# Chapter 9 Characterizing Contemporary Land Use/Cover Change on Isabela Island, Galápagos

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## Introduction

Areas within and adjacent to human settlements in the Galápagos Islands have undergone significant changes in the last three decades. Humid upland areas on inhabited islands have been transformed by introduced and invasive plants and animals (Walsh et al. 2008; Henderson and Dawson 2009; Watson et al. 2009; Guézou et al. 2010). Coastal communities have become more urbanized with the expansion and densification of buildings and the development of transportation infrastructure to support growinglocal and tourist populations (Walsh et al. 2010; Gardener and Grenier 2011; Cléder and Grenier 2010).

Timely and accurate information about land use/cover change is invaluable for guiding land management and conservation decisions in and around protected areas like the Galápagos National Park (GNP). For example, understanding current patterns and processes of land use/cover change is key for the development of site-specific management plans (Brandt and Townsend 2006) and conservation strategies (Alo and Pontius 2008). However, such assessments are often difficult to conduct in remote areas of developing countries because of limited data, financial constraints, and issues of accessibility (Brandt and Townsend 2006). Such is the case in the Galápagos Islands where information about current land use/cover and past trends is lacking in spite of the rapid changes taking place in the archipelago (Gonzalez et al. 2008).

Land use and land cover information for Galápagos is often incomplete and outdated. The first archipelago-wide maps of land use in Galápagos were produced by the National Institute of Galápagos in 1987 as part of an effort to inventory features of the natural environment (INGALA, PRONAREG, ORSTOM 1987). However, land use maps were not produced for two of the four inhabited islands, Isabela and

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Floreana. More recently, The Nature Conservancy, with cooperation from several Ecuadorian government agencies, produced a series of land use/cover maps of the Galápagos using data collected in 2000 (TNC and CLIRSEN 2006). The lack of data for some islands and the coarse nature of existing maps have hampered efforts to quantify changes in vegetation (Villa and Segarra 2010) and human-mediated degradation (Watson et al. 2009) on inhabited islands.

Remote sensing and image interpretation have become standard approaches for mapping land use/cover. Remotely sensed imagery can not only cover large spatial extents but can also capture information for features of small grains and extents, particularly with the increased availability of high spatial resolution data products. Image interpretation and GIScience methodologies include automated approaches for mapping that are efficient and easily repeatable, which can reduce the costs associated with in situ data collection. Further, remote sensing can provide information on areas that are difficult to access because of their isolation, difficult terrain, or other constraints (e.g., private land restrictions).

The goal of this chapter is to provide an improved understanding of contemporary land use/cover dynamics in the Galápagos Islands by drawing on a case study of southern Isabela Island. The study area, which encompasses the rural community of Santo Tomás and an area within the adjacent Galápagos National Park, is an important site for exploring landscape change in the archipelago. The humid upland areas are important places where agricultural activities and some of the first human settlements in Galápagos coincide with sites of high biodiversity (MacFarland and Cifuentes 1996). The objective is to first explore the dynamics of land use/cover using a combination of remote sensing data and methods, and field observations. An object-based classifier is applied to high spatial resolution satellite images from 2004 (QuickBird) and 2010 (WorldView-2) to generate land use/cover maps of the region. The dominant cover classes are quantified in each period, and from–to change matrices are calculated to determine the degree of change and major transitions between 2004 and 2010. In addition to general classes representing the most common land use/cover types identified during fieldwork in 2008 and 2009 (barren, built-up, dry pasture/grass, crops/pasture/grass, lava, soil, and forest/shrub), the distributions of two invasive plants are also mapped—common guava (*Psidium guajava* L.) and rose apple (*Syzygium jambos* L). Second, descriptive statistics derived from secondary data sets that include two population censuses (2001 and 2010), an agricultural census (2000) and a living standards survey (2009), as well as information from interviews with local residents (conducted in 2008) are leveraged to contextualize the land use/cover results.

## Study Area: Santo Tomás , Isabela Island

This study is centered on the rural community of Santo Tomás (52 $km^2$) and an adjacent area within the Galápagos National Park (37 $km^2$). This site is located along the southeastern slope of Sierra Negra Volcano on Isabela Island, between

