Chapter 10
The Monteverde Cloud Forest: Evolution of a Biodiversity Island in Costa Rica

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Abstract Monteverde, Costa Rica represents an example of dynamic processes shaping an ever-changing, landscape-scale biodiversity island. Monteverde is internationally renowned for biodiversity conservation efforts initiated by non-governmental organizations and private citizens that led to the creation of the Monteverde Reserve Complex—a network of reserves spanning the region. Located in the Tilarán Mountain Range, an area of high endemism in the Central American isthmus, Monteverde's reserves provide habitat for over half of the species found in the entire country of Costa Rica, including 55 species of birds, mammals, amphibians and reptiles with some degree of threatened status on the IUCN Red List. One characteristic that makes Monteverde unusual is the number of research scientists that have settled in the area and studied the region over multiple decades. Some of these scientists helped secure international funding to purchase land for the Monteverde Cloud Forest Biological Preserve and the Children's Eternal Rainforest and participated in the creation of local non-governmental organizations to promote conservation, education, and sustainable community development. Recognizing that Monteverde's biodiversity island requires habitat connectivity across a larger landscape to support seasonal migratory species, Monteverde's organizations established the Bellbird Biological Corridor. The impacts of changing climate conditions—in particular, the increase of daily minimum temperatures and the increase in number of consecutive dry day periods—are being observed in Monteverde's cloud forests and further threaten the conservation of habitat and species. Holistic policies and programs spanning tourism, agriculture, transportation, energy, and environmental sectors are needed for continued conservation successes.

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10.1 Introduction

The arc of the Central American isthmus spans approximately 1,835 km (1,140 mi) from the southeast in Panama to the northwest in Guatemala. At its narrowest point, the isthmus is only 50 km (30 mi) wide. The region serves as a land bridge between North and South America, a critical path and melting pot for species from both hemispheres that colonized the isthmus during the past three million years. Coastal plains on both Atlantic and Pacific slopes are connected by a mountainous spine. Yet the mountains also form a barrier of separation between Atlantic and Pacific slopes, which have distinct ecological conditions shaped by both geology and climate patterns. As a result, in a relatively small area, Central America has great biodiversity with many micro-climates. In Costa Rica alone, Holdridge (1967) described 13 life zones.

Monteverde, Costa Rica is a small town (population less than 1,000) at the end of a meandering mountain road. The town of Monteverde lends its name to the surrounding region, which includes the population center of Santa Elena, and several other communities including San Luis, Cerro Plano, Cañitas, and La Lindora. Monteverde also lends its name, particularly within the international tourism industry, to the region's natural environment—the Monteverde Cloud Forest.

In this chapter, we describe the broader region of Monteverde, including both the town and the region's cloud forests, as a case study example of the processes shaping a dynamic, large-scale biodiversity island.[1] Monteverde is internationally renowned for privately-owned biodiversity conservation efforts that led to the creation of the greater Monteverde Reserve Complex—a network of reserves spanning the region. Its exceptional natural environment is complemented by a distinctive socio-cultural environment which was fundamental to the establishment of the network of reserves and more recently the expansion of the biological corridor extending outward from Monteverde through the region (see Sect. 3.3). Monteverde's outstanding conservation successes are tempered by many challenges. Based on our personal experience as administrators of local organizations and active participants in community-based conservation initiatives during the past three decades, it the authors' perspective that the ability of Monteverde's citizenry—including governmental offices,

[1] For background and general description of the region's ecology and conservation history, we rely heavily on the seminal work of Nalini Nadkarni and Nathaniel Wheelwright, *Monteverde: Ecology and Conservation of a Tropical Cloud Forest*, first published in 2000 with updated chapters published in 2014. We encourage readers interested in a more in-depth understanding of Monteverde to reference this outstanding resource. Our reflections on conservation initiatives in Monteverde, including the Bellbird Biological Corridor, the Children's Eternal Rainforest, Enlace Verde, and local reforestation projects are largely derived from our personal involvement in these initiatives and organizations.

non-governmental organizations, private-sector businesses, and engaged individual community members—to self-reflect, adapt to local issues and to external, global-scale threats, and continue to lead biodiversity conservation efforts makes for an interesting case study.

Nestled high in the Tilarán Mountain Range in northwestern Costa Rica, the Monteverde region is home to the Monteverde Reserve Complex, a 27,500-hectare block of protected forest comprised of three privately owned reserves (the Monteverde Cloud Forest Biological Preserve, Children's Eternal Rainforest, and Bosqueterno) and the state-owned Santa Elena Cloud Forest Reserve (see Fig. 10.1). The Reserve Complex is the centerpiece of a larger protected area, which we will refer to as the Monteverde Arenal Bioregion (MAB), that includes the state-owned Arenal Volcano National Park and Alberto Manuel Brenes Biological Reserve (see Fig. 10.2) and other smaller reserves. The MAB is connected to other protected areas via biological corridors, including the Bellbird Biological Corridor, which aims to connect Monteverde with the mangrove forests on Costa Rica's Pacific gulf coast.

