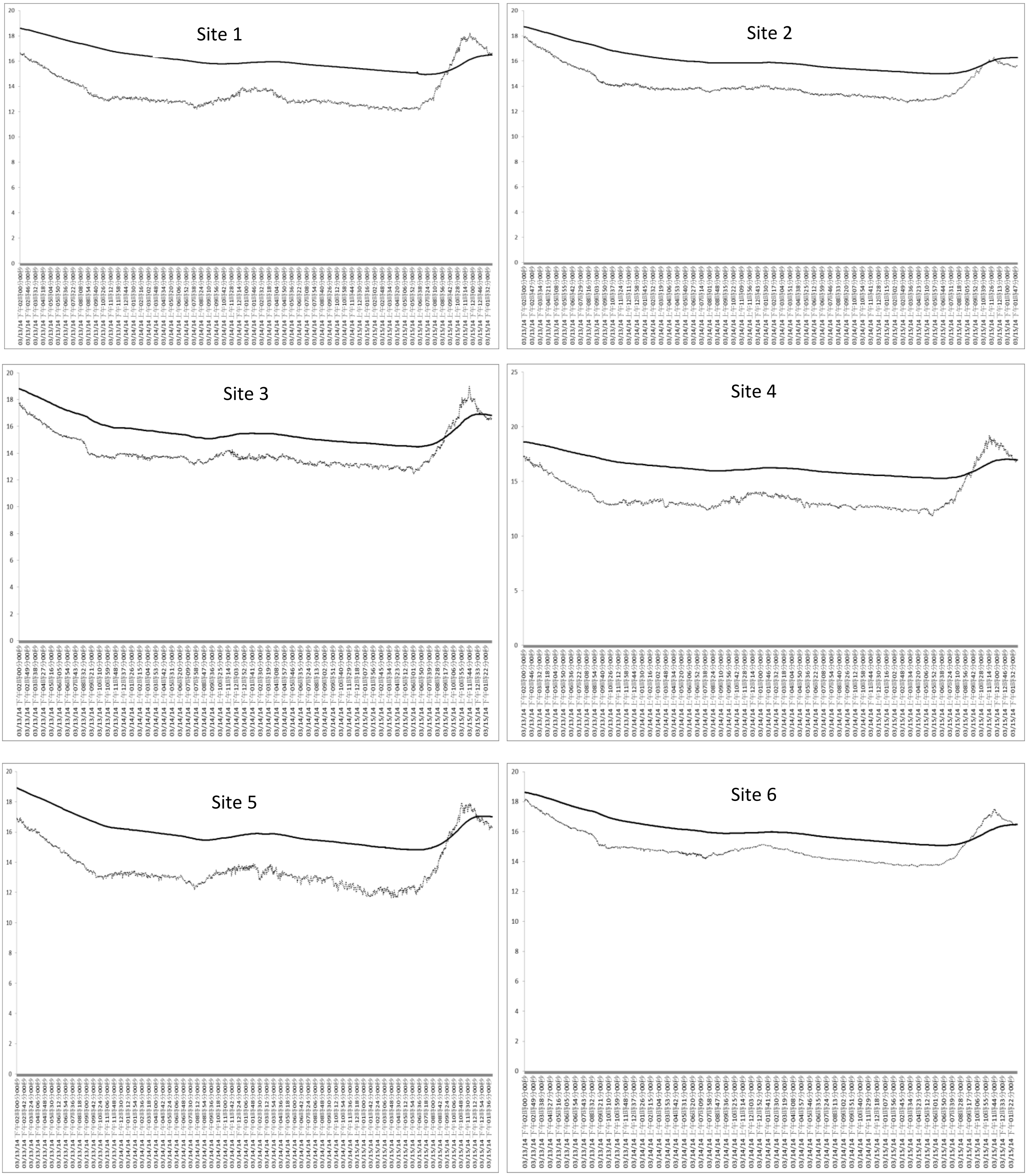


Figure 20. Soil temperature (solid line) and air temperature (dotted line) at 6 sites measured from May 11 to 13, 2014.

