Chapter 11
Research in Agricultural and Urban Areas in Galapagos: A Biological Perspective

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Introduction

Since the creation of the Galapagos National Park in 1959, biological research has greatly contributed to the conservation of the islands and to scientific knowledge in fields like evolutionary biology, taxonomy, biogeography, and population ecology of endemic, native, and introduced species (Parque Nacional Galapagos 2009). However, the ecology of terrestrial ecosystems has been less studied, in particular in agricultural and urban areas.

Conversion of natural ecosystems to agricultural or urban land is the result of a combination of social, economic, and environmental factors that create complex mosaics with different productivity levels, biogeochemical features, and interactions among organisms (Asner et al. 2004). Agricultural and urban areas in Galapagos represent only about 3% of the terrestrial environment but their relevance for the conservation of the islands is unquestionable, since they are the epicenter of human activities that affect natural ecosystems (Caujapé-Castells et al. 2010). The invasion of exotic species, like guava and the goats, began in the agricultural areas of the large islands (ECOLAP and MAE 2007; Itow 2003). The different human activities carried out in these areas have created a matrix of environmental changes that need to be understood to improve the management of protected areas in Galapagos and elsewhere. Studies addressing the effects of human activities on ecosystems are now a priority in research and conservation agendas worldwide (Martino 2001; Prins and Wind 1993), but in the Galapagos these areas of research are still in their beginnings.

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Terrestrial ecosystems in Galapagos may also be affected by climate change. Studies by the Intergovernmental Panel on Climate Change (IPCC) project a rise of 1.5–4.5°C in the world's mean temperatures in this century and an increase of climatic anomalies such as the El Niño–Southern Oscillation (ENSO) (Houghton et al. 1996; McCarthy et al. 2001). ENSO events in Galapagos are associated with significant rainfall increases and changes in the vegetation cover in terrestrial ecosystems (Robinson and del Pino 1985; Trueman and d'Ozouville 2010). The effects of these future temperature and rainfall increases, as well as of different management strategies, on biological processes may include changes in nutrient dynamics, primary productivity, and the structure of biological communities (Aronson and McNulty 2009; Asner et al. 2004; Bauer et al. 2006; Hollister et al. 2006; Pellens and Garay 1999; Trueman and d'Ozouville 2010). To predict the direction and magnitude of such changes, baseline data should be collected on how nutrients in soil and plants and animal communities vary with land use and ecosystem type, as well as seasonal dynamics in soil nutrients and diversity.

In 2011, long-term research was begun to understand the effects of land use and climate change on the structure and functions of agricultural and urban ecosystems on San Cristobal Island, the second most populated island in the archipelago, with 7,500 inhabitants (ECOLAP and MAE 2007; INEC 2010). Specifically, the aim was to evaluate the effects of land use and climate change on nutrient dynamics, plant productivity, and diversity of animal communities, focusing on soil macroinvertebrates and terrestrial birds. In this chapter, some preliminary results are presented, specifically examining how variability in soil *C/N* ratio, percent vegetative cover, and diversity of bird and soil macroinvertebrate communities relate to land use.

Study Areas

In August 2011, four study sites with different land use patterns were selected: urban, organic agriculture, pasture and guava, and restoration sites (Fig. 11.1). The urban site was located near the facilities of GAIAS and the Galapagos Science Center of the Universidad San Francisco de Quito, Ecuador, and the University of North Carolina at Chapel Hill, USA. This site has native, xerophytic vegetation with small trees (e.g., *Bursera graveolens*), shrubs (e.g., *Gossypium darwinii*), and cactus (e.g., *Jasminocereus thouarsii*), as well as some introduced plant species (e.g., *Ricinus communis*). The organic agriculture site was located at Hacienda El Cafetal, near the town El Progreso. Although vegetation in this site is dominated by shrubs of coffee *Coffea* cf. *arabica*, other introduced tree species were also present (e.g., *Cedrela odorata*). Ferns (cf. *Polypodium* sp.) occurred in the undergrowth. The pasture and guava site was located at Hacienda La Tranquila, in the village La Soledad. Vegetation was dominated by introduced plant species, including grasses (e.g., *Paspalum dilatatum*) and trees of guava *Psidium guajava*. The restoration site was also located in Hacienda La Tranquila and was formerly an area of pasture, infested with guava and mora (*Rubus niveus*); few individuals of these two species were still present in the area. The reforested native species included *Lecocarpus darwinii* and