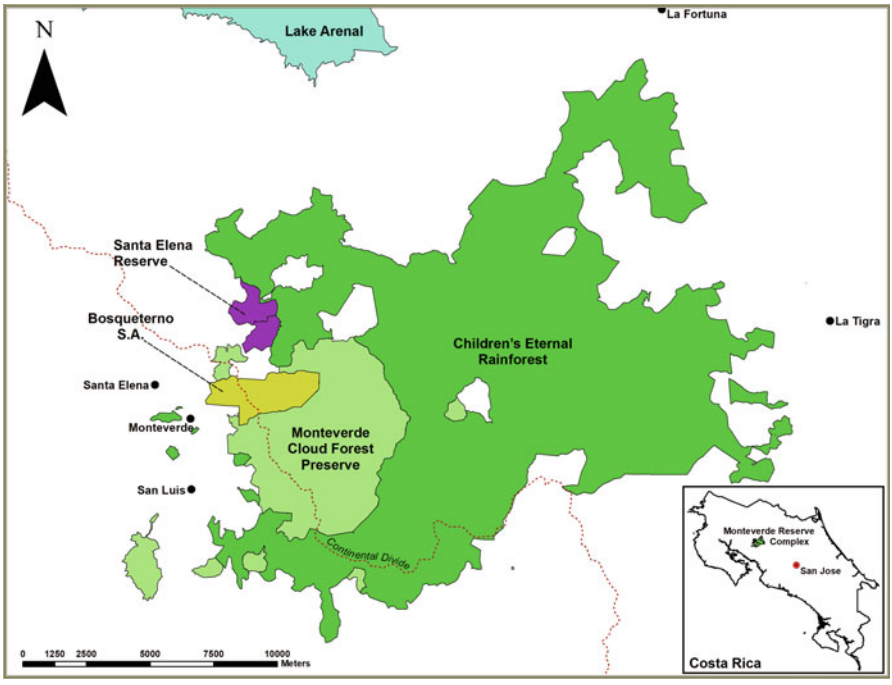

Fig. 10.1 The Monteverde Reserve Complex is comprised of three privately-owned reserves—the Children's Eternal Rainforest, owned by the Monteverde Conservation League; the Monteverde Cloud Forest Biological Preserve, owned by the Tropical Science Center; and Bosqueterno S.A., a corporation whose land assets are managed by the Tropical Science Center and which is owned by Quaker families who settled in Monteverde in the 1950s. Map Source: Yuber Rodríguez, Monteverde Conservation League 2020

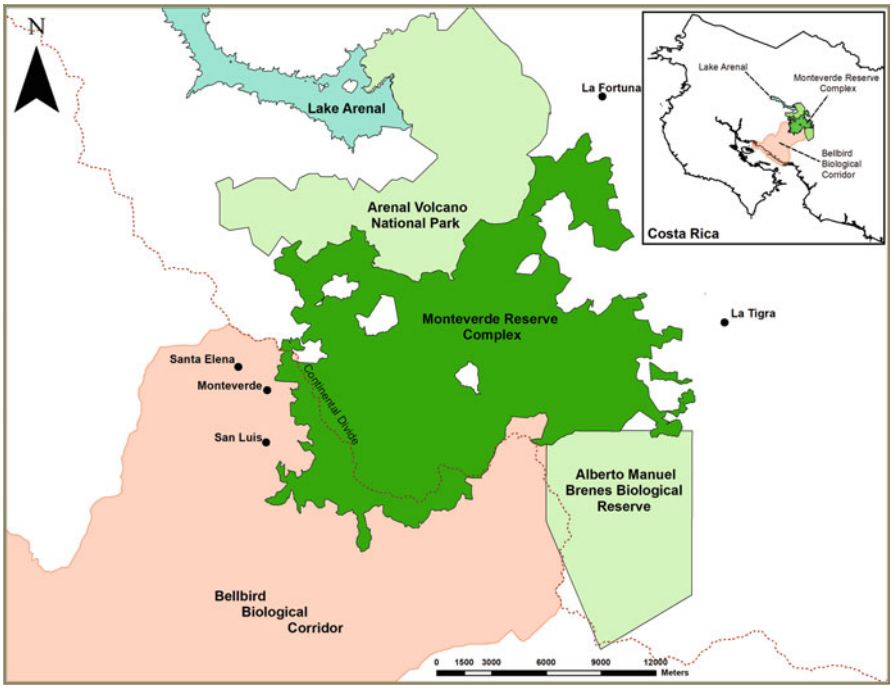

Fig. 10.2 The Monteverde Arenal Bioregion surrounding the Monteverde Reserve Complex includes two large government-owned protected areas—Arenal Volcano National Park and the Alberto Manuel Brenes Biological Reserve, several smaller reserves and protected areas, and the Bellbird Biological Corridor which connects Monteverde with the Gulf of Nicoya. Map Source: Yuber Rodríguez, Monteverde Conservation League 2020

The properties within the Monteverde Reserve Complex span seven Holdridge life zones (Haber 2000a; Holdridge 1967; Tosi et al. 1969). The elevational gradient of the Monteverde Reserve Complex ranges from 700 meters above sea level (masl) on the Pacific slope up to the Continental Divide—1,850 masl at its highest point—and down the Atlantic slope to 466 masl. The species on the Pacific slope have greater affinity with the tropical dry forest ecosystem, while organisms on the Atlantic slope tend to be more adapted to the humid conditions of the tropical rain forest. The species found at higher elevations are also tolerant to cool, humid conditions and are adapted to resist strong easterly trade winds, heaviest between December – March with gusts up to 80 kmph (Tropical Science Center unpublished data). Much of the Monteverde region falls within the tropical montane cloud forest vegetation type (see Fig. 10.3), which, according to Nadkarni and Wheelwright (2000: 9) is "one of the world's most threatened ecosystems."

As traditionally understood, islands undergo geological processes of formation—the eruption of volcanoes creating igneous landforms, and the collision and subduction/abduction of continental plates lifting up land masses. While geological forces created the underlying conditions for the establishment of the cloud forest and the

Fig. 10.3 A landscape view of the Monteverde Cloud Forest Preserve and the Children's Eternal Rainforest from the Continental Divide looking down the Atlantic slope. The Monteverde Reserve Complex represents the largest privately-owned protected area in Central America. Image Source: Fabricio Camacho Céspedes

evolution of the ecological niches that established along the Continental Divide in the Tilarán Mountain range in Costa Rica, the formation of Monteverde's biodiversity island was driven by strong socio-political, economic, cultural components over decades, rather than millennia. Expansionist development policies encouraged human population incursion into forested regions. Frontiersmen's axes felled seemingly inexhaustible tropical forests, fires "cleaned" the land, and cattle farms expanded across the landscape. As Harvey and Haber (1999) describe, this process resulted in the creation of small, sometimes single remnant tree biodiversity islands throughout the Monteverde region.