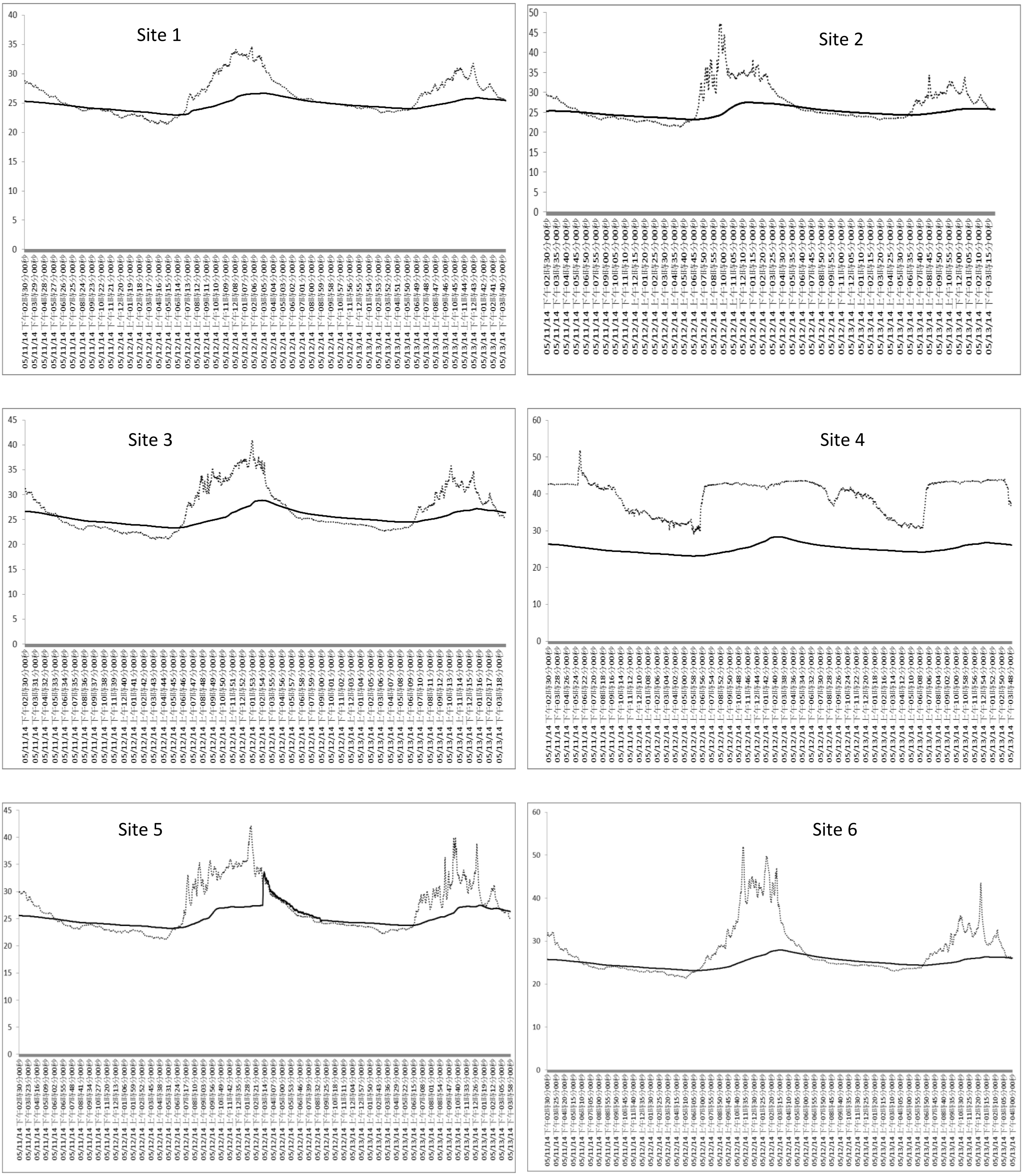


Figure 21. Soil temperature (solid line) and air temperature (dotted line) at 6 sites measured from August 6 to 8, 2014.