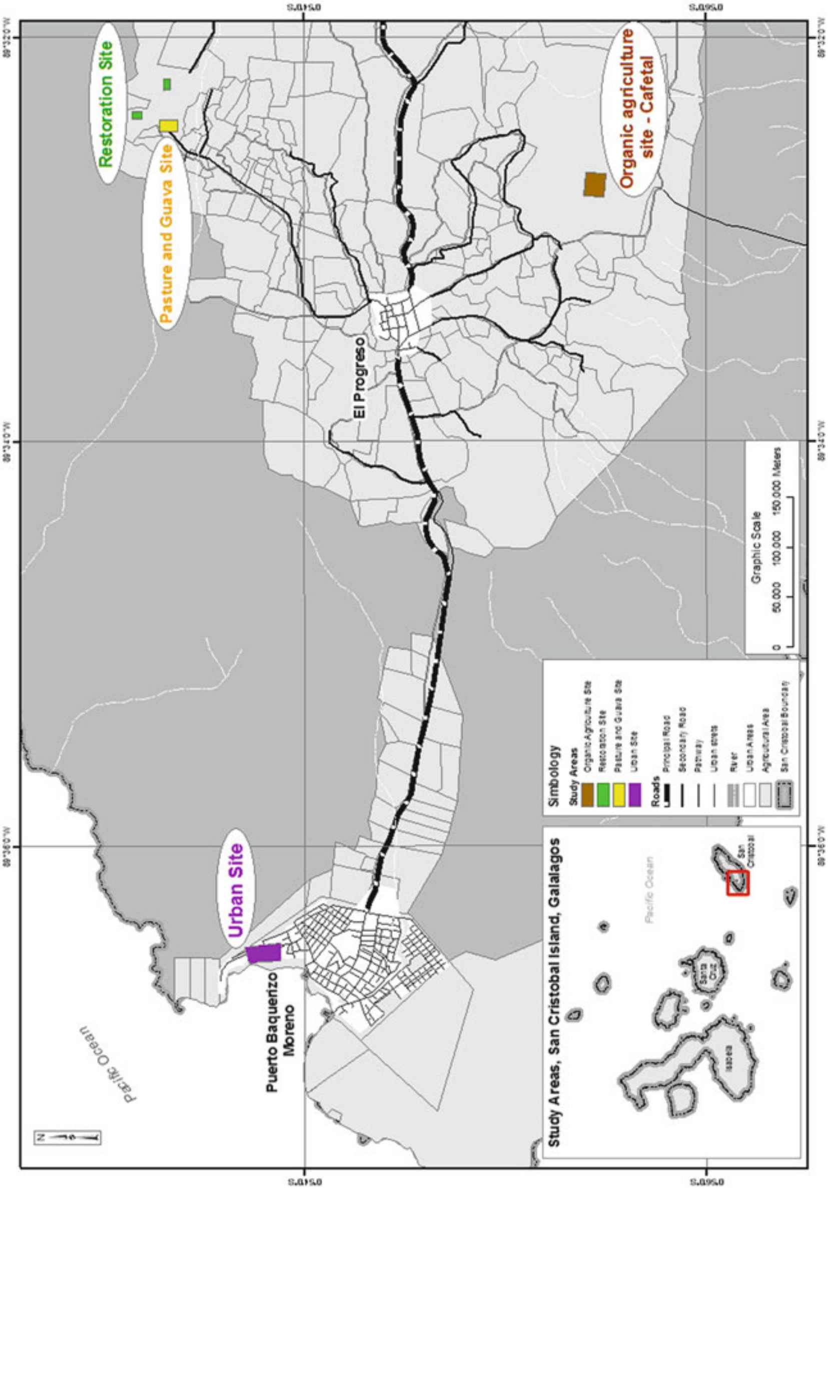

Fig. 11.1 Location of the study sites, San Cristobal, Galapagos

Scalesia pedunculata. Mean linear distance between sites was 4.6 km ± 3.3. The most distant study sites were the urban and restoration sites (linear distance 8 km). The closest sites were the restoration and the pasture and guava sites (0.39 km).