Agricultural expansion in the surrounding landscape completed the transformation of the remaining forests in the Monteverde region into a biodiversity island. Forested highland hillsides were replaced by coffee plantations and dairy cattle operations. Rivers flowing to the Caribbean were dammed and diverted to the Pacific, providing hydropower and supplying irrigation to the dry northwestern province of Guanacaste. The arid tropical dry forest and drained coastal wetlands were replaced with extensive fields of cattle, rice, sugar cane, and eventually pineapple. To the north of the Monteverde region, extensive tourism development

modified the landscape near the Arenal Volcano; ornamental plants, pineapple, and family farms dominated areas east of the Monteverde Reserve Complex.

Yet in the midst of this landscape transformation, there were also concerted efforts to protect the region's natural resources. In the 1950s, Quaker settlers in Monteverde recognized the need to maintain forested lands that protected highland springs, the community's primary water source. This area, known as Bosqueterno, would eventually become the nucleus of the Monteverde Cloud Forest Biological Preserve, which was founded in 1972. In 1977, the Costa Rican government declared protected areas in the region (the Arenal Forest Reserve, later to become the Zona Protectora Arenal Monteverde, or ZPAM). The government was unable to purchase or effectively manage the lands it had declared as a reserve, however, and private landowners continued agricultural expansion into their farms in this area. Private conservation initiatives, led by the Tropical Science Center and Monteverde Conservation League, sprang up in an effort to purchase primary rainforest before it was felled (see Sect. 3.1). In the 1980s and 1990s, Costa Rica's international debt would be swapped for investments into the expansion of the Monteverde biodiversity island, eventually—in combination with funds raised by youth around the world—creating the Children's Eternal Rainforest.

The focus has shifted over time from protecting water to protecting specific endangered species, then to ecosystem conservation (Burlingame 2000). Most recently, the Monteverde community is engaged in an evolving initiative integrating farm-scale to watershed-scale ecosystem management and sustainable economic development with the goal of climate change resiliency for the region's biodiversity and the growing human population (Brenes et al. 2019). Simultaneously, research scientists and conservation organizations are working to develop a more unified approach to share data, collaborate across disciplines, and perhaps develop new methods and approaches for understanding and disseminating information about the region's ecology (Allen and Hoekstra 1992; Zamsow et al. 2018).

The following sections highlight natural history characteristics as well as some of the organizations and initiatives that make Monteverde's biodiversity island unique and of critical importance as a large node in Costa Rica's national landscape matrix of conservation. We then describe some of the challenges for ongoing biodiversity conservation, many of which are not unique to the Monteverde region. We remind the reader that the complete story of biodiversity conservation in Monteverde, Costa Rica is far more complex than we are able to present in this snapshot.

10.2 Species Accounts

> *"Biodiversity in the broadest sense is a characteristic feature of Monteverde"*. Wheelwright 2000:420.

The diversity of micro-climates (or life zones) in the Monteverde region positively impacts the area's overall biodiversity. The Atlantic slope of Monteverde has the greatest bird diversity in Costa Rica—40% of Central America's mammal species

have been identified in Monteverde. The area is home to one-third of Costa Rica's plant species, including as many families of epiphytes as the entire country of Mexico. Ten percent of Monteverde's plants are endemic to Costa Rica's Tilarán mountain range (Wheelwright 2000).In this section, we offer a brief glimpse into Monteverde's natural history. For a much more complete and detailed description refer to Nadkarni and Wheelwright (2000, 2014).

10.2.1 Epiphytes, Orchids

Characteristic to Monteverde's vegetation are its diverse epiphyte communities which represent the most diverse plant group in Monteverde with more than 800 species including 471 species of monocots, 230 species of dicots, and 177 species of ferns (Haber 2000a, b). These communities not only add to the overall biodiversity in Monteverde, but also play a significant role in cloud forest ecosystem dynamics. For example, many of these plants decompose in the forest canopy, producing an abundant accumulation of canopy soil that is rich in organic matter and which contributes to nutrient cycling and conservation (Nadkarni 1981; Nadkarni et al. 2002). The canopy epiphyte root-humus mat exhibit high potential water storage capacity (Köhler et al. 2007). However, the actual water availability in this canopy-mat is conditioned to rainfall and evaporation patterns (Köhler et al. 2007), which is one of the main contributing factors that suggest that this may be one of the most vulnerable communities to the effects of climate change (Clark et al. 2014).

Orchids represent the most diverse epiphyte family in Monteverde with more than 450 species (Haber 2000a, b), of which more than 30 species are new to science (Atwood and Dressler 1995). This richness makes Monteverde one of the most, if not the most, orchid-diverse locations on the planet (Haber 2000a, b). The most important aspects that add up to this diversity are the abundance of life zones, pollinators and the intensity of studies in the area (Atwood and Dressler 1995). Orchid diversity in Monteverde represents about one third of the estimated number of orchid species in Costa Rica (Atwood and Dressler 1995). Although it is one of the most prominent families in terms of species diversity, many species known as miniature orchids are inconspicuous and difficult to recognize among other epiphytes by the untrained eye.

10.2.2 Vascular Plants

Within the seven Holdridge life zones (Holdridge 1967) included in the Monteverde Flora Project study area, there are three forest types—Pacific slope seasonal forest, cloud forest, and Atlantic slope rain forest (Haber 2000a). The Monteverde Flora Project was an initiative of the Missouri Botanical Garden and the Manual to the Plants of Costa Rica Project. Through the Monteverde Flora Project, the flora of the

Monteverde area, from the Continental Divide down both Atlantic and Pacific slopes to 700 masl, was collected and identified (Haber 1991, 2000a, b).

In addition to the Monteverde Flora Project, multiple studies since the mid-1970s have contributed to the identification and classification of Monteverde's flora (e.g., Dyer 1979; Hartshorn 1983). By 2000, the list of vascular plants for Monteverde included 3,021 species with 755 species of trees (Haber 2000a, b). This represents about one-third of all vascular plant species in Costa Rica (Haber 2000a, b). About 10% of Monteverde's flora species are endemic to the Tilarán Mountains (Haber 2000a, b), and over 10% of the 216 of the common or characteristic tree species of the life zones of Monteverde face some degree of threat as per the IUCN Red List (see Table 10.1).

