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HURRICANE RECOVERY AT CABEZAS DE SAN JUAN, PUERTO RICO, AND RESEARCH OPPORTUNITIES AT CONSERVATION TRUST RESERVES

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ABSTRACT

The Cabezas de San Juan Natural Reserve (El Faro), an exposed peninsular area located in the Subtropical dry forest of northeastern Puerto Rico, was impacted by hurricanes Hugo (1989) and Georges (1998). From 1998 to 2008, a 0.10 ha plot was used to assess forest structure, species composition, and stem growth. During post-hurricane recovery, stem density, tree height, basal area, and aboveground woody biomass all increased on the plot. The 10-yr mean annual dbh (i.e., diameter at 1.4 m above the ground) growth was 0.11±0.00 cm yr^{-1} for the 181 stems of 16 species that survived the measurement period. All of the originally recorded tree species survived and two new ones entered the plot in 2004, one of which had disappeared by 2008. *Leucaena leucocephala* (Lam.) DeWit, an aggressive secondary species, showed the greatest increase in stems, gaining 470 ha^{-1} in 10 years. Las Cabezas de San Juan is one of 29 properties totaling 9,820 ha that is managed by the Conservation Trust of Puerto Rico. Conservation Trust properties offer educational and research opportunities for cooperators.

Key words: *Subtropical dry forest,* Leucaena leucocephala*, hurricanes, diameter growth, Puerto Rico Conservation Trust properties.*

INTRODUCTION

The 178-ha northeastern tip of Puerto Rico, locally known as Las Cabezas de San Juan Natural Reserve (hereafter called El Faro), is an area with a long history. Indians crossing the Caribbean were the first sailors to use the promontories as reference points; subsequently, during the island's settlement and colonization, the offshore waters became the final resting place for numerous sunken vessels (Cardona Bonet 1989). El Faro's historic lighthouse, built in 1880, stands on the local highpoint (Weaver *et al*. 1999a). The panoramic view from the lighthouse includes the northeastern coast and surrounding waters, the offshore chain of islands known as the Cordillera, and the forests of the nearby Luquillo Mountains. In 1981, the lighthouse was recorded in the National Register of Historic Sites.

In the late 1960s, El Faro was privately owned and threatened with development. In 1986, the nature reserve was established to protect the scenic beauty of the area and to provide educational opportunities for the public (Cerame Vivas 1988). El Faro is now owned by a public corporation (CODREMAR) attached to the Department of Natural and Environmental Resources, and is administered by the Conservation Trust of Puerto Rico. About 50,000 island residents and tourists visit El Faro annually (Weaver *et al*. 1999b).

The purpose of this collaborative work with the Conservation Trust was to: summarize information on forest structure, species composition, and tree increment from a permanent forest plot; and to compare tree increment with similar sites in Puerto Rico and the U.S. Virgin Islands. Other Conservation Trust reserves are briefly mentioned to show past research work and existing educational opportunities for island students.

SITE

El Faro, which ranges in elevation from sea level to 67 m, lies within the Subtropical dry forest life zone and contains mangrove swamp, tidal flats, secondary littoral woodland, and secondary semi-evergreen forest (Ewel and Whitmore 1973; Weaver *et al*. 1999a, 1999b). The permanent plot was situated on slightly concave terrain sloping gently northward within secondary semi-evergreen forest.

El Faro is exposed to persistent winds and receives an average rainfall of about 900 mm yr^{-1} (Briscoe 1966, Calvesbert 1970). The site has been exposed to the impact of several major hurricanes during the past century (Bates 1929, Salivia 1972, Walker *et al*. 1991). Recent storms include Hurricane Hugo of 1989 with sustained winds >225 km hr^{-1} and a trajectory directly over El Faro (Brennan 1991), and Hurricane Georges of 1998 with sustained winds of 180 km hr^{-1} and a trajectory south of the reserve (U.S. Geological Survey 1999). Hurricane Hugo severely impacted the vegetation and Hurricane Georges caused damage to a lesser extent. For about a century before the reserve was established local residents used the peninsula to gather fuel wood and graze livestock.