Methods

Fieldwork was carried out in August 2011 and in January 2012 by 2–3 fieldworkers. These two months were selected as representative of the dry and wet seasons of the islands (Trueman and d'Ozouville 2010). However, although mean temperature and relative humidity were higher in January 2012 (23.2°C–77.4% vs. 26.3°C–79.7%, mean temperature–relative humidity in August and January, respectively), precipitation was zero during the January sample and in the previous month (SEST 840080 Meteorological Station).

In each study site, seven randomly selected 50 m transects were built. In each transect, two randomly located 1 m^2 plots were selected, separated from each other by at least 10 m for a total of 14 plots per study site (range of plot separation in a site: 10–500 m). From the approximate geometrical center of each plot, one soil sample from 0 to 10 cm depth and two subsamples of the adjacent vegetation (life leaves of all the species inside the plot) were collected once in each climatic season. Soil and leaf samples were dried at ambient temperature, sieved at 2 mm (for soil), and transported to a laboratory in Quito to assay for carbon (C) and nitrogen (N) concentrations. Carbon concentration in leaves was calculated as 50% of organic weight (Schlesinger 1991). Carbon concentration in soil and nitrogen concentration in soil and leaves were directly measured with Walkley-Black and Kjeldahl methods, respectively. For the statistical analyses (see below), the carbon and nitrogen concentrations were averaged for the two leaf samples and the mean concentrations per plot per season were used for the calculations.

In each plot and season, vegetation cover was estimated, as a proxy of primary productivity, using a spherical densiometer. Four different measures of vegetation cover were performed, one in each cardinal direction, and a mean vegetation cover was calculated for each climatic season. A rate of change of vegetation cover was computed by dividing the mean percentage of cover in the wet season by the mean percentage of cover in the dry season for each plot to include this variable in the statistical analyses (see below).

The diversity of soil invertebrates was assessed through surveys of two subplots of 25 cm^2 in each of the 1 m^2 plots in the study areas. In each subplot, 2–4 different surveys were conducted, from the soil surface to 5 cm depth, in each climatic season. Invertebrates were photographed and identified for their taxonomic order; no specimens were collected. Shannon diversity indices (Smith and Smith 2000) were calculated with the number of orders and the number of individuals in each order, found in each survey for each subplot. For the statistical analyses (see below), the indices of the two subplots were averaged and the mean index per plot per season was used for the calculations.

To assess bird diversity, three fixed observation points were selected along the transect system in each study site. We carried out 2–4 30 min censuses, from 0600 to 0800 h and from 1600 to 1800 h, in each observation point in the dry and rainy seasons. In the censuses, bird species actively using the area around the observation point, within a 30 m radius, were recorded. Birds were identified with field guides. Occasionally (less than 20% of all surveys), we could not identify ground finches to the species level and recorded them as *Geospiza* sp. In even fewer cases (less than 5% of all surveys), the species could not be identified and we recorded those individuals as "not indentified." Shannon diversity indices were calculated for each survey, including the *Geospiza* sp. and the "not identified" bird categories in those surveys with identification problems.

Quantitative Analyses

Repeated-measures multifactorial ANOVAs were carried out to compare the ecosystem variables among sites in both climatic seasons: transformed (arcsin sqrt (p)) percentages of carbon and nitrogen in soil and leaf samples, *C/N* ratios in soil, transformed percentages of vegetation cover, and diversity indices of soil macroinvertebrates. This model was selected since measurements for all these variables were taken from the same plots in each season. A multifactorial ANOVA was carried out to compare diversity indices of birds among sites and between seasons. A one-way ANOVA was used to compare the transformed (sqrt (p)) wet/dry rate of the change of vegetation cover among sites.