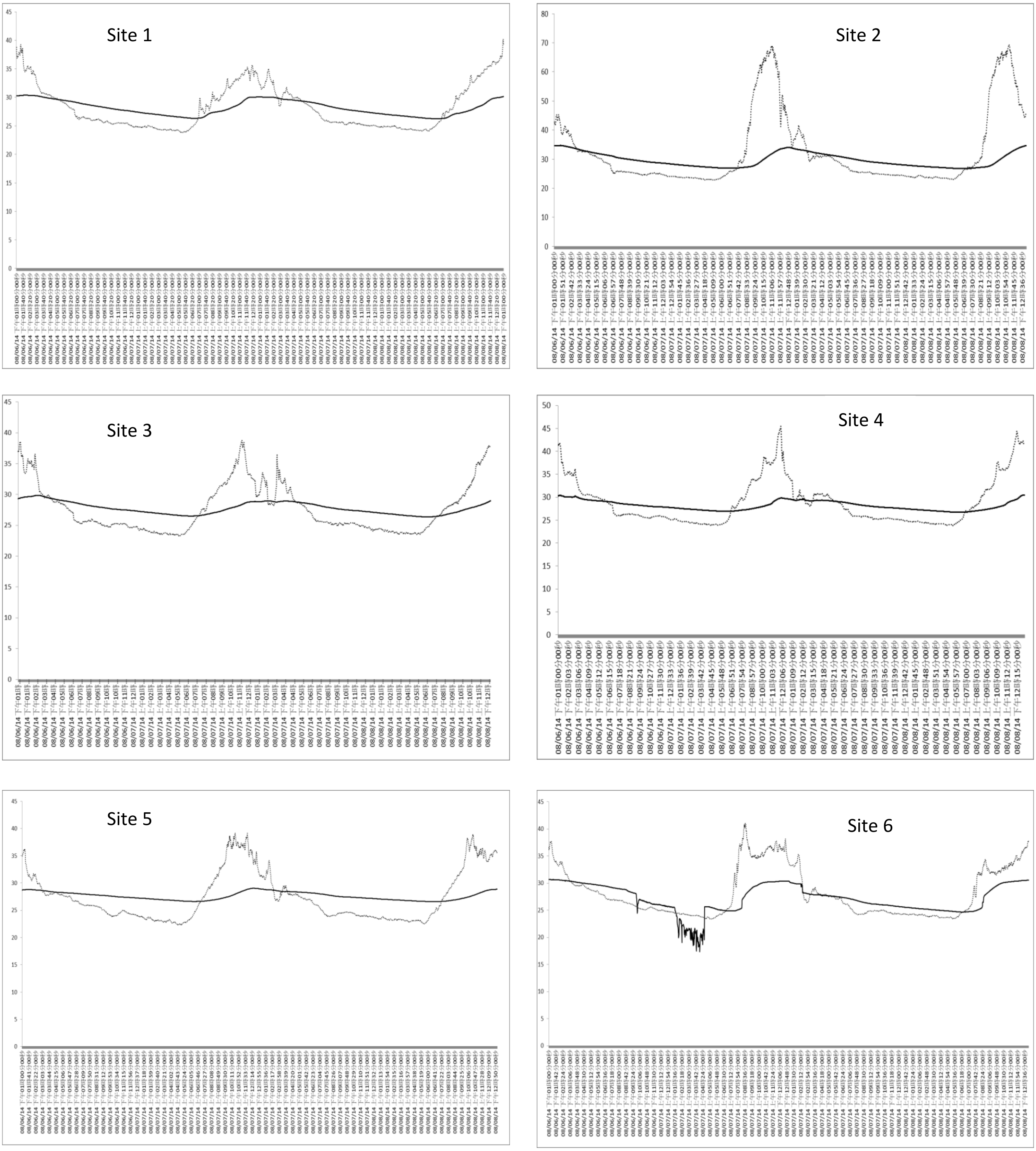
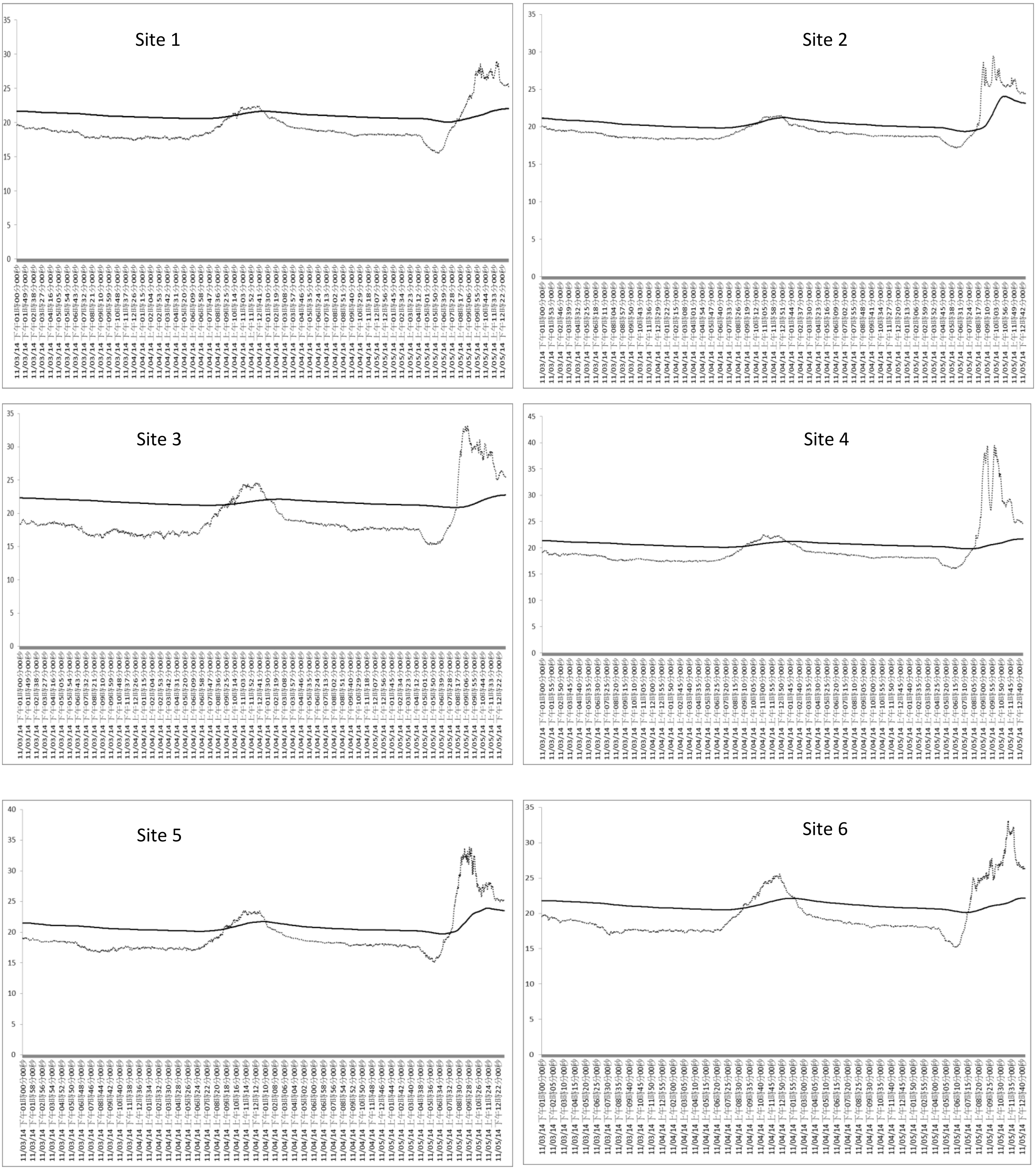