METHODS

In December 1998, a 0.10 ha plot (i.e., 50 x 20 m, divided into 10 subplots each 10 x 10 m) was established about 200 m north of the lighthouse. All stems ≥4.1 cm in dbh (i.e., diameter at 1.4 m above the ground) were identified to species and tagged (Fig. 1). Dbh and height were measured to the nearest 0.1 cm and 0.1 m, respectively. Subsequent measurements were made in 2004 and 2008 when ingrowth (i.e., new stems attaining minimum dbh) and mortality were tallied. Equations derived from previous tree sampling in subtropical dry-moist transition forest at Cinnamon Bay, St. John, U.S. Virgin Islands, were used to estimate total aboveground woody biomass (hereafter, biomass) (Weaver 1996). Tree species were identified using local sources (Francis and Lowe 2000, Little and Wadsworth 1964, Little *et al*. 1974). Nomenclature follows relatively recent taxonomic studies (Liogier 1985-1997).

RESULTS

In 1998, the total number of stems was 2,170±217.1 ha^{-1} (range on subplots, 1,100-3,200 stems ha^{-1}) and basal area averaged 16.50±2.26 m^2 ha^{-1} (range on subplots, 9.77-33.05 m^2 ha^{-1}) (Table 1). The largest trees on the plot included a *Bursera simaruba* at 39.0 cm, two *Pisonia subcordata* at 29.7 and 28.8 cm, and a *Bourreria succulenta* at 24.7 cm. By 2008, stems had increased by an average of 77 ha^{-1} yr^{-1} and basal area by an average of 0.30 m^2 ha^{-1} yr^{-1} (Table 1). Ingrowth during the 10-year period averaged 115 stems ha^{-1} yr^{-1} and mortality 38 stems ha^{-1} yr^{-1}. The surge in ingrowth resulted in proportionately more stems in the smaller dbh classes (Fig. 2). During the same period, the average height of the stand grew from 5.4±0.09 m (range of 217 stems, 1.9-9.1 m) to 6.0±0.07 m (range of 294 stems, 2.7-9.1 m), and biomass increased from 64 to 67 t ha^{-1}.

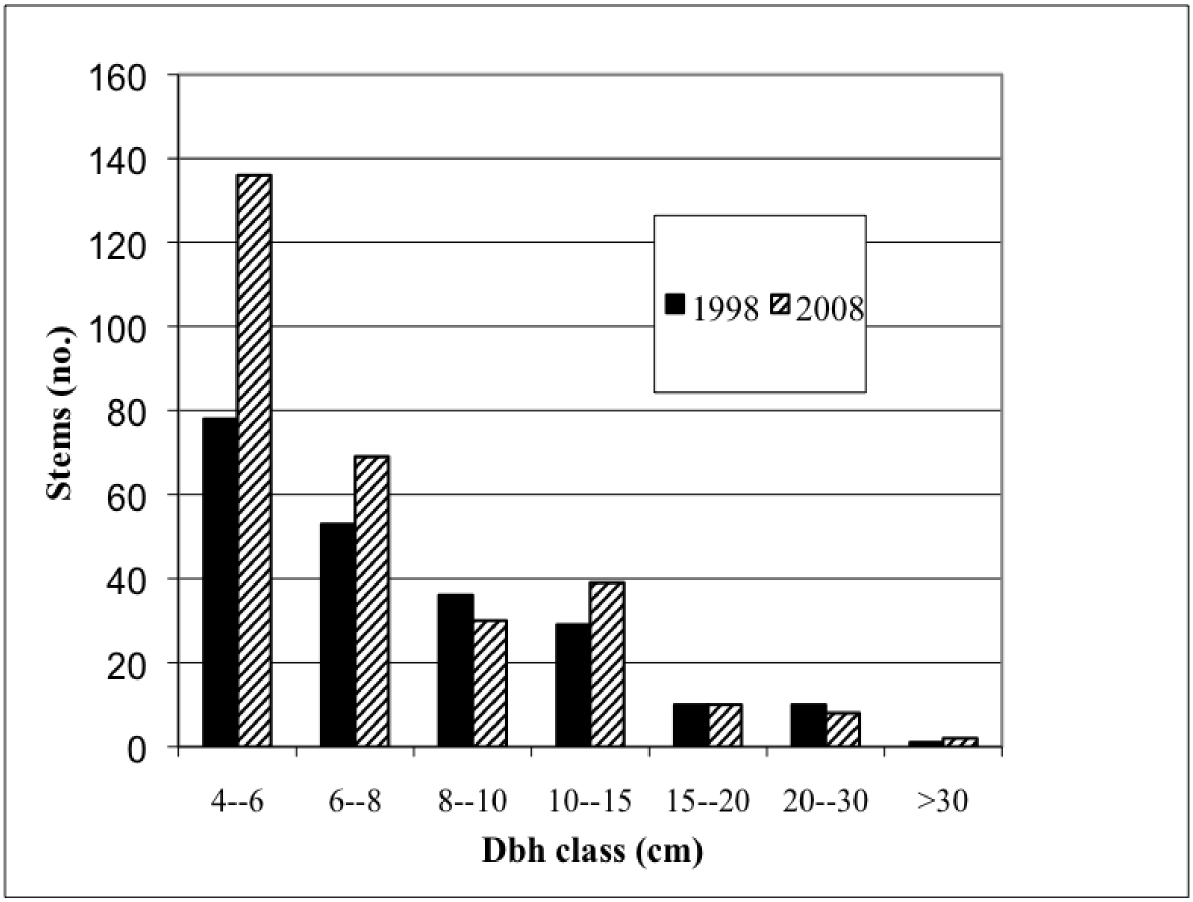
Figure 1. The permanent plot located in secondary subtropical dry forest (i.e., secondary semi-evergreen forest) at Las Cabezas de San Juan (El Faro) Natural Reserve in northeastern Puerto Rico (photo taken in 2003).