The diversity of wild avocados—66 species of Lauraceae representing eight genera (Haber 2000a, b)—in Monteverde is notably greater than in adjacent areas. Lauraceae play a key role as a food source for many frugivorous birds, including Three-wattled Bellbirds (*Procnias tricarunculata*) and Resplendent Quetzals (*Pharomacros moccino*) (see Fig. 10.4), which synchronize their migration routes to follow the fruiting patters of these and other tree species (Powell and Bjork 1994). The lipids contained in the wild avocados serve as one of the main sources of energy to support the reproduction of these iconic birds.

10.2.3 Avifauna

Many early scientific publications (e.g., Snow 1977; Wheelwright 1983) focused on Monteverde's spectacular avifauna, capturing the attention of the international birding community. Natural history films (e.g., BBC's *Forest in the Clouds*), books (e.g., National Geographic's *Mountain Worlds*), and magazine articles (e.g., *International Wildlife's* "Is This the Garden of Eden?") based on the region's impressive biodiversity also brought international attention to the area (Burlingame 2000).

To date, more than 400 of Costa Rica's 850 avian species have been reported in the area (Fogden 2000), including a number of IUCN Red Listed species such as the Great Curassow (*Crax rubra*), Keel-billed Motmot (*Electron carinatum*), Blue-and-gold Tanager (*Bangsia arcaei*), the above-mentioned Three-wattled Bellbird and Resplendent Quetzal, and the Bare-necked Umbrellabird (*Cephalopterus glabricollis*) (see Table 10.1). Avian diversity is amplified by the combination of resident and migratory communities, which include latitudinal and altitudinal migrants. Among the latter, the most economically important species is the Resplendent Quetzal, due to its importance to Monteverde's ecotourism industry.

Table 10.1 Species found in the Monteverde area which are listed as Near Threatened, Vulnerable, Endangered, Critically Endangered, Extinct in the Wild, or Extinct on the IUCN Red List

Species	Common name	IUCN Red List Status	Citation
Plants[a]			
Agonandra macrocarpa		Vulnerable	Nelson (1998a)
Bombacopsis quinata		Vulnerable	Sandiford (1998)
Capparis discolor		Near Threatened	Mitré (1998a)
Chrysophyllum hirsutum		Near Threatened	World Conservation Monitoring Centre (1998a)
Costus nitidus		Endangered	Skinner (2014)
Dichapetalum costarricense		Vulnerable	World Conservation Monitoring Centre (1998b)
Elaeagia uxpanapensis		Endangered	World Conservation Monitoring Centre (1998c)
Eugenia salamensis		Endangered	Nelson (1998b)
Ficus lateriflora		Critically Endangered	Page (1998)
Ilex costaricensis		Vulnerable	Mitré (1998b)
Magnolia poasana		Near Threatened	Khela (2014)
Ocotea monteverdensis	Quizzará Blanco	Critically endangered	Joslin et al. (2018)
Ocotea viridiflora		Vulnerable	World Conservation Monitoring Centre (1998d)
Oreomunnea pterocarpa		Endangered	Americas Regional Workshop (1998)
Persea schiedeana	Coyo Avocado	Endangered	Wegier et al. (2017)
Pouteria austin-smithii		Vulnerable	World Conservation Monitoring Centre (1998e)
Pouteria congestifolia		Vulnerable	World Conservation Monitoring Centre (1998f)
Pouteria fossicola		Vulnerable	World Conservation Monitoring Centre (1998g)
Sideroxylon capiri		Near Threatened	World Conservation Monitoring Centre (1998h)

(continued)

Table 10.1 (continued)

Species	Common name	IUCN Red List Status	Citation
Sideroxylon persimile		Near Threatened	World Conservation Monitoring Centre (1998i)
Terminalia bucidoides		Endangered	Nelson (1998c)
Ticodendron incognitum	Duranzo de Ardilla	Near Threatened	Rivers et al. (2019)
Zinowiewia costaricensis		Near Threatened	Mitré (1998c)
Amphibians[2]			
Agalychnis annae	Blue-sided Treefrog	Endangered	IUCN SSC Amphibian Specialist Group and NatureServe (2014)
Agalychnis lemur	Lemur Leaf Frog	Critically Endangered	Solís et al. (2008d)
Atelopus varius	Variable Harlequin Frog	Critically Endangered	Pounds et al. (2010)
Bolitoglossa subpalmata	La Palma Salamander	Endangered	Pounds et al. (2008c)
Craugastor andi	Atlantic Robber Frog	Critically Endangered	Pounds et al. (2008a)
Craugastor angelicus	Angel Robber Frog	Critically Endangered	Pounds et al. (2008b)
Craugastor podiciferus	Cerro Utyum Robber Frog	Near Threatened	Solís et al. (2010a)
Duellmanohyla uranochroa	Costa Rica Brook Frog	Endangered	NatureServe and IUCN SSC Amphibian Specialist Group (2013)
Ecnomiohyla fimbrimembra	Heredia Treefrog	Endangered	Solís et al. (2008a)
Ecnomiohyla miliaria	Cope's Brown Treefrog	Vulnerable	Solís et al. (2010b)
Incilius periglenes	Golden Toad	Extinct	Savage et al. (2008)
Isthmohyla angustilineata	Narrow-lined Treefrog	Critically Endangered	Solís et al. (2008c)
Isthmohyla rivularis	American Cinchona Plantation Treefrog	Critically Endangered	Solís et al. (2010c)
Isthmohyla tica	Starrett's Treefrog	Critically Endangered	IUCN SSC Amphibian Specialist Group and NatureServe (2013a)

(continued)

Table 10.1 (continued)