Figure 22. Soil temperature (solid line) and air temperature (dotted line) at 6 sites measured from November 3 to 5, 2014.



(B) Soil porosity

Average soil porosity and water content of each site are shown in Table 2. The average porosity and water content of 3 sites with eco-friendly farming practice (Sites 1, 3, and 5) are 47.7% and 35.6%, respectively. The average porosity and water content of 3 sites with conventional farming practice (Sites 2, 4, and 6) are 47.7% and 35.4%, respectively. There is no difference between sites with two farming practices in terms of soil porosity and little difference between sites with two farming practices in terms of water content.

Table 2. Average soil porosity and water content of 6 sites of tea plantation in Rueisuei Township, Hualien County, Taiwan, 2014

Site	Average porosity	Average water content
1	42%	35.60%
2	41%	37.30%
3	54%	33.50%
4	52%	35.60%
5	47%	37.60%
6	50%	33.40%

B. Biodiversity study

(A) Insects and other arthropods

A total of 56,987 arthropods (mainly insects) were collected from 4 sampling events at 6 sites. Pitfall traps collected the most number (39,044) of individuals while soil sampling collected the least number (1,278) of individuals (Table 3). More than 65% (37,228/56,987) of the total catch came from site 5 (Table 3). It took a lot of time and effort to identify the species collected. We have only finished identifying the arthropod species collected in the first 2 sampling events by far. Identification of species collected in the rest 2 sampling events is still underway. However, more than 500 arthropod morphospecies have been identified (Table 3). Some representative specimens collected are presented in Fig. 23 and 24.

Table 3. Number of arthropod species and individuals collected in 4 sampling events by 4 different methods at 6 sites of tea plantation in Rueisuei Township, Hualien county, Taiwan, 2014. The identification of species has not finished and the data on number of species only represents the results of the first two sampling events

	Window traps		Pitfall traps		Beating		Soil sampling	
	Species *	Individuals	Species *	Individuals	Species *	Individuals	Species *	Individuals
Site 1	31	151	54	1622	14	2169	9	105
Site 2	53	149	40	1097	6	1256	11	166
Site 3	33	202	88	1881	60	2261	16	174
Site 4	53	242	58	2541	17	2910	14	188
Site 5	103	3902	40	31007	34	1951	21	368
Site 6	20	254	20	896	4	1218	12	277
Total	197	4900	167	39044	95	11765	43	1278

Table 4 shows the difference of species and individuals collected at the 3 sites with eco-friendly farming practice and the 3 sites with conventional farming practice. Individuals collected at sites with eco-friendly practice (41,793) are nearly 4 times of those collected at sites with conventional practice (11,194) (Table 4). Based on available data, the number of identified species collected at sites with eco-friendly practice (390) is 1.7 times of that collected at sites with conventional practice (238) (Table 4).

Figure 23. Representative arthropods collected in this study. From top left clockwise are beetle mite (Oribatida) from site 5, commonly found in soil samples; Blattaria (Phyllodromiidae) from site 3, uncommon; centipede (Chilopoda) from site 3, rare; millipede (Diplopoda) from site 1, rare; scuttle fly (Phoridae) from site 5, common in window traps; springtail (Hypogastruridae) from site 4, abundant in pitfall traps; springtail (Entomobryidae) from site 1; common; short winged mold beetle (Pselaphidae) from site 3, rare.

Figure 24. Representative arthropods collected in this study. From top left clockwise: thrip (Thripidae) from site 2, uncommon; booklice (Psocoptera) from site 3, uncommon; ant (Formicidae) from site 6, rare; webspinner (Embiidina) from sit 3, rare; whip-scorpion (Thelyphonidae) from site 3, rare; dark-winged fungus gnats (Sciaridae) from site 5, common;aphid (Aphididae) from site 2, uncommon; isopod (Isopoda) from site 3, uncommon.