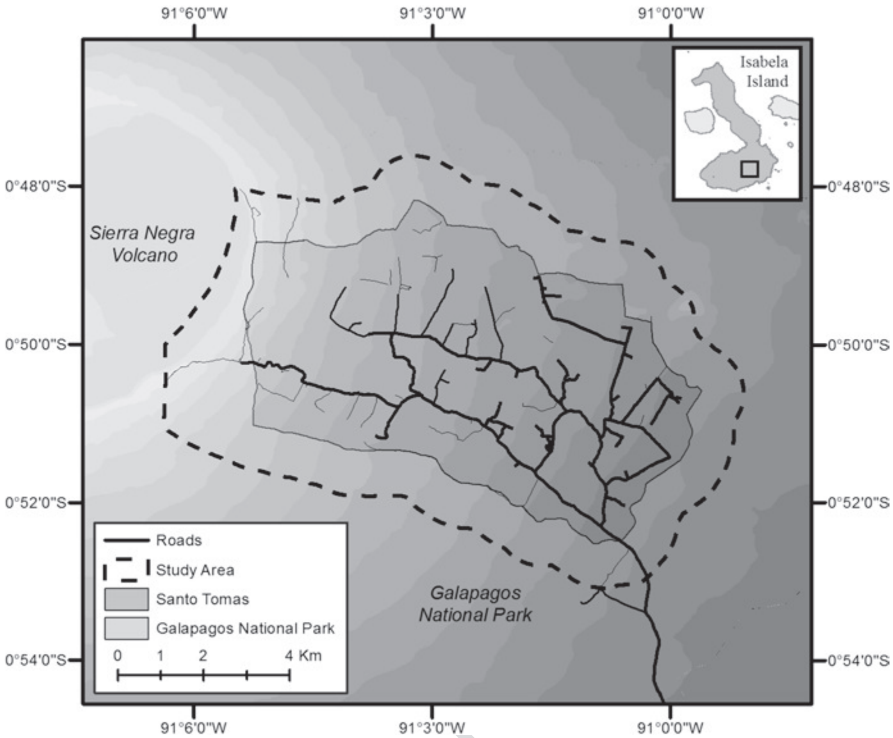


**Fig. 9.1** The study area encompasses Santo Tomás and an adjacent area in the Galápagos National Park in southern Isabela Island

0°47′–0°53′ S and 91°06′–90°59′ W (Fig. 9.1). The climate is semi-arid and subtropical with two distinct seasons—a rainy, warm period from December to June and a dry, cool episode from July to November (Collins and Bush 2011). The relief of the study area is gently sloping, with isolated hills formed by parasitic cones. Elevation ranges from 80 to 1,040 m and slope angles range from 0 to 42°. Vegetation in the site is divided into two commonly recognized zones that progress upward in elevation: (1) the transition zone composed primarily of evergreen plants and (2) the humid zone where introduced vegetation dominates areas once occupied by endemic Scalesia and fern–sedge communities (Wiggins and Porter 1971; Froyd et al. 2010).

Santo Tomás (officially, Tomás de Berlanga) is a community of less than 200 persons that has been continuously inhabited since the late 1890s. It is characterized by smallholder agriculture, agroforestry, and small-scale livestock production. An increasing amount of land within the community is no longer actively managed or given any particular use, which has led to the spread of plants introduced for cultivation (Walsh et al. 2008). The national park, in contrast, strictly controls access to protected areas and limits activities within its boundaries in order to protect native and endemic flora and fauna.

# Methods

## *Satellite Image Data and Preprocessing*

A QuickBird satellite image acquired on 22 October 2004 and a WorldView-2 image acquired on 23 October 2010 were used in this analysis. The images coincide with the period of peak agricultural production from July to December and were selected based on the availability of nearly cloud-free satellite data. The QuickBird sensor collects data in four visible/near-infrared bands and one panchromatic band. The multispectral bands (ranging from 450 to 900 nm) have spatial resolutions of 2.4 m, while the panchromatic band (450–890 nm) has a 0.6 m pixel resolution. The WorldView-2 sensor collects multispectral data in eight visible and near-infrared channels ranging from 450 to 1,040 nm (2.0 m pixel spatial resolution) and one panchromatic channel (450–800 nm; 0.5 m spatial resolution). In addition to the blue (450–501 nm), green (510–580 nm), red (630–690 nm), and near-infrared (770–895 nm) bands found in QuickBird, four new bands were added to aid in vegetation, soil, and water discrimination—coastal blue (400–450 nm), yellow (585–625 nm), red-edge (705–745 nm), and a second near-infrared (860–1,040 nm) channel.

The QuickBird multispectral data were orthorectified using ground control points (GCPs) obtained in the field. Root mean square (RMS) error for the 2004 image was 0.32 m using 13 field GCPs. The WorldView-2 data were co-registered to the corrected QuickBird image. RMS error of the WorldView-2 image was less than 1 pixel (0.91 m) with 48 GCPs. Following the same methodology, the QuickBird and WorldView-2 panchromatic bands were also co-registered to the rectified multispectral bands using 27 GCPs, with RMS errors of less than one-half pixel.

To make the images compatible for change detection, the WorldView-2 multispectral data were resampled to a 2.4 m × 2.4 m pixel size using cubic convolution resampling. The image data were not corrected for atmospheric or radiometric errors due to the lack of available atmospheric parameters at the time of image acquisition over the study area. Clouds and cloud shadows were masked prior to image classification to minimize spectral confusion.

The addition of band ratios, indices, and texture measures has been shown to improve land use/cover classification results (Huang et al. 2002). The simple ratio vegetation index (NIR band/red band) was calculated from the multispectral data, and mean texture was derived from the panchromatic band using a gray-level co-occurrence matrix (GLCM) for each image. An image layer stack consisting of the multispectral bands, vegetation index, and texture measure was created for each image and used as the classification input.

## *Field Data and Classification Scheme*

In situ land use/cover data were collected in the study area from July to August 2008 and July to August 2009 to provide training and validation data for the classifications.

**Table 9.1** Characteristics of land cover classes identified in the highlands of southern Isabela

| Land use/cover | Description |
|---|---|
| Barren | Non-vegetated areas such as exposed soil and lava rock outcrops |
| Built-up | Man-made features including buildings, roads, and structures for animals |
| Crops/pasture/grass | Agricultural areas for crop cultivation, managed pastures, and natural grassland |
| Dry pasture/grass | Dry or senescent vegetation including managed pastures and natural grassland |
| Forest/shrub | Areas covered with dense growth of mostly evergreen trees or taller shrubs, including native and introduced species |
| Guava | Sites dominated by guava (*Psidium guajava*), an invasive woody shrub |
| Rose apple | Areas dominated by dense growth of rose apple (*Syzygium jambos*), an invasive tree |

Sampling areas ($n=263$) were stratified by land cover type and purposefully selected to capture features of interest, such as patches of invasive species, crops, and buildings. At each location, the land cover type was noted, a site description was recorded, and digital photographs were taken. The observations were geo-located with differentially corrected (post-processing) Global Positioning System (GPS) coordinates. One-third of the sample points ($n=86$) were used to train the classifications, while the remaining two-thirds ($n=177$) were reserved for validation.