Species	Common name	IUCN Red List Status	Citation
Isthmohyla zeteki	Zetek's Treefrog	Near Threatened	Solís et al. (2008b)
Lithobates vibicarius	Rancho Redondo Frog	Vulnerable	IUCN SSC Amphibian Specialist Group and NatureServe (2013b)
Nototriton gamezi	Monteverde Moss Salamander	Vulnerable	Pounds et al. (2008f)
Nototriton picadoi	La Estrella Salamander	Near Threatened	Bolaños et al. (2008b)
Oedipina poelzi	Quarry Worm Salamander	Endangered	Bolaños et al. (2008a)
Oedipina uniformis	Cienega Colorado Worm Salamander	Near Threatened	Wake et al. (2008)
Pristimantis altae	Mountain Robber Frog	Near Threatened	Pounds et al. (2008d)
Pristimantis caryophyllaceus	La Loma Robber Frog	Near Threatened	Pounds et al. (2008e)
Reptiles[b]			
Celestus hylaius	Rain Forest Caiman Lizard	Near Threatened	Solórzano et al. (2013)
Trimetopon simile	Dunn's Tropical Ground Snake	Endangered	Porras et al. (2013)
Insects (Odonata)[c]			
Libellula mariae		Near Threatened	Paulson (2009b)
Palaemnema baltodanoi		Endangered	Paulson and von Ellenrieder (2006a)
Perigomphus pallidistylus		Vulnerable	Paulson and von Ellenrieder (2006b)
Birds[d]			
Ara ambiguus	Great Green Macaw	Endangered (once abundant in Atlantic Slope lower elevations, but has not been recently sighted)	BirdLife International (2016a)
Antrostomus carolinensis	Chuck-will's Widow	Near Threatened	BirdLife International (2018a)
Bangsia arcaei	Blue-and-gold Tanager	Near Threatened	BirdLife International (2018b)
Buteogallus solitarius	Black Solitary Eagle	Near Threatened	BirdLife International (2016b)

(continued)

Table 10.1 (continued)

Species	Common name	IUCN Red List Status	Citation
Cephalopterus glabricollis	Bare-necked Umbrellabird	Endangered	Birdlife International (2016c)
Contopus cooperi	Olive-sided Flycatcher	Near Threatened	BirdLife International (2017a)
Crax rubra	Great Curassow	Vulnerable	BirdLife International (2016d)
Electron carinatum	Keel-billed Motmot	Vulnerable	BirdLife International (2016e)
Grallaricula flavirostris	Ochre-breasted Antpitta	Near Threatened	BirdLife International (2017b)
Hylocichla mustelina	Wood Thrush	Near Threatened	BirdLife International (2017c)
Morphnus guianensis	Crested Eagle	Near Threatened	BirdLife International (2017d)
Patagioenas subvinacea	Ruddy Pigeon	Vulnerable	BirdLife International (2016f)
Pharomachrus mocinno	Resplendent Quetzal	Near Threatened	Birdlife International (2016g)
Procnias tricarunculatus	Three-wattled Bellbird	Vulnerable	Birdlife International (2016h)
Sclerurus albigularis	Gray-throated Leaftosser	Near Threatened	BirdLife International (2016i)
Setophaga cerulea	Cerulean Warbler	Near Threatened	BirdLife International (2019a)
Spizaetus ornatus	Ornate Hawk-Eagle	Near Threatened	BirdLife International (2016j)
Sturnella magna	Eastern Meadowlark	Near Threatened	BirdLife International (2019b)
Tinamus major	Great Tinamou	Near Threatened	BirdLife International (2017e)
Touit costaricensis	Red-fronted Parrotlet	Vulnerable	BirdLife International (2018c)
Vermivora chrysoptera	Golden-winged Warbler	Near Threatened	BirdLife International (2018d)
Mammals[5]			
Ateles geoffroyi	Black-handed Spider Monkey	Endangered	Cuarón et al. (2008)
Ectophylla alba	Caribbean White Bat	Near Threatened	Rodriguez and Pineda (2015)
Leopardus tigrinus	Northern Tiger Cat	Vulnerable	Payan and de Oliveira (2016)
Leopardus wiedii	Margay	Near Threatened	de Oliveira et al. (2015)

(continued)

Table 10.1 (continued)

Species	Common name	IUCN Red List Status	Citation
Myrmecophaga tridactyla	Giant Anteater	Vulnerable (once present in Monteverde, but not recently sighted)	Miranda et al. (2014)
Panthera onca	Jaguar	Near Threatened	Quigley et al. (2017)
Sylvilagus brasiliensis	Tapeti	Endangered	Ruedas and Smith (2019)
Tapirus bairdii	Baird's Tapir	Endangered	García et al. (2016)
Tayassu pecari	White-lipped Peccary	Vulnerable (once present in Monteverde, but not recently sighted)	Keuroghlian et al. (2013)
Vampyrum spectrum	Spectral Bat	Near Threatened	Solari (2018)

[a]Based on database search of IUCN Red List (iucnredlist.org) using the 216 species listed in Table 3.2. Common or characteristic tree species of the life zones in the Monteverde area in the chapter Plants and Vegetation (Haber 2000a, b) in Nadkarni and Wheelwright (2000). An exhaustive list of the status of all flora in the Monteverde area is beyond the scope of this chapter. Furthermore, many of the 3021 species of vascular plants known to the Monteverde area have not been evaluated for their IUCN Red List endangered status. Therefore, a representative sample of the most common or characteristic tree species (216 of the 755 known tree species in Monteverde) was deemed appropriate for the purposes of this chapter

[b]Based on database search of IUCN Red List (iucnredlist.org) using the complete species list of Amphibians and Reptiles of Monteverde provided in Pounds and Fogden (2000). This was also cross-referenced with the most recent unpublished Amphibians and Reptiles species lists for the Monteverde Cloud Forest Biological Preserve compiled by the Tropical Science Center (2019 unpublished data) to ensure any new species added to the lists of observed species in the Monteverde area were included