Table 4. Comparison between the number of arthropod species and individuals collected in 4 sampling events by 4 different methods at 3 sites of tea plantation with eco-friendly farming practice and 3 sites with conventional farming practices in Rueisuei Township, Hualien county, Taiwan, 2014. The identification of species has not finished and the data on number of species only represents the results of the first two sampling events

	Window traps		Pitfall traps		Beating		Soil sampling	
	Species	Individuals	Species	Individuals	Species	Individuals	Species	Individuals
Eco-friendly	140	4255	131	34510	86	6381	33	647
Conventional	105	645	82	4534	24	5384	27	631

(B) Vertebrates

A total of 56 species and 887 individuals of vertebrates, including 7 species and 45 individuals of amphibians, 4 species and 6 individuals of reptiles, 37 species and 794 individuals of birds, 8 species and 42 individuals of mammals, were recorded from this study (Table 5). Not many reptiles were recorded though two poisonous snakes were found at site 1 and site 3, respectively (Fig. 25). All vertebrate species recorded are listed in Appendix II. In addition, bird species seen or heard outside the transect line are listed in Appendix III.

Table 6 shows the difference between species and individuals collected at the 3 sites with eco-friendly farming practice and the 3 sites with conventional farming practice. More number of specie and individuals were found at sites with eco-friendly practice, no matter amphibians, reptiles, birds or mammals (Table 6). The number of birds found on sites with eco-friendly practice was almost 2.5 times of that on sites with conventional practice (Table 6).

Figure 25. A cobra, *Naja naja* (left), found under a tea tree at site 1 and a many-banded krait, *Bungarus multicinctus* (right), trapped in Sherman trap at site 3.

Table 5. Number of vertebrate species and individuals recorded in 4 sampling events by 3 different methods at 6 sites of tea plantation in Rueisuei Township, Hualien County, Taiwan, 2014

	Amphibians		Reptiles		Birds		Mammals	
	Species	Indivi-duals	Species	Indivi-duals	Species	Indivi-duals	Species	Indivi-duals
Site 1	1	2	1	1	22	262	4	9
Site 2	2	2	0	0	16	142	4	7
Site 3	7	36	2	2	23	140	0	0
Site 4	4	5	1	1	11	70	3	10
Site 5	0	0	1	1	18	161	3	14
Site 6	0	0	1	1	8	19	2	2
Total	7	45	4	6	37	794	8	42

Table 6. Comparison between the number of vertebrate species and individuals recorded in 4 sampling events by 3 different methods at 3 sites of tea plantation with eco-friendly farming practice and 3 sites with conventional farming practices in Rueisuei Township, Hualien County, Taiwan, 2014

	Amphibians		Reptiles		Birds		Mammals	
	Species	Indivi-duals	Species	Indivi-duals	Species	Indivi-duals	Species	Indivi-duals
Eco-friendly	7	38	3	4	33	563	7	23
Conventional	5	7	2	2	24	231	6	19

C. Social Interview

Based on the result of interview (Fig. 26), the area of tea plantation in Rueisuei was 200 hectares in the 1960s. The area of tea plantation decreased later to less than 100 hectares until the invention of honey-flavored black tea. The increase of tea plantation began 10 years ago and now the total area is about 100 hectares. There are at least 6 tea varieties planted in Rueisuei Township. Tea seedlings mainly come from western Taiwan.

Organic fertilizer was applied to sites 1, 3, 5. Chemical fertilizer and organic fertilizer were applied to sites 2 and 4. Chemical fertilizer was applied to site 6. Frequency of fertilizer application varied from twice a year to 5 times per year. No insecticide was applied to sites 1, 3, and 5, while insecticide was applied to sites 2, 4, and 6 in spring and winter to control some caterpillars and mites. No insecticide was applied to sites 2, 4, and 6 in the summer when tip-tea type is to be harvested. Disease seems not to be a problem to tea growers in Rueisuei area. Weeds were controlled by pulling and/or cutting manually or by brush cutter at sites 1, 2, 3, 5. Manager of site 2 use betel nut leaves as mulch because there are many betel nut trees around his tea plantation. Herbicide was applied to sites 4 and 6, and along the border of site 2. Labors (almost all of them are females with an average age of 55) hired to control weeds and picking tea tips or leaves is paid NTD 1,000 (USD 33) per day. A labor hired to cut weeds by brush cutter (usually male) is paid NTD 2,000 (USD 67) per day. Female labors work more than 300 days per year compare to 50 days 10 years ago. Manager of sites 1, 3 and 5 hires 20-30 labors working in her tea plantation. Labor is the now the main cost for tea management in eco-friendly tea farms. However, the honey-flavored tea produced by eco-friendly farming practice sells so good that income of tea growers at least doubled compare to 10 years ago.