Seven classes representing the most common land uses and covers in the study area were identified during field visits and selected for image classification: barren, built-up, crops/pasture/grass, dry pasture/grass, forest/shrub, guava, and rose apple (Table 9.1). Guava (*Psidium guajava* L.) and rose apple (*Syzygium jambos* L.) are considered among the worst invaders in the Galápagos Islands because of their ability to significantly transform terrestrial ecosystems (Tye et al. 2002).



### *Object-Based Classification*

Supervised classification of the 2004 and 2010 images was performed with the object-based image analysis approach (OBIA). OBIA is a knowledge-based classification method that attempts to mimic the way humans interpret remote sensing images (Hay and Castilla 2008). Homogenous groups of pixels, or objects, are the basic unit of analysis and thus avoid the “salt-and-pepper” effect in pixel-based classifications of high spatial resolution data (Blaschke et al. 2000). Further, OBIA can exploit the textural, spatial, and topological characteristics of image objects (Lang 2008) to improve the value and accuracy of classifications (Benz et al. 2004). Walsh et al. (2008) successfully mapped guava cover in Isabela’s highlands using an OBIA classifier with high spatial resolution satellite data.

**Table 9.2** Segmentation parameters for OBIA classification

| | Input layers | Scale | Color/shape | Compactness/ smoothness |
|---|---|---|---|---|
| *QuickBird image (2004)* | | | | |
| Level 1 | Multispectral bands (4) | 18 | 0.6/0.4 | 0.2/0.8 |
| | Simple ratio | | | |
| | GLCM texture | | | |
| Level 2 | Multispectral bands (4) | 40 | 0.7/0.3 | 0.2/0.8 |
| | GLCM texture | | | |
| *WorldView-2 image (2010)* | | | | |
| Level 1 | Multispectral bands (8) | 18 | 0.6/0.4 | 0.2/0.8 |
| | Simple ratio | | | |
| | GLCM texture | | | |
| Level 2 | Multispectral bands (8) | 40 | 0.7/0.3 | 0.2/0.8 |
| | GLCM texture | | | |

The WorldView-2 data were first segmented into objects with the multiresolution segmentation algorithm in Definiens Professional 5 (Definiens AG, München, Germany). Multiresolution segmentation is a bottom-up, region-merging procedure (Benz et al. 2004) that creates objects corresponding to features of interest in the image without extensive processing times. The goal is to minimize the heterogeneity of extracted image objects while maximizing contrast to neighboring objects. In this study, image objects were generated at two levels through a bottom-up approach. Small objects were created to represent buildings, roads, and other small features (level 1), and a set of larger objects (level 2) were produced to represent vegetation patches, including forests and open fields (Table 9.2). All layers in the image stack were weighted equally, and user-defined criteria describing the threshold for object heterogeneity—scale, color/shape, and smoothness/compactness—were selected iteratively through a visual assessment of object fit (Meinel and Neubert 2004).

The image objects were then classified using a rule-based classification approach. In Definiens Professional, each land use/cover category in the classification scheme contains a set of expressions, or rules, that describe the class. Knowledge-based rules can draw on spectral data contained in the image bands and/or contextual information such as the textural, spatial, and topological characteristics of image objects. Objects corresponding to points in the training data set were isolated, and their spectral, textural, and contextual attributes were used to establish the rules for each class.

The classification algorithm then evaluated the membership value of each image object to the list of classes, and the class with the highest membership value (ranging from 0 to 1) was assigned to the image object. The objects were first separated into "vegetation" and "non-vegetation" classes based on mean simple ratio (SR) vegetation index values. Objects with SR values between 4.5 and 18 were assigned membership in "vegetation," and objects with low membership to the class were categorized as "non-vegetation." "Non-vegetation" objects were further refined into several subclasses (i.e., buildings, lava, dry pasture/grass, and soil) at level 1, while "vegetation" subclasses were defined at level 2 (Table 9.3). The classifications at levels 1 and 2 were then merged to create a single thematic land use/cover map.