Simple linear regressions were carried out to evaluate the influence of carbon and nitrogen concentration, as well as of the soil *C/N* ratio on vegetation cover and diversity of soil macroinvertebrates in both climatic seasons; transformed variables were used for the calculations when appropriate. Increased available nitrogen in soil may increase primary productivity and vegetation cover (Galloway et al. 2003), whereas increased *C/N* ratios in soil may reduce decomposition rates (Ordoñez 2010), thereby impacting the community dynamics of soil invertebrates. Considering that some invertebrates may be prey for most bird species (see Abott et al. 1977), a Pearson correlation was calculated between the Shannon diversity indices of soil macroinvertebrates and birds across seasons.

Results

The study sites differ significantly in nitrogen and soil concentration in soil and leaves (see below). The restoration site showed the highest nitrogen and carbon concentrations in soil, whereas the pasture and guava site had the lowest concentrations of these two elements in soil in both climatic seasons ($N/F_{3,52}=4.45$, $p=0.07$; $C/F_{3,52}=3.13$, $p=0.033$) (Figs. 11.2 and 11.3, Table 11.1).

The highest nitrogen concentration in leaves was found in the organic agriculture site in both seasons, whereas the lowest was recorded in the pasture and guava site

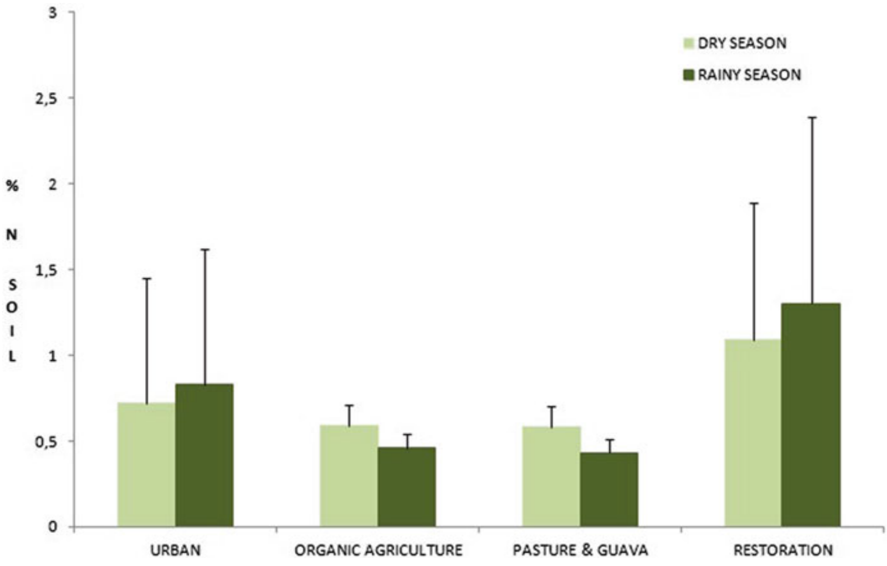

Fig. 11.2 Mean percentage (± standard deviation) of the percentage of nitrogen in soil in the four study sites in the dry and rainy season samples

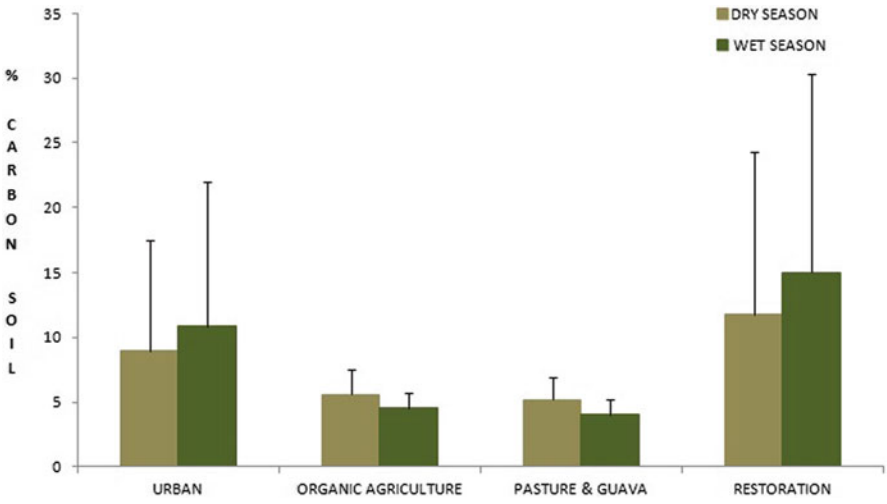

Fig. 11.3 Mean percentage (± standard deviation) of the percentage of carbon in soil in the four study sites in the dry and rainy season samples

($F_{3,52}=44.76$, $p<0.0001$). Nitrogen concentrations in leaves were significantly higher in the wet season in all sites ($F_{1,52}=45.76$, $p<0.0001$) (Fig. 11.4, Table 11.1).