Figure 26. NIEN A-Duan (left, the one facing the camera), manager of sites 1, 3 and 5, hosting customers at her Tea Corp. and HSU Yi-Cheng (right, the one on the very left), employee of Chi-Lin Tea Corp., being interviewed.

Among the 100 hectares of tea plantation in Rueisuei, at least 60% is now cultivated by eco-friendly practice (no pesticide application at all). The rest tea plantation is mainly innocuous, i.e., pesticides are applied at its minimum and follow the government regulation. Farmers' Association is the most important institution to tea growers and Tea Research and Extension Station (TRES) is the key institution for training and extension. Only one out of 5 tea production and marketing groups in Rueisuei Farmers' Association is active and the members of this group are in general younger farmers. Farmers do share and exchange knowledge and skills on tea growing through the arrangement of Farmers' Association. However, there are lots of know-hows in term of making teas and tea growers seldom talk about how they make their own teas. Nearly 100 labors are hired by tea growers in Rueisuei. Local women, especially indigenous women and foreign spouses, are the main labor forces for now and probably for the future decade. Like other rural areas in Taiwan, Rueisuei is also facing the threat of aging. Most of the younger generation moved to urban area though there are a few either stayed or returned from urban areas and joined the tea farming and business in recent years. Gender is not a big problem in Rueisuei: females have equal access to all resources but politics. Some, but not all, tea farmers in Rueisuei have experienced more frequent drought compare to 10 years ago. To deal with potential damage of drought, some invested on expensive irrigation system while others chose to plant drought-resistant tea varieties. Ample water supply does help tea trees recover sooner from drought or typhoon.

Discussion

A SEPL requires, among other things, the sustainable use of biological diversity. Therefore, a landscape qualified to be a SEPL must have evidence that its biological diversity is retained and enhanced. The purpose of this study is to find out if tea plantations with eco-friendly farming practice in Rueisuei have higher biodiversity than those with conventional farming practice. Our data proved that eco-friendly farming practice does have higher biodiversity than those with conventional farming practice (Table 4 and Table 6). The active use of the eco-friendly farming practice, originally planned to "protect" small green leaf hoppers, has maintained higher overall biodiversity in tea plantations. For arthropods, individuals collected at sites with eco-friendly practice (41,793) are nearly four times of those collected at sites with conventional practice (11,194) (Table 2). Based on available data, the number of identified species collected at sites with eco-friendly practice (390) is 1.7 times of that collected at sites with conventional practice (238) (Table 2). As for vertebrate, more number of specie and individuals were found at sites with eco-friendly practice, no matter amphibians, reptiles, birds or mammals (Table 4). The number of birds found on sites with eco-friendly practice is almost 2.5 times of that on sites with conventional practice (Table 4).

Regarding physical environment of the tea plantation, our data showed that eco-friendly farming practice offered a more stable temperature environment than that of conventional farming practices though there was no or little difference between sites with two farming practices in terms of soil porosity and water content. In other words, the soil condition of the 6 sites chosen by farmers for tea growing was basically very similar. However, the fact that soil temperature between sites with two farming practices was different indicates that it is related to different ways of management. The eco-friendly farming practice allowed weeds to grow, which made a more extensive ground cover. Grass was cut or pulled once every 2-4 weeks depends on how fast grasses grew. Removed grass was left in furrows of the tea plantations as mulch and green manure that improved the nutrient of tea cultivation. It seems that all these created a more stable soil temperature. It is worth noting that manager of site 2 used betel nut leaves, an abundant resource around his tea plantation, as mulch. In this way, he did not have to use herbicide to inhibit weed growth but only spraying herbicides to the walkway of his tea plantation. During the planning stage of this study, site 2 was considered as one of the conventional farming group. However, through interviewing, we found that manager of site 2 also applied certain eco-friendly farming practice as described above. This explained partially why soil temperature and the number of soil arthropod of site 2 were not necessary lower than that of site1 (Table 3).

The eco-friendly farming practice, though requiring labor-intensive management, allows population of small green leaf hopper fluctuates in the tea plantation. Table 7 describes cascade effects of different levels of small green leaf hopper population to levels of damage, harvest, honey-flavor of tea, and price of tea. As the number of small green leaf hopper increases, more tea buds and leaves are damaged. More insect damage means less harvest. However, the more intensive damage the tea plantation suffered, the stronger the aroma and flavor, or the higher the quality, of tea buds and leaves and these buds and leaves can be used to make more expensive tea product. The price of honey-flavored black tea ranges from USD60 to USD120 per 600 gm, depends on the quality of the tea produced. Premium tea is sold as high as USD400 per 600 gm. Tea growers now do not worry about loss in quantity caused by damage of small green leaf hoppers because this loss is always compensated by the increase of unit price. In fact, feeding by leafhoppers is no longer considered as "damage" but "benefit." As the population of small green leaf hopper decreases, less tea leaves are damaged and these tea leaves can still be processed into some other tea products, e.g. oolong tea, which are sold at lower prices.