**Table 9.3** QuickBird image (2004): OBIA classification rules including features and membership thresholds

| Final class | Subclasses | Feature | Function[a] and threshold |
|---|---|---|---|
| Barren | Lava | Brightness | <260 |
| | | Mean GLCM texture | 1.35 ʅ 9 |
| | | NDVI | <0.3 |
| | Soil | Mean simple ratio | 1 \ 1.5 |
| | | Brightness | 240 ʃ 400 |
| | | NDVI | 0.1 ʅ 0.5 |
| Built-up | Building | Area | <306 $m^2$ |
| | | Length | <36 $m^2$ |
| | | Max difference (to neighbors) | 0 ʅ 1.25 |
| | | Mean red band | 190 /-\ 2,250 |
| | Road | Classified as lava or soil | 3–21 |
| | | Length/width | |
| Crops/pasture/grass | Grass—bright | Brightness | 275 ʃ 400 |
| | | Mean red band | 89 ʃ 200 |
| | | NDVI | 0.42–0.67 |
| | Grass—dark | Brightness | 345 ʃ 460 |
| | | Mean green band | 229 ʃ 300 |
| | | Mean red band | 70 ʃ 110 |
| | | NDVI | 0.42–0.67 |
| | Crops/pasture | Brightness | 425 ʃ 460 |
| | | Mean green band | 240 /-\ 330 |
| | | Mean red band | 80 ʃ 110 |
| | | NDVI | 0.5–0.766 |
| Dry pasture/grass | | Brightness | 289 ʃ 370 |
| | | NDVI | 0.1–0.8 |
| Forest/shrub | Trees—green | Mean green band | 260 /-\ 360 |
| | | NDVI | 0.7–0.78 |
| | Trees—yellow | Brightness | 270 ʃ 380 |
| | | Mean green band | 255 ʃ 375 |
| | | NDVI | 0.5–0.7 |
| | | Distance to right image border | 2,500–4,700 m |
| | | Distance to bottom image border | 1,750–3,650 m |
| Guava | | Brightness | 250 ʅ 360 |
| | | Mean green band | 230 ʅ 300 |
| | | Mean NIR band | 480 ʅ 825 |
| | | NDVI | 0.53–0.72 |
| Rose apple | | Brightness | 250 ʃ 340 |
| | | Mean green band | 225 ʅ 310 |
| | | NDVI | 0.6–0.74 |
| | | Distance to right image border | 3,850–6,900 m |
| | | Distance to bottom image border | 1,500–5,500 m |

[a]Fuzzy membership functions: ʅ = lower than (nonlinear), ʃ = greater than (nonlinear), \ = lower than (linear), / = greater than (linear), /-\ = approximate range

The same object-based segmentation and classification approach was applied to the QuickBird image by adjusting the input parameters and threshold values. Image objects at levels 1 and 2 were derived from the image data according to the segmentation parameters in Table 9.2. Training data corresponding areas of invariant land cover (e.g., stable guava patches, established roads) were used to define the membership rules for each class. Objects with SR values between 1.5 and 8.1 were classified as "vegetation," while all other objects were assigned to the "non-vegetation" category. The objects were further classified at levels 1 and 2 based on the classification scheme rules (Table 9.4) and merged into a single output classification, as with the WorldView-2 image.

Accuracy of the 2010 (WorldView-2) classification was assessed with field reference points ($n=177$) not used as training data during image classification. Standard error matrices were calculated to determine the overall accuracy, producer's and user's accuracies, and overall kappa statistic on a per-pixel basis. Field data to test the accuracy of the 2004 (QuickBird) classification were not available. Post-classification LULC change analysis was performed by overlaying the classified images from 2004 and 2010 and calculating "from–to" change at the pixel level. Change statistics were also generated for the two management zones, Santo Tomás and the Galápagos National Park.

## *Sociodemographic Data and Analysis*

Data from publicly available secondary data sets and information from interviews with local residents were leveraged to contextualize land use/cover change in Isabela's highlands. The socioeconomic, demographic, and agricultural production factors that likely influence household land use decisions were considered. The secondary data used in this study—Population and Housing Census (2001 and 2010), National Agricultural Census III (2000), and the Galápagos Living Standards Survey (2009)—are publicly available data sets collected and published by the Ecuadorian census agency (INEC).

Demographic changes in Santo Tomás were drawn from the population and housing censuses conducted in 2001 and 2010. Descriptive statistics on the size and age distribution of the population, number and size of households, and primary occupations were calculated in SPSS Statistics v.19 (IBM SPSS Statistics, Chicago, Il.) from individual- and household-level data spatially located at the community level. Information on agricultural production was taken from the agricultural census conducted in 2000 and the 2009 living standards survey. The number and proportion of absentee landowners, products cultivated and quantities harvested, number and types of livestock produced, and the number of farms with hired labor were described from basic statistics generated from household-level data for the entire community of Santo Tomás .

The secondary demographic and agricultural data were supplemented by household interviews conducted with Santo Tomás landholders during July and August 2008. A questionnaire with structured and open-ended questions was administered

**Table 9.4** WorldView-2 image (2010): OBIA classification rules including features and membership thresholds

| Final class | Subclasses | Feature | Function[a] and threshold |
|---|---|---|---|
| Barren | Lava | Brightness | <280 |
| | | Mean GLCM texture | 1.35 ʅ 9 |
| | | Mean red-edge band | 124 ʅ 375 |
| | Soil | Brightness | 290 ʃ 445 |
| | | NDVI | 0.2 ʅ 0.6 |
| Built-up | Building | Area | <306 $m^2$ |
| | | Length | <36 m |
| | | Max difference (to neighbors) | 0 ʅ 1.75 |
| | | Mean red band | 100 /-\ 2,000 |
| | Road | Classified as lava or soil | |
| | | Length/width | 3–21 |
| Crops/pasture/ grass | Grass—bright | Brightness | 310 ʃ 420 |
| | | Mean red band | 65 ʃ 180 |
| | | NDVI | 0.5–0.7 |
| | Grass—dark | Brightness | 355 ʃ 460 |
| | | Mean green band | 229 ʃ 300 |
| | | Mean red band | 70 ʃ 110 |
| | | NDVI | 0.7–0.76 |
| | Crops/pasture | Brightness | 425 ʃ 460 |
| | | Mean green band | 240 /-\ 330 |
| | | Mean red band | 80 ʃ 110 |
| | | NDVI | 0.5–0.766 |
| Dry pasture/ grass | | Brightness | 335 ʃ 405 |
| | | Mean red-edge band | >473 |
| | | NDVI | 0.26 / 0.6 |
| Forest/shrub | Trees—green | Mean green band | 233 /-\ 300 |
| | | NDVI | 0.766–0.84 |
| | Trees—yellow | Brightness | 275 ʃ 455 |
| | | Mean green band | 230 ʃ 300 |
| | | NDVI | 0.54–0.735 |
| | | Distance to right image border | 2,500–4,700 m |
| | | Distance to bottom image border | 1,750–3,650 m |
| Guava | | Brightness | 270 ʅ 425 |
| | | Mean green band | 195 ʅ 260 |
| | | Mean NIR-2 band | 540 ʅ 1,045 |
| | | NDVI | 0.61–0.8 |
| Rose apple | | Brightness | 200 ʃ 427 |
| | | Mean green band | 200 ʅ 240 |
| | | NDVI | 0.7–0.8 |
| | | Distance to right image border | 3,850–6,900 m |
| | | Distance to bottom image border | 1,200–5,500 m |