Table 1. Changes in species composition and structure, and dbh growth on the El Faro plot between 1998 and 2008.

Tree species	1998 Stand		2004 Stand		2008 Stand		Mean 10-yr
	Stems ($no.ha^{-1}$)	BA ($m^2\ ha^{-1}$)	Stems ($no.ha^{-1}$)	BA ($m^2\ ha^{-1}$)	Stems ($no.ha^{-1}$)	BA ($m^2\ ha^{-1}$)	dbh growth cm yr^{-1}±SE (no.)[1]
Bourreria succulenta Jacq.	390	3.61	440	4.31	490	4.94	0.19±0.02 (37)
Bursera simaruba (L.) Sarg.	40	1.92	50	2.07	50	2.25	0.15±0.06 (4)
Capparis hastata Jacq.	90	0.23	90	0.27	110	0.34	0.10±0.02 (9)
Capparis indica (L.) Fawcett & Rendle	20	0.08	20	0.09	20	0.09	0.02±0.02 (2)
Cassine xylocarpa Vent.	200	0.71	200	0.81	190	0.88	0.09±0.02 (18)
Citharexylum fruticosum L.	30	0.14	30	0.15	40	0.17	0.03±0.03 (3)
Coccoloba microstachya Willd.	50	0.13	50	0.15	70	0.22	0.11±0.05 (5)
Erothroyxlum rotundifolium Lunan	40	0.10	100	0.21	120	0.22	0.17 (1)
Ginoria rohrii (Vahl) Koehne	370	1.70	340	1.50	300	1.38	0.05±0.01 (28)
Guapira fragrans (Dum.-Cours.) Little	10	0.03	30	0.09	60	0.15	0.20 (1)
Leucaena leptocephala (Lam.) DeWit	180	0.50	410	0.97	650	1.50	0.20±0.01 (11)
Maytenus cymosa (Krug) Urban	10	0.03	10	0.04	10	0.04	0.09 (1)
Pictetia aculeata (Vahl) Urban	110	0.25	110	0.27	100	0.28	0.05±0.01 (10)
Pisonia subcordata Sw.	320	5.61	310	5.00	330	5.33	0.12±0.02 (27)
Securinega acidoton (L.) Fawcett & Rendle	30	0.09	90	0.24	150	0.38	0.12±0.08 (3)
Tabebuia heteropylla (DC.) Britton	160	1.13	140	0.97	140	1.01	0.06±0.01 (14)
Zanthoxylum monophyllum (Lam.) P. Wilson	120	0.24	120	0.31	100	0.27	0.08±0.01 (7)
Subtotals (181)	2170	16.50	2540	17.45	2930	19.45	0.11±0.00
Ingrowth -- new species in 2004							
Croton astroites Dryand	---	---	10	0.02	---	---	---
Eugenia biflora (L.) DC.	---	---	10	0.02	10	0.02	---
Totals	2170	16.50	2560	17.49	2940	19.47	---

[1]Growth of survivors from the first measurement in 1998; SE = standard error; n = number of stems in sample.