Table 7. Cascade effects of different levels of small green leaf hopper population to levels of tea buds and leaves damage, harvest, honey-flavor of tea, and price of tea.

Population of small green leaf hopper	High	Medium	Low
Damage of tea buds and young leaves	Heavy	Medium	Little
Harvest	Lean	Medium	Fat
Honey flavor of tea	Strong	Medium	Weak
Price of tea	High	Medium	Low*

As a result, tea plantation are managed to ensure small green leaf hopper feeding on tea buds. Insecticides are not applied so that no small green leaf hopper is killed by chemicals. Herbicides are not used so that grass can grow freely in the field and provide shelter for the leafhoppers. Timely grass cutting would force small green leaf hoppers to feed on tea buds and young leaves. The grass regrows within several days after cutting and the leaf hoppers may return to these shelters. Since the small green leaf hopper is the target for protection in tea plantation with eco-friendly practice, it is in reality an umbrella species, i.e., other species in this human-influenced ecosystem are indirectly protected from pesticide killing and pollution. Tea plantation managed in this way receives facilitates greatly the conservation of biodiversity.

Treating small green leaf hoppers as allies also bring social benefit. Our data showed that tea growers hired more labors, or created more jobs, for management and harvest. Labors now work more than 300 days per year comparing to 50 days per year 10 years ago. Nearly 100 labors are hired by tea growers in Rueisuei area and this greatly facilitates the rural development. There is also a sign that younger generation is attracted to stay in or return to their hometown to join tea farming and/or run tea business.

In conclusion, we have provided evidence that tea plantation with eco-friendly practice in Rueisuei of Hualien County benefits the local people economically, socially and conserve biological diversity. The tea plantations with eco-friendly farming practices and the surrounding farm, forest, stream and communities in Rueisuei, therefore, represent a unique SEPL in Taiwan. Lessons learned from Rueisuei can be and should be shared with agricultural producers and stakeholders to promote the sustainable use of biological diversity.

Appendix I. Key questions asked in the interviews with tea farmers, labors hired by the tea farmers and the General Secretory of Rueisuei Farmers' Association.

1. How big is the land area of the tea plantation you manage? Is it bigger comparing to 10 years ago?
2. How many tea varieties do you grow? What is the source of seedlings?
3. How many tea varieties are there in Rueisuei area?
4. Please state the cultivation regime of your tea plantation.
5. How frequently do you apply fertilizer? Do you use organic or chemical fertilizer? How much does it cost?
6. How frequent do you apply insecticides and/or fungicides? How much does it cost?
7. If you apply insecticides, how do you maintain the population of small green leaf hoppers in your tea plantation?
8. If you do not apply insecticides, how do you deal with insect pest outbreak?
9. How frequently do you control weeds? Do you sue machine, human labor or herbicide to remove weeds? How much does it cost?
10. How frequently do you irrigate? How much does it cost?
11. How many labors do you hire? What kinds of work do they do? How much does it cost?
12. What is the daily wage of labors you hire?
13. Do you hire more labors comparing to 10 years ago?
14. What is the average yield per hectare? How many times of harvest per year?
15. Do you roast tea by yourself? Do you roast tea for other tea farmers?
16. What is the net return per hectare per year?
17. Has your income increased comparing to 10 years ago? By how many percent?
18. What is total land area of tea plantation in Rueisuei? Is it bigger comparing to 10 years ago?
19. What is the total land area of organic tea plantation in Rueisuei? Is it bigger comparing to 10 years ago?
20. What is the total land area of innocuous tea plantation in Rueisuei? Is it bigger comparing to 10 years ago?
21. How many tea production and marketing groups in Rueisuei Farmers' Association?
22. How many labors in total are hired to work for tea farming in Rueisuei? Is this number higher comparing to 10 years ago?
23. Which of the following institutions or organizations is the most important ones to your tea production and marketing: Community, Farmers' Association, Tea

Research and Extension Station (TRES), Rueisuei Township Office, Hualien County Government? Why?

24. What is your opinion on the future of honey-flavored black tea? What are some of the challenges?
25. What are some of the efforts devoted to marketing the popular honey-flavored black tea? And by whom?
26. What is the average age of tea farmers in Rueisuei?
27. Is younger generation willing to join the tea farming?
28. What is the percentage of female tea farmers in Rueisuei?
29. Is there a female leader in tea production and marketing groups?
30. Is there any sacred land in Rueisuei area?
31. Have you noticed any climate change in Rueisuei area (eg., drought) in the past 10 years?
32. Is your tea plantation recovered from typhoon or drought easily? Is the recovery better or worse than 10 years ago?
33. Do all tea farmers in Rueisuei area try their best to protect small green leaf hoppers?
34. Do all tea farmers know how to make honey-flavored back tea?
35. How many generations are there in your family? Do they all rely on income from tea making?
36. How did your learn tea farm management? Do you share skills and experiences with other tea farmers?

Appendix II. List of vertebrate species recorded along transect.