[a]Fuzzy membership functions: ʅ = lower than (nonlinear), ʃ = greater than (nonlinear), \ = lower than (linear), / = greater than (linear), /-\ = approximate range

to the heads of 45 households and/or their spouses (representing approximately 23% of landholders in Santo Tomás ) using a purposeful sampling scheme.[1] The interviews included questions about household demographics, land use patterns, invasive plants, and changes in the community over the last decade. Patterns in the data were analyzed with particular attention to changes in agricultural land use and invasive plant cover.

# Results

## *Land Use/Cover Classification and Change Detection*

Overall accuracy of the 2010 classification was 88.70%, with a kappa statistic of 0.87 (Table 9.5). Although overall accuracy exceeded the 85% threshold (Foody 2002), forest/shrub cover was not as accurately classified. Forest and shrub patches were confused with guava in areas where taller trees cast shadows on neighboring vegetation and resulted in some forested objects being misclassified as guava because of similar spectral responses. The forest class also suffered from errors of commission, particularly due to the misclassification of agriculture and grassland as forest and shrub. Spectral confusion between these classes may be the result of the spectral heterogeneity of pixels used to train the crops/pasture/grass class. Field data to test the accuracy of the 2004 classification were not available, but the same classification approach was applied to both images in an effort to produce classifications with comparable accuracies. Visual assessment of the 2004 classification showed that invariant features, such as the Sierra Negra caldera, main roads, and surface mines, were correctly classified.

Comparison of the land cover classifications reveals significant land use/cover conversion between 2004 and 2010 (Table 9.6, Fig. 9.2). Across the study area, guava remained the most dominant land cover, increasing from 35.5 to 39.7% of the landscape. The largest expansion of guava occurred in the national park, where an additional 273 ha of land were invaded between 2004 and 2010 (Table 9.7). Santo Tomás experienced only a small net gain in guava (2.2%). However, guava is by far the most dominant land cover in the community and covers nearly 47% of the agricultural zone. The largest patches of stable guava, corresponding to fields and entire farms in some cases, are located in western and northern Santo Tomás . New areas of invasion (since 2004) are smaller and occur adjacent to existing patches within Santo Tomás and to the north and south along the national park border.

Crops/pasture/grass occupied an extensive area in 2004 (28.8%) that declined to just over 20% of the landscape in 2010 (Table 9.6). Agriculture in Santo Tomás

[1] A random sampling strategy was originally intended but had to be adapted after it was revealed that cadastral maps used to locate properties were more than 30 years old and no longer accurate. The small number of households still living in Santo Tomás as well as landholders now residing in Puerto Villamil were interviewed to approximate planned sampling levels.

**Table 9.5** Confusion matrix for 2010 WorldView-2 classification

| | Reference class | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Mapped class | Barren | Built-up | Crops/ pasture/ grass | Dry pasture/ grass | Forest/ shrub | Guava | Rose apple | Total | User's accuracy |
| Barren | 31 | 0 | 0 | 1 | 0 | 0 | 0 | 32 | 96.9% |
| Built-up | 1 | 33 | 0 | 0 | 0 | 0 | 0 | 34 | 97.1% |
| Crops/pasture/ grass | 0 | 0 | 26 | 0 | 3 | 0 | 0 | 29 | 89.7% |
| Dry pasture/grass | 0 | 0 | 1 | 13 | 0 | 2 | 0 | 16 | 81.2% |
| Forest/shrub | 0 | 1 | 3 | 1 | 20 | 1 | 1 | 27 | 74.1% |
| Guava | 0 | 0 | 3 | 0 | 2 | 23 | 0 | 28 | 82.1% |
| Rose apple | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 11 | 100.0% |
| Total | 32 | 34 | 33 | 15 | 25 | 26 | 12 | 177 | – |
| Producer's accuracy | 96.9% | 97.1% | 78.8% | 86.7% | 80.0% | 88.5% | 91.7% | – | – |
| Overall = 88.70% | | | | | | | | | |
| Kappa = 0.87 | | | | | | | | | |