[c]An exhaustive study of all insect orders in the Monteverde area has yet to be completed. We have chosen to use the order Odonata as an example subset of insects representing the Monteverde area. Based on database search of IUCN Red List (iucnredlist.org) using the complete species list ($n = 102$) of Odonata collected at 700 m or higher on both Pacific and Atlantic slopes within the Monteverde area provided by Haber (personal communication, 2020 unpublished data). An additional species of Odonata, *Epigomphus subsimilis*, found in the lower Pacific slopes (355 m) is IUCN Red Listed as Endangered (Paulson 2009a, b). 51 of the 102 species identified by Haber in the Monteverde area have not been evaluated for inclusion in the IUCN Red List Database, and five of those 51 species were not included in the Catalogue of Life database (http://www.catalogueoflife.org/col/search/all). One Odonata species was included in the IUCN Red List database, however its status could not be determined due to deficient data

[d]Based on database search of IUCN Red List (iucnredlist.org) using the complete species list of Birds of the Monteverde Area provided in Fogden (2000). This was also cross-referenced with the most recent unpublished Bird species list for the Monteverde Cloud Forest Biological Preserve compiled by the Tropical Science Center (2019 unpublished data) to ensure any new species added to the lists of observed species in the Monteverde area were included

[e]Based on database search of IUCN Red List (iucnredlist.org) using the complete species list of Mammals of Monteverde provided in Timm and LaVal (2000). This was also cross-referenced with the most recent unpublished Mammals species lists for the Monteverde Cloud Forest Biological Preserve compiled by the Tropical Science Center (2019 unpublished data) to ensure any new species added to the lists of observed species in the Monteverde area were included

Fig. 10.4 The Resplendent Quetzal (*Pharomacros moccino*) and the Three-wattled Bellbird (*Procnias tricarunculata*) represent two of Monteverde's iconic, IUCN Red Listed bird species. Both species have attracted scientific researchers to the region and have played an important role in attracting bird watchers and nature-based tourism in general to Monteverde. (Image Sources: Alvaro Cubero (Resplendent Quetzal) and Orlando Calvo (Three-wattled Bellbird))

Even this flagship species has not escaped environmental threats; the Tropical Science Center[2] estimates a current population of 55 individual quetzals (male, female and juveniles) in the Monteverde Cloud Forest Biological Preserve (TSC unpublished data) in contrast to the 50 reproductive couples estimated by Wheelwright (1983). Hamilton et al. (2003) report habitat loss and fragmentation on the Pacific Slope as the main causes of population declines of Three-wattled Bellbirds in Monteverde. This species declined from 135 individuals in 1997, to just 90 in 2002. Current monitoring efforts by the Tropical Science Center in the Monteverde region revealed that the population of Bellbirds may be increasing; 102 individuals were identified in 2018 and 120 in 2019 (TSC unpublished data).

Over one-third of Costa Rica's hummingbird species have been identified in Monteverde (Feinsinger 1977). It is believed that cooler air temperatures at higher elevations may result in a lower abundance of pollinating insects, thus providing conditions that support a higher diversity of hummingbirds due to lower resource competition. Several species of vascular plants, including *Justicia sp.* (Acanthacea)

[2]The Tropical Science Center (TSC) is Costa Rica's oldest environmental non-profit, non-governmental organization. TSC was established in 1962 by research scientists Leslie Holdridge, Joseph Tosi, and Robert Hunter together with several local businessmen. See Sect. 3.1.1 for further description of TSC's role in the Monteverde Reserve Complex.

and *Satyria sp.* (Ericaceae), have coevolved pollination systems to capitalize on diverse hummingbird phenotypes (Deliso 2008).

10.2.4 Insects

There has been no comprehensive study of insects in Monteverde, by far the most diverse and abundant group of organisms in the region. The region is home to 102 species of damselflies and dragonflies (W Haber personal communication). Monteverde's butterflies have been studied by Haber (1993) and Stevenson (W Haber and R Stevenson, unpublished data), who indicate a total of 658 species in the Monteverde zone (Stevenson and Haber 2000, W Haber personal communication). More than half of the area's butterfly species are altitudinal migrants, moving up and down the Pacific and Caribbean slopes with the wet and dry seasons (Stevenson and Haber 2000). Habitat availability is critically important, and changing climate conditions are driving up-slope migration of Pacific lowland butterfly species—in addition to lowland birds and mammals—into the Monteverde area (J Porter personal communication; Wheelwright 2000; Timm and LaVal 2000).

Ant faunas of cloud forests are strongly specialized for cloud forest habitat and sharply differentiated from the adjacent lowlands. The ant fauna of Monteverde has been extensively studied by Longino, who estimated that about 70 species are cloud forest specialists (J Longino personal communication). About a third of these are widespread, known from other cloud forest sites in Central America. Most of the rest are restricted to the cloud forests of Costa Rica and adjacent parts of Panama. A few are known only from Monteverde, but it is difficult to know if this is true local endemism or a result of under-sampling elsewhere. Recent DNA studies are showing that some of the species shared among different Costa Rican mountain ranges actually have deep genetic divergences and have been isolated from each other for millions of years (J Longino personal communication).

10.2.5 Larger Mammals

Three species of monkeys—Mantled Howler Monkeys (*Alouatta palliata)*, White-faced Capuchins (*Cebus capucinus*), and the IUCN Red List endangered Black-handed Spider Monkeys (*Ateles geoffroyi*); agoutis (*Dasyprocta punctate*), pacas (*Cuniculus paca*), and prehensile-tailed porcupines (*Coendou mexicanus*) among other rodents; coatis (*Nasua narica*), peccaries (*Tayassu pecari* and *Pecari tajacu*), sloths (*Bradypus variegatus* and *Choloepus hoffmanni*), kinkajous (*Potos flavus*), olingos (*Bassaricyon gabbii*), and opossums (*Didelphis marsupialis* and *Marmosa mexicana*) may be observed during visits to one of Monteverde's reserves. The area is home to all six of Costa Rica's wild felines (*Herpailurus yagouaroundi, Leopardus pardalis, Leopardus tigrinus, Leopardus wiedii, Panthera onca, Puma*

concolor). Camera trap research shows regular and widespread presence of pumas and ocelots, and occasional presence of jaguars (Zamzow et al. 2018). Baird's Tapir (*Tapirus bairdii*), Costa Rica's largest land mammal and IUCN Red Listed as endangered (see Table 10.1), is also present in lower abundance. As is the case for other taxonomic groups in the Monteverde region, comprehensive monitoring programs to estimate populations and conservation status of mammals have not been established in Monteverde.