Figure 2. Number of stems by diameter (dbh) class at Las Cabezas de San Juan Natural Reserve (El Faro) in 1998 and 2008.



The 10-yr mean annual dbh growth (MAI) was 0.11±0.00 cm yr^{-1} for the 17 species that survived the entire period (Table 1). Individual species ranged between 0.02 and 0.20 cm yr^{-1}. *B. succulenta*, *B. simaruba*, *Guapira fragrans*, and *Leucaena leucocephala* all grew at comparatively rapid rates. Three species increased numerically by 3- to 5-fold: *Erythroxylum rotundifolium*, *L. leucocephala*, and *Securinega acidoton*. *Croton astroites* and *Eugenia biflora* grew into the plot in 2004, but only the latter survived until 2008.

DISCUSSION

Long-term data on forest structure, species composition, and estimates of MAI are available from several natural forest sites within Puerto Rico and the U.S. Virgin Islands (Weaver 2009). Many of these sites are within the wet and rain forests of the Luquillo Experimental Forest (LEF). Only four sites could be considered as either dry, or dry to moist forest transition areas, and only three provide data on forest structure and composition accompanied by MAI (Table 2). Historically, studies of dbh growth were concentrated in areas where timber production was considered to be a viable land use.

El Faro and Guánica each receive <1,000 mm yr^{-1} of rainfall. In comparison, Cinnamon Bay watershed receives 1,240 mm yr^{-1} and Cambalache

Table 2. Comparative data for stand structure, species composition, and dbh growth of tree species in dry, or dry to moist transition, forests of Puerto Rico and the U.S. Virgin Islands.

Forest name[1]	**Species**[2] **no.**	**Stems**[3] **no. ha^{-1}**	**BA**[4] **m^2 ha^{-1}**	**Dbh growth cm yr^{-1} (no.)**	**Dbh range**[5] **cm**	**Duration**[6] **yrs**	**Elevation m**
Cabezas de San Juan[7]	17	2365	18.04	0.11 (181)	4-39	1998-2008	30
Commonwealth Reserve System[7]							
Guánica	1	NA[7]	NA[7]	0.04 (34)	4-11	1944-1975	150
Cambalache ridge	13	4845	17.9	0.09 (237)	4-15	1950-1976	60
St. John, U.S. Virgin Islands[7]							
Cinnamon Bay	63	3274	30.4	0.07 (1742)	4-80	1983-2003	60-240

[1]Sources: Commonwealth reserve system (Weaver 1979) and Cinnamon Bay (Weaver 1990, 2006; Weaver and Chinea-Rivera 1987).
[2]Number of species that survived the respective measurement periods.
[3]Mean number of stems at beginning and end of study.
[4]Mean of BA (basal area) at beginning and end of study.
[5]Dbh range at beginning of study. Values rounded to nearest whole number.
[6]Duration = number of years monitored.
[7]Plot areas: Cabezas, 0.10 ha; Guánica, no plot; Cinnamon Bay, 16 plots each 0.05 ha in size; Cambalache, 0.10 ha.
[8]At Guánica, individual trees were measured (i.e., plotless sample).

about 1,400 mm yr^{-1} (Weaver 1979, 2006). The latter two sites are in the subtropical moist forest life zone (Ewel and Whitmore 1973). Most of the Cinnamon Bay plots are on well-drained slopes and ridges where tree growth rates and physiognomy are similar to transition (i.e., transition from subtropical dry to subtropical moist) forests. The Cambalache plot, previously disturbed for agricultural activities, is situated on a well-drained ridge underlain by limestone soils. At the time of measurement, the stand was extremely dense and exhibited a physiognomy typical of dry forest.

Changes in Stem Density and Species

In 1994, a preliminary reconnaissance on the north slope of El Faro near the current plot revealed that *L. leucocephala* accounted for 7.6 percent of the stems (Weaver and Coll Rivera 2002). In 1998, the relative abundance of *L. leucocephala* on the plot was to 8.3 percent, and by 2004 and 2008, it had increased to 16.0 and 22.1 percent of the total stems, respectively. *L. leucocephala*, an aggressive secondary species common throughout the West Indies, typically invades abandoned pastures in dry coastal areas (Little and Wadsworth 1964). *L. leucocephala* needs light to regenerate and survive. In the absence of major disturbance, however, the forest canopy will gradually close and gaps will be limited to those caused by the death of individual stems (i.e., background mortality). If plot monitoring continues, future surveys will likely demonstrate a cyclic rise and decline of *L. leucocephala* along with other species that successfully regenerate after disturbance – possibly *B. succulenta*, *G. fragrans*, and *S. acidoton* – all of which increased in stem numbers in the post-hurricane stand.