On the other hand, the pasture and guava site had the highest carbon concentration in leaves, whereas the lowest concentration was found in the urban site

Table 11.1 Mean values (± standard deviation) of the studied variables in the four study sites (D, dry season; R, rainy season)

	Urban		Organic agriculture		Pasture and guava		Restoration	
Variable	D	R	D	R	D	R	D	R
% Nitrogen soil	0.72±0.73	0.83±0.79	0.59±0.12	0.46±0.08	0.58±0.12	0.43±0.08	1.09±0.80	1.3±1.09
% Carbon soil	8.95±8.53	10.85±11.14	5.56±1.93	4.54±1.15	5.16±1.73	4.03±1.14	11.78±12.50	15.00±15.29
% Nitrogen leaves	1.87±0.43	2.55±0.72	2.82±0.25	3.60±0.47	1.63±0.30	2.28±0.25	2.30±0.47	2.78±0.56
% Carbon leaves	41.68±2.10	37.74±2.22	44.80±0.61	41.68±2.10	45.86±0.43	43.10±1.38	45.34±0.30	38.72±1.02
C/N soil	11.33±5.53	12.04±5.83	9.24±1.64	9.85±1.75	8.78±1.17	9.34±1.28	9.68±3.64	10.28±3.82
% Vegetation cover	12.02±5.51	12.28±6.40	87.42±16.94	64.45±2.70	25.7±32.50	22.7±9.30	22.42±14.70	14.52±10.38
H macroinvertebrates	0.69±0.26	0.78±0.39	1.03±0.27	1.53±0.22	1.33±0.44	0.92±0.27	1.10±0.32	1.14±0.24
H birds	1.17±0.26	1.37±0.26	1.11±0.26	1.44±0.31	1.45±0.20	1.27±0.23	1.47±0.34	1.54±0.44

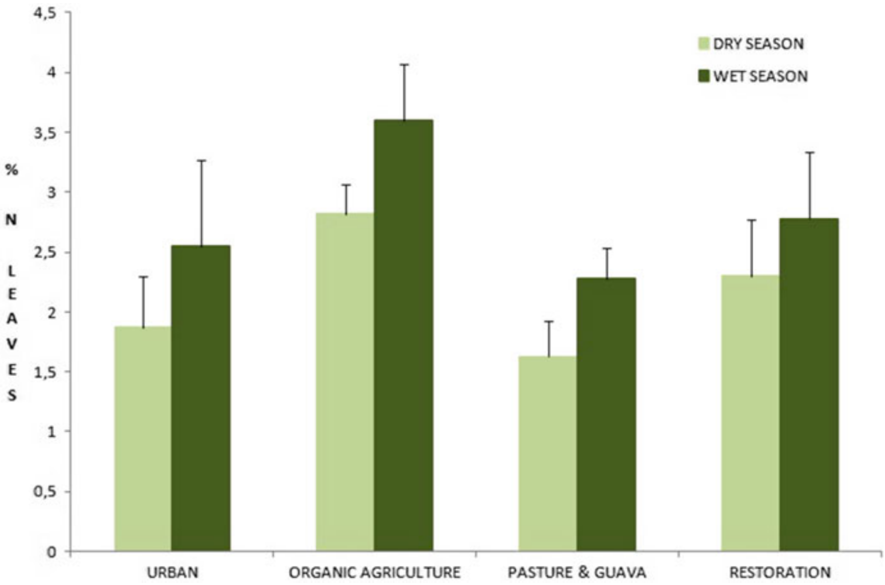

Fig. 11.4 Mean percentage (± standard deviation) of the percentage of nitrogen in leaves in the four study sites in the dry and rainy season samples

($F_{3,52}=29.99$, $p<0.0001$). Carbon concentrations in leaves were significantly lower in the wet season in all sites ($F_{1,52}=425.3$, $p<0.0001$) and there was a significant interaction between site and season ($F_{3,52}=24.94$, $p<0.0001$), suggesting the strong influence of climate on this variable (Fig. 11.5, Table 11.1).