By night, insectivorous, nectar-feeding, and frugivorous bats parallel the daytime roles of birds—pollinating, dispersing seeds, and preying on invertebrates in Monteverde's forests (Timm and LaVal 1998; Muchhala 2003). These ecosystem services are essential in maintaining the functional integrity of the cloud forest ecosystem. Montverde's bat diversity includes 58 species, which represents nearly half of the total bat diversity in Costa Rica (Timm and LaVal 2000; Wainwright 2007). Migration outside of Monteverde's protected areas on the Pacific Slope for foraging and pollination make bats especially important in the process of natural habitat restoration, as they help disperse fruits and seeds of pioneer species such as Piperaceae and Solanaceae. More research on bat migration is needed, however, in order to more fully understand their contribution to habitat restoration, which may in turn promote greater bat conservation (Caughlin et al. 2007).

10.2.6 Amphibians

Historically, Monteverde was home to 60 species of amphibians, including 2 caecilians, 5 salamanders, and 53 anurans, many of which are part of a "distinctive upland assemblage rich in endemic species" (Pounds and Fogden 2000). As is the case globally, Monteverde's amphibians have experienced dramatic and alarming declines over the past four decades due to habitat loss as well as the amphibian chytrid fungus, *Batrachochytrium dendrobatidis (Bd)* (James et al. 2015; Whitfield et al. 2017; Whitfield et al. 2016). In 1990, researchers found only 25 of the 50 anuran species expected to be present in the Monteverde area; notably absent was the iconic and endemic Golden Toad (*Incilius periglenes*) (Pounds and Fogden 2000).

However, Monteverde's extensive protected areas apparently function as a refuge and foster recovery for some species. For example, Forrer's Leopard Frog (*Lithobates forreri*) was later found (Pounds and Fogden 2000), the Green-eyed Frog (*L. vibicarius*) (see Fig. 10.5) and Starrett's tree frog (*Isthmohyla tica)* also reappeared in remote areas of the Children's Eternal Rainforest, and other species have since been rediscovered as well (Garcia-Rodriguez et al. 2012; Whitfield et al. 2017; M. Wainwright personal communication). In the case of *L. vibicarius*, research indicates that these remnant populations can survive and persist even with Bd infection (Whitfield et al. 2017).

Fig. 10.5 The Green-eyed Frog (*Lithobates vibicarius*) was thought to be extinct but later reappeared in the Children's Eternal Rainforest. (Image Source: Mark Wainwright)

10.2.7 Soils and Microbial Communities

The taxonomy and ecology of soil fauna are largely missing from biodiversity inventories in Monteverde, although two studies have examined the biology of cloud forest canopy soils (Nadkarni et al. 2002; Rains et al. 2003). This could be the next frontier of biological research in the area. The implementation of new DNA sequencing technologies available in Costa Rica provides a significant opportunity to study the composition of microorganisms in cloud forest soil ecosystems.

10.2.8 Endemism, Climate Change, and Species Decline

The Monteverde region exhibits high endemism rates in comparison to areas at lower elevations. For example, Haber (2000a, b) reports approximately 10% of Monteverde's plant species to be endemic to the Tilarán mountain range. A comprehensive study of endemic species, invasive species, and the vulnerability of endemic species to invasive species and changes in climate is needed for the region.

In the 50 years between 1940 and 1990, deforestation and agricultural expansion were the primary forces creating the island-effect around Monteverde; however, the primary current threat to Monteverde's biodiversity is climate change. Strikingly, the number of dry days and the number of dry days in runs—five or more consecutive days with no precipitation, which have an impact on mist frequency in the cloud forest—have shown a steadily increasing trend over time (Pounds et al. 2006). Through the 1970s, there were less than 10 dry days in runs per year, with some years having no such runs (Pounds et al. 2006); 108 total dry days were recorded in 2019, with most of the zero precipitation days during January–April (Monteverde Institute, unpublished data). The shift of environmental variables regulating ecosystem function may produce a rapid transformation in life zone distribution and species composition across the region. Should this change happen more quickly than ecosystems and species are able to adapt, species declines—and extinctions—will likely result.

New disease vectors invading the Monteverde region may become a leading cause of species declines (Pounds et al. 2006). This is perhaps most vividly highlighted by the example of amphibian species declines and extinctions at the hands of the chytrid fungus *B. dendrobatidis*, mentioned above. This phenomenon may be exacerbated by changing climate conditions.

10.3 Biodiversity Conservation in Monteverde

> *"Within Costa Rica, the Monteverde Zone is atypical, with its multi-cultural population, the large number of people within high education al levels, sharp awareness of conservation and sustainable development, relative prosperity based on dairy farming and ecotourism, and ability to create grassroots organizations to deal with local issues"*. (Burlingame 2000: 374)