Increases in stem numbers and species diversity a few years after hurricanes San Felipe and San Cipriano of 1928 and 1932 were observed in the forests of the nearby LEF (Crow 1980, Weaver 1983). The post-hurricane increases in stem numbers and diversity, similar to those at El Faro, were attributed to the regeneration of secondary species and their coexistence with mature species over a period of years. Recently, similar changes have been observed on a permanent tabonuco plot after hurricanes Hugo and Georges (Weaver 2002).

Dbh Growth

The MAI of 0.11 cm yr^{-1} for all survivors at El Faro is comparatively rapid for Subtropical dry forest (Table 2). Previously recorded MAI for *Bucida buceras* trees, one of the largest tree species in the dry Guánica Forest, were less than half that amount (Little and Wadsworth 1964, Weaver 1979). The MAI for all species combined at Cinnamon Bay watershed during 20 years and at Cambalache forest during 26 years were less than at El Faro (Table 2).

The relatively rapid MAI for the El Faro plot may be due to several factors. First, the concave relief of the El Faro plot helps to concentrate runoff and store soil moisture after moderate rainfalls. Next, hurricanes Hugo and Georges opened the stand, reduced basal area, and provided favorable conditions for the regeneration and growth of numerous species. Lastly, the low wood density (i.e., low specific gravity) of *B. succulenta*, *B. simaruba*, and *G. fragrans* probably accounts for their comparatively rapid dbh increment. Tree species characterized by lower wood density have less investment in wood production (Grubb 1977) and generally grow more rapidly in dbh than species with denser woods. The remaining fast growing species, *L. leucocephala*, is secondary, and rapidly colonizes open fields and forest openings.

MAI varies according to many factors, including species and size, stand conditions (i.e., tree density and basal area), and crown exposure and dominance within the canopy (Anonymous 1953, Wadsworth 1947). Other influencing factors are topographic position, stand elevation, and forest types in mountainous areas (Weaver 1979, 1983). Moreover, thinning stimulates growth in stands typically being managed for timber production (Anonymous 1950, Crow and Weaver 1977, Wadsworth 1952).

Table 3. Properties administered by the Puerto Rico Conservation Trust.

Classification of Area[1]	Size (ha)
Protected Natural Area (ANP)	
Bosque Pterocarpus	12.2
Cuevas El Convento	243.2
Hacienda Buena Vista	186.1
Jorge Sotomayor del Toro	25.0
Río Encantado	655.3
Río Guaynabo	10.2
Río Maricao	57.3
San Cristóbal Cañon	590.8
Sierra La Pandura	70.4
Subtotal	**1850.5**
National Wildlife Refuge (RVS)	
El Buey	**323.7**
Natural Reserves (RN)	
Bosque Pterocarpus	310.2
Cabezas de San Juan	174.8
Hacienda La Esperanza	861.8
La Parguera	520.8
Punta Ballenas	65.9
Punta Guaniquilla	169.8
Punto Yeguas	113.9
Subtotal	**2217.2**
Conservation Easements (SC)	
El Rabanal	6.3
El Tambor	87.9
Foreman	16.6
Montes Oscuros	2946.5
Subtotal	**3057.3**
Other Properties	
Antiguo Acueducto San Juan	5.1
Casa Ramón Power y Giralt	0.0
Cerro Las Mesas	4.1
Edificio Antiguo Banco de España	0.1
Finca Los Frailes	275.0
Finca Shapiro	2.0
Medio Mundo y Daguao	1347.0
Subtotal	**1633.3**
Grand Total	**9820.0**

[1]Properties shown on map (Figure 3).