No significant differences were found in the *C*/*N* ratios in soil among sites, but *C*/*N* ratios in soil were significantly higher in the wet season in all sites ($F_{1,52}=293.4$, $p<0.0001$) (Table 11.1).

Vegetation cover was significantly denser in the organic agriculture site, whereas the most sparse cover occurred in the urban site in both seasons ($F_{3,52}=33.90$, $p<0.0001$). Vegetation cover was significantly denser in the dry season study period in all sites ($F_{1,52}=7.62$, $p=0.0079$) and there was a significant interaction between site and season ($F_{3,52}=3.79$, $p=0.0018$) (Fig. 11.6, Table 11.1). No significant differences were found in the rate of change of vegetation cover among sites.

A total of 14 orders of soil invertebrates were recorded in the dry and rainy season samples in the four study sites. Gastropoda (snails), Diplopoda (millipedes), Isopoda (pill bugs), and Haplotaxida (earthworms) were frequently recorded. Significant differences were found in the diversity indices among sites; the lowest diversity occurred in the urban site in both seasons. The highest diversity in the dry season was found in the pasture and guava site, whereas in the rainy season the highest diversity was found in the organic agriculture site ($F_{3,52}=14.25$, $p<0.0001$). There was also a significant interaction between site and season since in the rainy season increase in diversity did not occur in all sites ($F_{3,52}=11.3$, $p<0.0001$) (Fig. 11.7, Table 11.1).

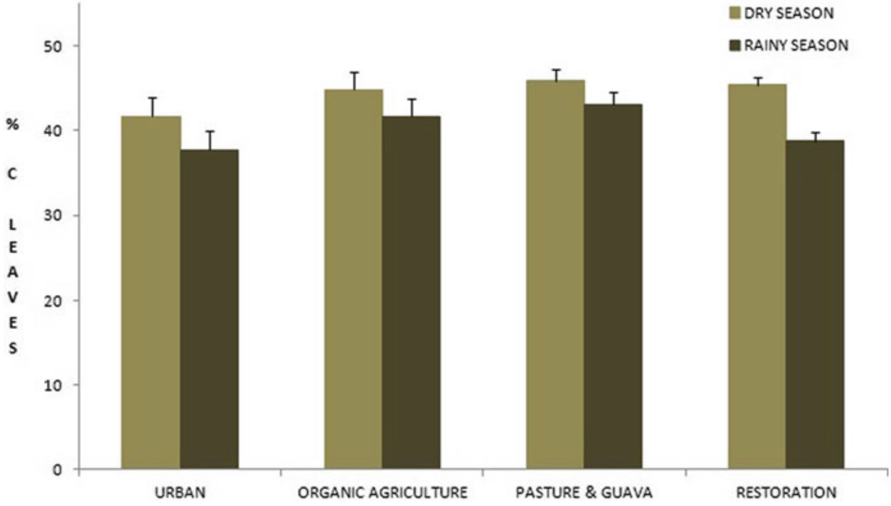

Fig. 11.5 Mean percentage (± standard deviation) of the percentage of carbon in leaves in the four study sites in the dry and rainy season samples