**Table 9.6** Land use/cover area and change (net area, percent relative to 2004), 2004–2010, Isabela highlands

| | Total area (ha) | | Percent of landscape (%) | | Change: 2004–2010 | |
|---|---|---|---|---|---|---|
| Land use class | 2004 | 2010 | 2004 | 2010 | Absolute (ha)[a] | Relative (%)[b] |
| Barren | 208.10 | 467.75 | 2.8 | 6.2 | 259.65 | 124.8 |
| Built-up | 23.65 | 26.11 | 0.3 | 0.3 | 2.45 | 10.4 |
| Crops/pasture/ grass | 2,167.76 | 1,569.64 | 28.8 | 20.8 | –598.12 | –27.6 |
| Dry pasture/ grass | 418.53 | 278.63 | 5.6 | 3.7 | –139.91 | –33.4 |
| Forest/shrub | 1,992.51 | 2,119.34 | 26.4 | 28.1 | 126.83 | 6.4 |
| Guava | 2,673.34 | 2,992.09 | 35.5 | 39.7 | 318.75 | 11.9 |
| Rose apple | 49.71 | 80.06 | 0.7 | 1.1 | 30.35 | 61.1 |
| Total | 7,533.61 | 7,533.61 | 100.0 | 100.0 | – | – |

[a]Net change between periods was calculated as (Area2010 – Area2004)
[b]Percent change relative to 2004 was calculated as 100 × (Area2010 – Area2004)/Area2004



declined by 28.8% (relative to 2004) (Table 9.7). A few, small patches of land were brought into agricultural production between 2004 and 2010 (totaling 389 ha), primarily in northern and eastern Santo Tomás . However, more than 800 ha of land in crops/pasture/grass were converted to other land covers like guava, dry pasture (a less intensive agricultural use), and forest. In the national park, where agricultural land use is prohibited, grasslands were transformed to guava along the caldera and to forest/shrub in the transition zone to the east (Fig. 9.2).

Although forest cover experienced a net increase across the study site, from 26.4% of the landscape in 2004 to 28.1% in 2010, opposing trends were observed in the national park and Santo Tomás (Table 9.6). Forest/shrub cover in the national park remained