Mammal

Sciuridae
Petaurista philippensis grandis
Callosciurus erythraeus thaiwanensis
Muridae
Rattus losea
Rattus norvegicus
Niviventer coxingi
Mus caroli
Leporidae
Lepus sinensis formosus
Soricidae
Suncus murinus
Talpidae
Mogera kanoana
Soricidae

Bird

Phasianidae
Coturnix chinensis
Bambusicola thoracicus sonorivox
Phasianus colchicus formosanus
Ardeidae
Ixobrychus cinnamomeus
Bubulcus ibis
Rallidae
Amaurornis phoenicurus
Gallinago stenura
Turnicidae
Turnix suscitator rostratus
Columbidae
Streptopelia tranquebarica
Streptopelia chinensis
Caprimulgidae
Caprimulgus affinis stictomus
Megalaimidae
Megalaima nuchalis
Picidae
Dendrocopos canicapillus
Campephagidae
Pericrocotus solaris
Laniidae
Lanius cristatus
Corvidae
Dendrocitta formosae formosae
Hirundinidae
Riparia chinensis
Hirundo rustica
Hirundo tahitica
Pycnonotidae
Pycnonotus taivanus
Hypsipetes leucocephalus
Cisticolidae
Prinia inornata flavirostris
Zosteropidae
Zosterops japonicus
Timaliidae
Pomatorhinus musicus
Muscicapidae
Phoenicurus auroreus
Sturnidae
Acridotheres javanicus
Motacillidae
Motacilla tschutschensis
Motacilla alba
Anthus hodgsoni
Emberizidae
Emberiza spodocephala

Lanius schach

Vireonidae

Erpornis zantholeuca

Oriolidae

Oriolus traillii ardens

Dicruridae

Dicrurus macrocercus harterti

Monarchidae

Hypothymis azurea oberholseri

Passeridae

Passer montanus

Estrildidae

Lonchura striata

Lonchura punctulata

Reptile

Elapidae

Naja naja

Bungarus multicinctus

Scincidae

Eumeces chinensis

Gekkonidae

Gekko hokouensis

Amphibian

Bufonidae

Duttaphrynus melanosticus

Rhacophoridae

Buergeria japonica

Polypedates braueri

Microhylidae

Microhyla ornata

Raniidae

Rana adenopleura

Rana latouchii

Rana limnocharis

Raniidae

Appendix III. Bird list recorded outside the study sites..

Phasianidae
Coturnix chinensis
Bambusicola thoracicus sonorivox
Phasianus colchicus formosanus
Ardeidae
Ardea alba
Egretta garzetta
Bubulcus ibis
Nycticorax nycticorax
Accipitridae
Pernis ptilorhynchus
Spilornis cheela hoya
Rallidae
Rallina eurizonoides formosana
Amaurornis phoenicurus
Scolopacidae
Tringa ochropus
Gallinago stenura
Turnicidae
Turnix suscitator rostratus
Glareolidae
Glareola maldivarum
Columbidae
Streptopelia orientalis orii
Streptopelia tranquebarica
Streptopelia chinensis
Treron sieboldii
Cuculidae
Cuculus optatus
Centropus bengalensis
Strigidae
Otus spilocephalus hambroecki
Otus lettia glabripes
Caprimulgidae
Caprimulgus affinis stictomus
Megalaimidae

Monarchidae
Hypothymis azurea oberholseri
Corvidae
Dendrocitta formosae formosae
Pica pica
Corvus macrorhynchos
Hirundinidae
Hirundo rustica
Hirundo tahitica
Pycnonotidae
Pycnonotus taivanus
Hypsipetes leucocephalus
Cettiidae
Horornis canturians
Phylloscopidae
Phylloscopus borealis
Locustellidae
Locustella sp.
Cisticolidae
Prinia flaviventris
Prinia inornata flavirostris
Paradoxornithidae
Sinosuthora webbiana bulomacha
Zosteropidae
Zosterops japonicus
Timaliidae
Cyanoderma ruficeps praecognitum
Pomatorhinus musicus
Megapomatorhinus erythrocnemis
Pellorneidae
Schoeniparus brunneus brunneus
Leiothrichidae
Alcippe morrisonia
Garrulax taewanus
Muscicapidae
Phoenicurus auroreus

Megalaima nuchalis

Picidae

Dendrocopos canicapillus

Pittidae

Pitta nympha

Campephagidae

Pericrocotus solaris

Laniidae

Lanius cristatus

Lanius schach

Vireonidae

Erpornis zantholeuca

Oriolidae

Oriolus traillii ardens

Dicruridae

Dicrurus macrocercus harterti

Bronzed Drongo braunianus

Sturnidae

Acridotheres javanicus

Motacillidae

Motacilla tschutschensis

Anthus hodgsoni

Emberizidae

Emberiza spodocephala

Passeridae

Passer montanus

Estrildidae

Lonchura striata

Lonchura punctulata