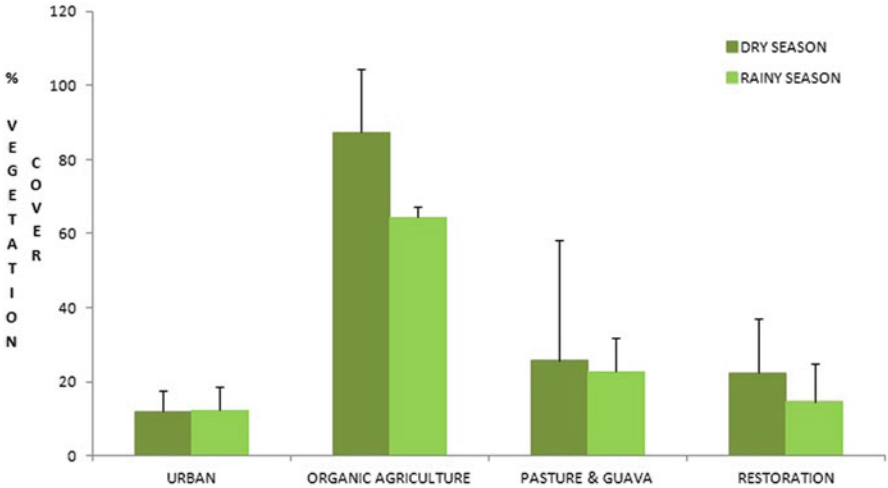

Fig. 11.6 Mean percentage (± standard deviation) of the percentage of vegetation cover in the four study sites in the dry and rainy season samples

A total of 11 bird species were recorded in the censuses in both seasons; two of them were exotic species, the smooth-billed ani *Crotophaga ani* and the cattle egret *Bubulcus ibis* (Appendix 1). The smooth-billed ani was recorded in all the study sites, but the majority of recordings were obtained in the organic agriculture site (1.58 observations per census) and in the pasture and guava site (1.23 obs./census), both in the dry season. Observations of the cattle egret were only made in the pasture

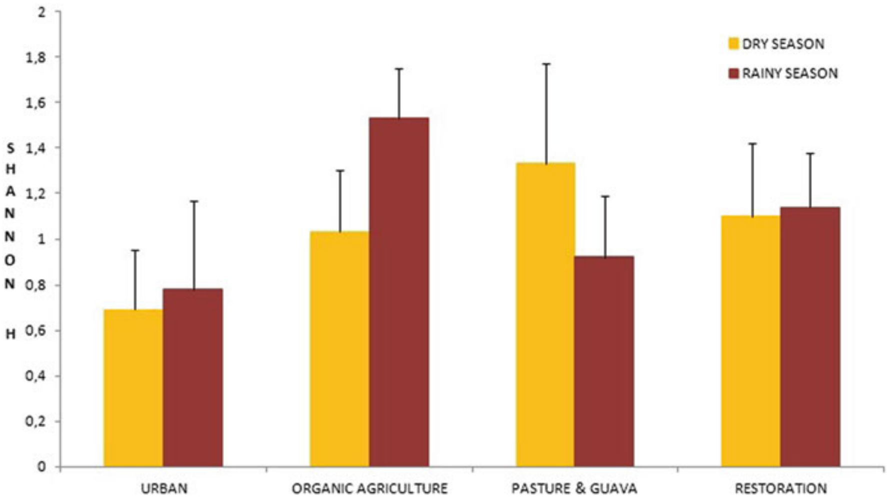

Fig. 11.7 Mean percentage (± standard deviation) of the Shannon biodiversity indices (H) of soil macroinvertebrates in the four study sites in the dry and rainy season samples

and guava site in both seasons (1.63 obs./census dry season, 0.17 obs./census rainy season) and in the dry season censuses of the restoration site (0.25 obs./census). The highest diversity of the terrestrial bird community was found in the restoration site in both seasons ($H = 1.46 \pm 0.34$ dry season, 1.54 ± 0.44 rainy season), but the differences among sites and between seasons were not significant (Table 11.1).

The linear regressions carried out to evaluate the relation between nutrient concentration in soils and leaves with vegetation cover and rate of cover change across all sites had low R^2s and were not significant, with the exception of the relation of the C/N ratio in soil with cover in the wet season that showed a low R^2 (0.18), a low and negative regression coefficient (–0.015), but the regression was significant ($p = 0.001$). Similarly, the linear regressions carried out to evaluate the relation between nutrient concentration in soils and leaves with diversity of macroinvertebrates across sites had low R^2s and were not significant, with the exception of the relation with the C/N ratio in soil in the wet season that showed a low R^2 (0.12), a low and negative regression coefficient (–0.019), but it was significant ($p = 0.008$). The correlation coefficient between invertebrate and bird diversity across sites ($r = 0.57$) was not significant.