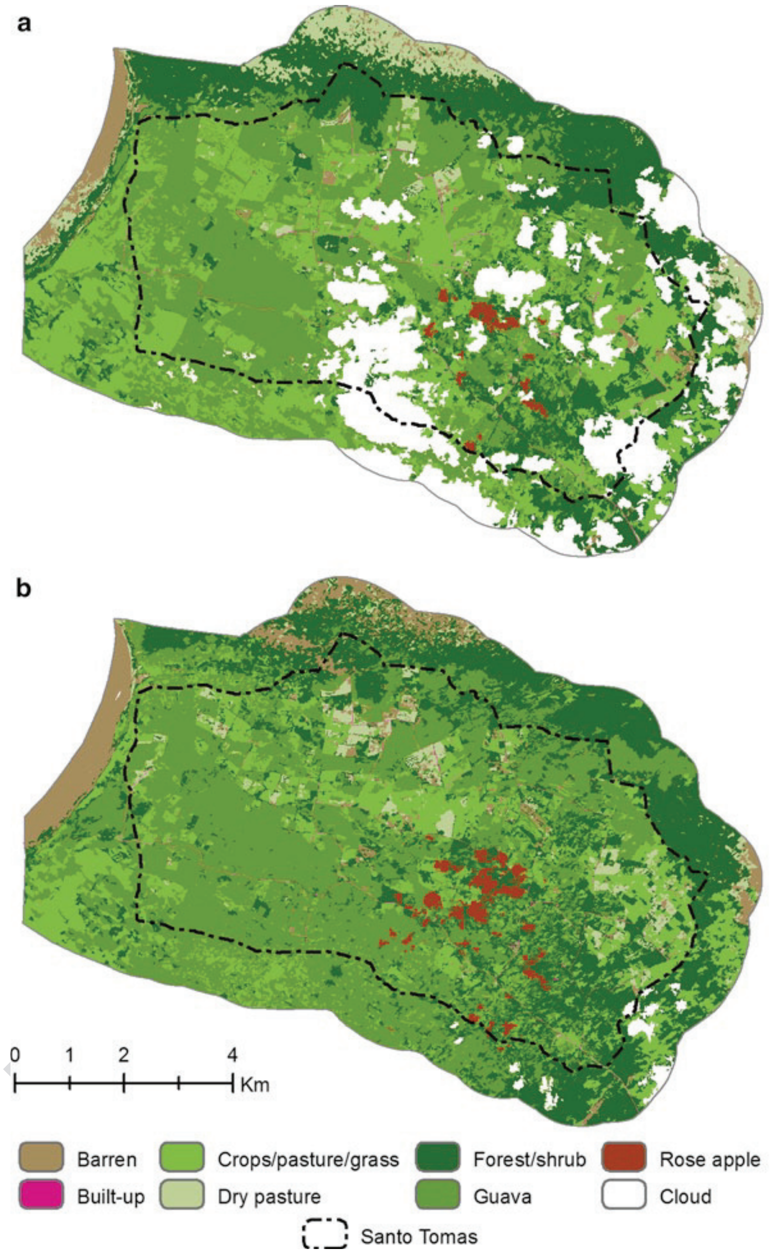


**Fig. 9.2** Land use/cover in the study area in 2004 (**a**) and 2010 (**b**)

**Table 9.7** Net change in land cover from 2004 to 2010 as a proportion of each management zone

| Land use class | Area of management zone (ha) | | Percent of management zone (%) | | Change: 2004–2010 | |
|---|---|---|---|---|---|---|
| | 2004 | 2010 | 2004 | 2010 | Absolute (ha)[a] | Relative (%)[b] |
| *Santo Tomás* | | | | | | |
| Barren | 48.49 | 87.75 | 1.1 | 1.9 | 39.26 | 81.0 |
| Built-up | 21.00 | 23.91 | 0.5 | 0.5 | 2.91 | 13.9 |
| Crops/pasture/grass | 1,449.45 | 1,032.70 | 32.2 | 22.9 | −416.75 | −28.8 |
| Dry pasture/grass | 82.35 | 216.43 | 1.8 | 4.8 | 134.08 | 162.8 |
| Forest/shrub | 798.01 | 963.62 | 17.7 | 21.4 | 165.61 | 20.8 |
| Guava | 2,058.99 | 2,104.27 | 45.7 | 46.7 | 45.28 | 2.2 |
| Rose apple | 49.70 | 79.29 | 1.1 | 1.8 | 29.59 | 59.5 |
| Total | 4,507.97 | 4,507.97 | 1.1 | 1.9 | – | – |
| *Galápagos National Park* | | | | | | |
| Barren | 159.62 | 380.00 | 5.3 | 12.6 | 220.38 | 138.1 |
| Built-up | 2.65 | 2.20 | 0.1 | 0.1 | −0.45 | −17.2 |
| Crops/pasture/grass | 718.31 | 536.94 | 23.7 | 17.7 | −181.37 | −25.2 |
| Dry pasture/grass | 336.19 | 62.19 | 11.1 | 2.1 | −274.00 | −81.5 |
| Forest/shrub | 1,194.51 | 1,155.72 | 39.5 | 38.2 | −38.79 | −3.2 |
| Guava | 614.35 | 887.82 | 20.3 | 29.3 | 273.47 | 44.5 |
| Rose apple | 0.01 | 0.78 | 0.0 | 0.0 | 0.77 | 9,514.3 |
| Total | 3,025.64 | 3,025.64 | 5.3 | 12.6 | – | – |

[a]Net change between periods was calculated as (Area2010 − Area2004)
[b]Percent change relative to 2004 was calculated as 100 × (Area2010 − Area2004)/Area2004



largely unchanged, declining by only 3.2%. In Santo Tomás , forest/shrub increased as a result of conversion of agriculture and guava, as previously mentioned.

The increase in barren land since 2004 (124.8%) resulted from new lava rock that covered the caldera of Sierra Negra following its eruption in 2005, an area in the north that transitions between dry vegetation and bare soil, and small clearings in Santo Tomás . Built features did not change substantially between 2004 and 2010, making up only 0.3% of the landscape (0.5% of Santo Tomás ) (Table 9.7). Rose apple, which also made up a small percentage of the total landscape in 2004, spread within central Santo Tomás . The area of invasion increased from 49.7 ha in 2004 (1.1%) to 79.29 ha in 2010 (1.8%). Although rose apple was restricted to Santo Tomás in 2004, by 2010, it had expanded into the national park, covering 0.78 ha of land.

## *Sociodemographic Trends*

The census data reveal interesting population shifts in Santo Tomás . Between 2001 and 2010, total population declined by 17.6%, at a rate of 2.2% per annum (Table 9.8). The number of households in Santo Tomás also declined, while mean

**Table 9.8** Demographic indicators and agricultural production for Santo Tomás , 2000–2009

| | 2001 | 2010 |
|---|---|---|
| Population (total)[a] | 199 | 164 |
| Number of households | 66 | 54 |
| Household size (mean) | 2.97 | 3.04 |
| Age (median) | 27 | 32 |
| | 2000 | 2009 |
| Landholders living in Santo Tomás (%) | 40.7 | 22.3 |
| Farms cultivating annuals/perennials (%) | 81.5 | 80.8 |
| Harvest sold (%) | 61.7 | 21.1 |
| Cattle | 1,972 | 888 |
| Hogs | 236 | 105 |
| Farms with paid laborers (%) | 37 | 25.4 |

[a]Includes floating (tourist) population

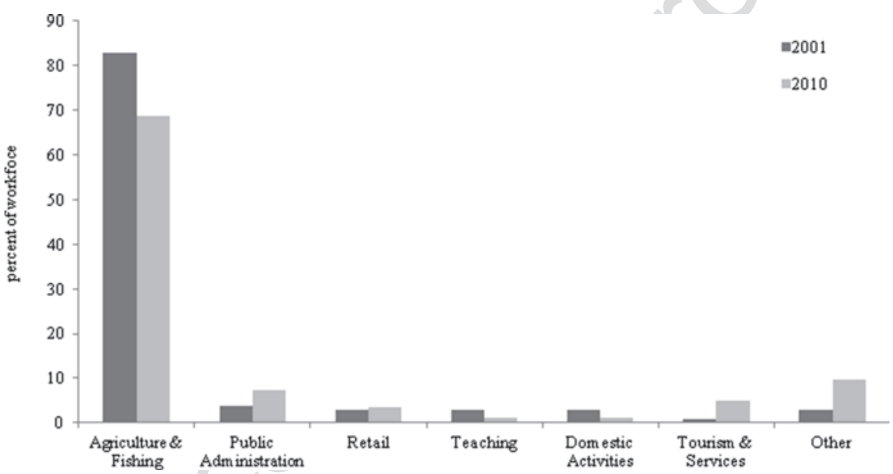


**Fig. 9.3** Proportion of Santo Tomás workforce employed in various sectors in 2001 and 2010

household size was relatively unchanged. A total of 66 households resided in Santo Tomás with an average of 2.97 members in 2001. By 2010, only 54 households remained. Median age for Santo Tomás increased slightly, from 27 years in 2001 to 32 years in 2010. Agriculture and fishing remained the largest employment sectors in Santo Tomás , despite significant increases in other categories (Fig. 9.3). While 83% of working age residents (15–64) reported agriculture or fishing as their primary occupation in 2001, only 68% participated in the sector by 2010.