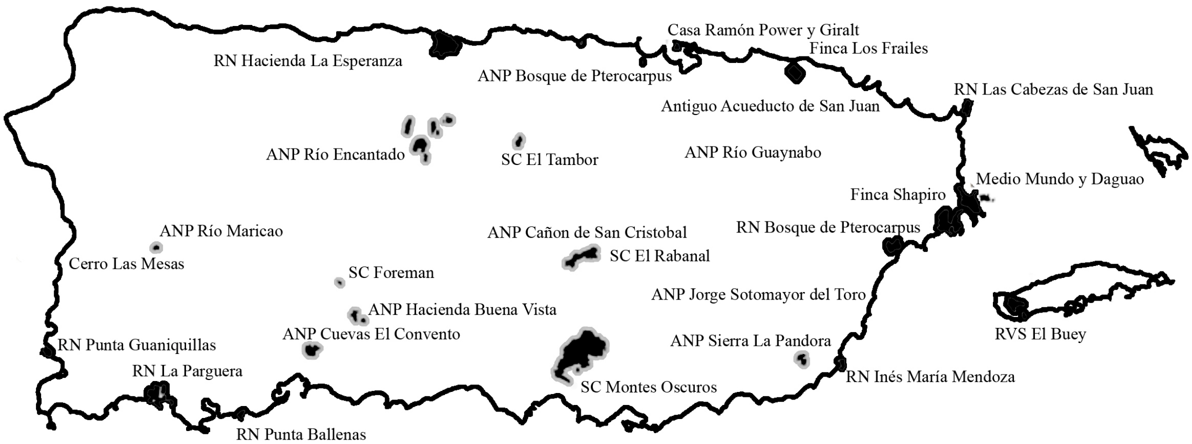
The structure and composition of forests vary considerably along the elevational gradient from the coastline to El Yunque's summits (Gould *et al*. 2006, Wadsworth 1951). Most of the long-term MAI rates on sampled plots along this gradient were between 0.09 and 0.14 cm yr^{-1} for all species combined (Weaver 1983). Exceptions include palm plots and previously thinned tabonuco plots, both of which had rates >0.20 cm yr^{-1}. Broadleaf species in palm forests grew more rapidly than in surrounding broadleaf forests possibly due to the greater amounts of growing space in the canopy caused by the growth form of narrow-crowned palms. In tabonuco forest, thinning reduced basal area and enhanced increment on residual stems.

The pilot management study located in subtropical wet forest contained plots where thinning had been implemented to improve the dbh growth rates of select crop trees (Anonymous 1958). The crop trees were all timber species that attained large size and were capable of growing at relatively rapid rates for extended periods; moreover, the crop trees were selected at ≥10 cm, a larger dbh. Consequently, trees in the pilot study areas grew very rapidly with a MAI by species between 0.37 and 0.42 cm yr^{-1} (Crow and Weaver 1977).

Conservation Trust Reserves in Puerto Rico

The Conservation Trust of Puerto Rico, founded in 1970, is a private, non-profit institution. The Trust's main objective is to protect the island's natural resources treasured for their ecological, historic, or scenic values, and to develop opportunities for research and environmental education for the people of Puerto Rico. The Trust carries out this mission through the acquisition and donation of properties, and the establishment of easements. El Faro is one of 28 properties that total 9,820 ha, as follows: protected natural areas (1,850.5 ha); a national wildlife refuge (323.7 ha); natural reserves (2,217.2 ha); conservation easements (3,057.3 ha); and other properties (1,633.3 ha) (Table 3, Fig. 3). The Conservation Trust properties have been described along with several other critical wildlife

Figure 3. Location and classification of Puerto Rico Conservation Trust properties in Puerto Rico.



areas (i.e., state forests, refuges, and other protected sites) in a comprehensive survey of Puerto Rico's protected areas (Ventosa-Febles *et al*. 2005).

Surveys of flora have been carried out at three Conservation Trust sites: Cañon de San Cristóbal (Francis *et al*. 1998); Punta Guaniquilla (Vázquez and Kolterman 1998); and El Faro (Weaver 1999a, 1999b). In addition, for >15 years El Faro has been included as one of several sites in the island's annual Christmas bird count. Most recently a 2-year study characterized the hydrological and biological characteristics, including water quality, of Laguna Grande (Soler-López and Santos 2010).

In summary, studies of flora, fauna, and water resources have been carried out for several years on several Conservation Trust properties. Cooperators have included naturalists, graduate students, and scientists working at universities and government agencies. The studies benefit both the Conservation Trust in their educational activities and the cooperators in their respective research and management programs.

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