Discussion

Although preliminary, the significant differences found in some of the studied ecological variables among sites suggest that the land use patterns have considerable effects on the structure and function of terrestrial ecosystems in the Galapagos.

However, similar analyses have not yet been conducted in "control" sites with native ecosystems to correctly assess the magnitude of the changes. Such analyses will begin in the second year of research and may help to better explain the observed differences.

The results provide evidence that pasture, in combination with guava, affects nutrient availability. The difference between the highest concentrations of nitrogen and carbon in the restoration site and the concentrations of both nutrients in the pasture and guava site was almost twofold in both seasons. The difference is even more remarkable considering that both sites are separated by only about 0.4 km and that five years ago the restoration site was also a pasture area (G. Sarigu, personal communication).

Nitrogen scarcity may be related to the very low concentration of this nutrient in the leaf samples from the pasture and guava site, as has been reported in other studies (van Arendonk et al. 1997; Ordoñez 2010). However, all the analyses do not permit a determination of the limiting factors affecting vegetation cover as an indicator of primary productivity, and the diversity of animal communities, specifically of soil macroinvertebrates and terrestrial birds.

Results suggest that, at least in the rainy season, vegetation cover and macroinvertebrate diversity are partially and negatively related to the *C*/*N* ratio in soil. This ratio is considered to be an indicator of the quality of leaf litter for decomposers, affecting the decomposition rates and the nitrogen supply for plants. High *C*/*N* ratios are related to less availability of nitrogen for plants since most of the nitrogen is assimilated by the decomposers (Alvarez-Sánchez 2001). This may explain the negative relationship between this ratio and vegetation cover found in the study areas. Higher macroinvertebrate diversity in areas with lower *C*/*N* ratios could be expected, but coverage and diversity patterns may also be influenced by other factors not related to nutrient supplies.

Human intervention, through selective cutting and pruning, for example, affected vegetation cover in all the study sites. The lower percentages obtained in the rainy season samples in some of the plots were caused by the previous cutting of vegetation in all sites by landowners for different reasons that could not be controlled in the study. The lowest values of the vegetation cover in the urban site are certainly also related to the drier conditions in the coastal zones of the islands (Trueman and d'Ozouville 2010).

Human influence on patterns of macroinvertebrate diversity may occur through the eventual use of pesticides, although we did not witness their use in the field, or indirectly by affecting vegetation cover and soil characteristics. In the pasture and guava site, for example, just before the rainy season, samples were occupied by cows and horses that ate a large portion of the plants and compacted the soil. Data collection across several years may help to better evaluate the influence of these other variables that could not be controlled in this study, provided we are able to record their occurrence adequately. This could be achieved by increasing the participation of local people in this research. These chrono-sequences may also provide us with insight into ecosystems' resilience and the impact of current climate change.

Although not significant, differences in bird diversity among sites point to the importance of native vegetation in the diversity of bird species. The site with the highest diversity indices in both seasons was the restoration site and, although diversity included records of two introduced bird species, the number of observations of these species was lower than in the other sites.

To my knowledge, this is the first study to analyze the effects of land use and climate on nutrient dynamics and community diversity in agricultural systems in the Galapagos. Evidently, more data and analyses are needed to understand the direction and extent of the impact of land use and climate changes on island ecosystems. Some of the ideas for future work (e.g., including protected areas with native vegetation as control sites) will be carried out in the short- to midterm, whereas others (e.g., chrono-sequences) may require collaboration with other researchers.

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Appendix A. Appendix 1. List of bird species recorded in each study site

Scientific name	Urban	Organic agriculture	Pasture and guava	Restoration
Crotophaga ani	X	X	X	X
Nesomimus melanotis	X	X	X	X
Dendroica petechia	X	X	X	X
Certhidea olivacea		X	X	X
Geospiza fortis	X	X	X	X
Geospiza fuliginosa	X	X	X	X
Platyspiza crassirostris		X	X	X
Camarhynchus pallidus		X	X	X
Camarhynchus parvulus		X		X
Myiarchus magnirostris	X			
Bubulcus ibis			X	X

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