The agricultural census and living standards survey provide additional details about the state of agricultural production and farming households. Between 2000 and 2009, the proportion of landholders who still lived on the farms declined from 40.7% to just over 22% (Table 9.8). Although the proportion of farms cultivating annual and/or perennial crops decreased only slightly, the majority of crops harvested in 2009 were not sold. With respect to livestock production, there was a net reduction in the number of cattle and hogs raised in Santo Tomás . Finally, in 2009, fewer farms hired laborers (25.4%) to assist with agricultural activities like clearing and planting than in 2000 (37%).

## Discussion

The rural community of Santo Tomás and adjacent land managed by the Galápagos National Park experienced substantial land use/cover changes from 2004 to 2010. The change detection analysis revealed a substantial decline (nearly 29%) in agricultural land use observed in 2010 compared with 2004 (Table 9.6). While some new areas were brought into production between 2004 and 2010, a significant amount of land (800 ha) was converted to less productive pastures (dry pasture) or transformed to woody vegetation including guava and forest/shrub (Fig. 9.2). Production data (Table 9.8) show that as agricultural land use has declined, production has also become less intense. The majority of annual and perennials grown in Santo Tomás in 2009 were not sold, and fewer livestock were reared than in the earlier period. Further, off-farm employment opportunities have increased, and fewer working age adults in Santo Tomás participate in the agricultural sector (Fig. 9.3).

These results seem to suggest that over the past decade, many households have abandoned agriculture, choosing instead to participate in off-farm activities to support the household (Table 9.8). During interviews, many heads of household noted a lack of diversity in what farms produce. Further, a market for their products does not exist on Isabela or other islands, limiting the income that can be derived from agriculture. Isabela's most recent strategic plan noted that agricultural production is not sufficient to reliably satisfy local demand throughout the year, so fruits, vegetables, and dairy products have to be imported from continental Ecuador (Vilema et al. 2003). In interviews, landholders also described a variety of barriers to farming, including the lack of freshwater for household use and irrigation, the presence of various pests, the lack of financing (i.e., access to credit), and limited technical assistance.

The abandonment of agricultural activities appears to be coupled with rural emigration and abandonment of land in the highlands. Population decline in Santo Tomás (Table 9.8) and an increase in the proportion of the population residing in the urban community (nearly 93%) likely reflect outmigration from rural areas. Interview data suggest that most landholders live in Puerto Villamil, the urban community south of Santo Tomás , and visit their farms only occasionally. Agriculture on Isabela is not mechanized, and rather than hiring additional laborers to maintain productivity (Table 9.8), many farms allow land to lie fallow indefinitely. The availability of employment opportunities in tourism and the service industry catering to tourists (Fig. 9.3) may be another factor driving emigration (Kerr et al. 2004). Isabela is not unique in this respect, as urban–rural migration and farm abandonment have been observed elsewhere in Galápagos (Rodriguez 1989; Kerr et al. 2004; Borja and Perez 2000).

The highlands have experienced significant increases in guava and forest/shrub cover at the expense of agricultural land (Table 9.6). According to interviews, farmers are no longer purposefully cultivating guava. Rather, it has become naturalized and now grows unaided throughout the highlands. Guava and other introduced plants, like rose apple, can spread rapidly in abandoned lands, directly contributing to the expansion of invasive species into the national park (Borja and Perez 2000; Walsh et al. 2008). Discussions with households demonstrate that farmers recognize the important of clearing guava, but doing so is time consuming and expensive. Due to the cost of manual removal and the need for control measures at regular intervals (every 6 months), some owners have chosen to abandon lands that are seriously invaded. The land cover analysis also demonstrated increasing forest/shrub cover in the last decade. Encroachment of introduced and invasive trees into formerly treeless vegetation zones in the highlands (Miconia and fern–sedge communities, sensu Wiggins and Porter 1971) may alter local environmental conditions and lead to declines in species diversity and native/endemic plant cover (Jäger et al. 2009).

## Conclusions

This chapter provides an enhanced understanding of contemporary land use/cover in the highlands of southern Isabela Island and points to a few of the processes driving land cover conversion—land abandonment, declining agricultural production, and the spread of invasive plants. The findings presented here are consistent with those reported by Villa and Segarra (2010) who found that agricultural land on San Cristobal Island was abandoned between 1987 and 2000 due to low returns on production and labor constraints. Future studies should attempt to quantify the socioeconomic and environmental factors that drive patterns of land use/cover change and landscape dynamics on Isabela Island. Empirical data on the impacts of changing land use/cover on biodiversity and ecosystem functioning in the highlands is limited and warrants attention.

In addition, this study offers a methodological approach to the assessment of land use/cover change that could be applied elsewhere in the Galápagos. Remote sensing provides an effective method for mapping spatial patterns of land use/cover and for quantifying spatial patterns and rates of change. The description of land use change and its driving forces can provide important information for land managers and decision makers in the archipelago. Several applications in Galápagos have been recognized, ranging from the generation of more complete information on species distributions (Trueman et al. 2010) and the development of weed risk assessment systems (Tye et al. 2002) to regional planning of natural resources (Villa and Segarra 2010) and identifying barriers to conservation and restoration projects (Gardener et al. 2010).

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