Given the Monteverde region's biodiversity, as highlighted in Sect. 2, and in light of past and current threats to the region's forests, biodiversity conservation initiatives have played a central role in maintaining the region's biodiversity and in the emergence of Monteverde as a world-renowned nature-based tourism destination. The Monteverde Reserve Complex—the amalgamation of the various protected areas described in the Introduction (see Sect. 1, Fig. 10.1)—is the accomplishment

of private citizens who established organizational structures and carried out fundraising to acquire and maintain large swaths of land in private ownership for conservation purposes. Initiatives from two Costa Rican NGOs, the Tropical Science Center (TSC, owner of the Monteverde Cloud Forest Biological Preserve) and the Monteverde Conservation League (MCL, owner of the Children's Eternal Rainforest) and their international fundraising counterparts grew out of the recognition that the Costa Rican government did not have the funds to effectively purchase or steward this area.While requiring Herculean effort to successfully carry out fundraising for land purchase, Monteverde had a compelling story about immediate threats to species such as the charismatic Resplendent Quetzal and the endemic Golden Toad. Furthermore, the concept of a Children's Eternal Rainforest—a privately-owned protected area established by many small contributions from children all over the world—began with Swedish elementary school students, whose fundraising efforts subsequently spread around the globe thanks to several international NGOs that were formed to collect funds raised by the students. The international fundraising efforts were able to raise hundreds of thousands of dollars from tens of thousands of small donations. In doing so, they brought further attention to and grew the mystique of Monteverde as a special place on the planet where biodiversity protection is paramount.

One of the great challenges of large-scale land conservation, whether public or private, is the cost of management. Purchase is a one-time event; maintenance and stewardship are forever. Neither the TSC nor the MCL was able to raise sufficient funding to establish long-term endowment funds to support the staff, materials, and other costs related to forest protection and management. They depend in part on revenue-generating use of the reserves to support annual budgets, which requires ongoing investment in infrastructure, and larger annual budgets for operations and maintenance. Both organizations have experienced periods of institutional growth to ramp up operations and generate more revenue, followed by periods of contraction and re-organization as revenue cycles ebbed.

How these organizations managed reserve borders and encroachments has been an important factor in the conservation successes of the Monteverde Reserve Complex. The MCL and TSC realized early on that effective conservation was better achieved through non-confrontational means, and, in contrast to government park rangers, their park guards do not carry weapons (Burlingame 2000). When park guards come across poachers and others encroaching on reserve properties, the guards take the approach of dialog and explain conservation goals. Many of the early forest guards were former hunters and farmers themselves, and they understood the mindset of those living around the reserves. While this approach did not always work in terms of stopping encroachment, it did succeed in building trust and respect between reserve personnel and neighbors. Anecdotal conversations with park guards reveal that while poaching continues to be a problem in the private reserves, there is much less hunting today than in the past; some hunters also simply move to neighboring properties (including state owned reserves) in order to respect the boundaries of the Monteverde Cloud Forest Biological Preserve and Children's Eternal Rainforest (H Chacón personal communication). Some neighboring

landowners have seen the economic opportunities associated with growing ecotourism, particularly from birdwatching (e.g., the 83 ha Curi Cancha Reserve), and have adopted conservation measures, leaving remnant forest trees on their properties and allowing pastures to return to forest.

10.3.1 The Monteverde Reserve Complex

10.3.1.1 Tropical Science Center, the Monteverde Cloud Forest Biological Preserve, and Bosqueterno, S.A.

The Monteverde Cloud Forest Biological Preserve (MCFBP), owned and operated by the Tropical Science Center, was founded in 1972. Through strategic land purchases, the MCFBP has grown from its initial 328 ha to 4,125 ha in 2019 (Burlingame 2000; C Hernandez personal communication).

Biologists who came to Monteverde to study the cloud forest were instrumental in fundraising and land purchase efforts, and helped generate broad interest about conservation of this unique ecosystem. In particular, George Powell played a crucial role in raising awareness—and funds—on an international scale in support of conservation of the Golden Toad, Resplendent Quetzal, Bare-necked Umbrellabird, and wild feline species. Powell was also the person who first approached the TSC, Costa Rica's first nonprofit conservation organization, about taking ownership of the newly acquired lands (Burlingame 2000).

As part of an effort to expand the MCFBP, in 1974 the TSC secured a 90-year lease on 554 ha of land belonging to Bosqueterno S.A., a Costa Rican corporation established by the Quaker community.[3] When Quakers originally settled in Monteverde in the 1950s, they set aside this land—high on the mountain, shrouded in dense cloud forest, and unsuitable for farming—in order to protect the community's principal water source (Burlingame 2000). A small portion of the Bosqueterno property forms part of the main trail system open to visitors in the MCFBP.

Visitation at the MCFBP has grown from 471 visitors in 1973–1974 (Burlingame 2000) to more than 100,000 visitors in 2019 (Y Méndez personal communication). As the Monteverde area's most visited reserve, the MCFBP has established a maximum limit of 250 persons at any given time on its 13 km of trails; the maximum limit for daily visitation is 450 people. Of the MCFBP's 4,125 ha, slightly more than 80 ha (or about 2% of the total reserve area) are open to the public (http://www.cct.or.cr/contenido/our-protected-areas).

The MCFBP's environmental education program, founded in 1992, brings local students to the cloud forest for talks, workshops, and hikes. Environmental educators

[3] The 554 ha owned by Bosqueterno, S. A. and managed by the Tropical Science Center are not included in the 4,215 ha owned by the Tropical Science Center.

also visit local classrooms and participate in environmental education activities in conjunction with the Monteverde Environmental Education Commission. The MCFBP's research and monitoring program is important for carrying out censuses of birds, amphibians, mammals, and other groups, as well as monitoring Resplendent Quetzals and other species of special interest. Most of the MCFBP's operations and programs—including environmental education, research and monitoring, forest protection, and maintenance—are funded via tourist visitation to the reserve, interest on investments, and participation in the Costa Rican government's Payments for Environmental Services (PES) program.[4]

Also located in the Monteverde area, the TSC's 250 ha San Luis Biological Reserve protects a critical tract of habitat connecting the cloud forest to the lower dry forests on the Pacific slope within the Bellbird Biological Corridor. This property is not open for tourism and is primarily used for conservation and research.

10.3.1.2 Monteverde Conservation League and the Children's Eternal Rainforest

One of the first objectives of the Monteverde Conservation League, a Costa Rican nonprofit organization founded in 1986 by a group of Monteverde residents, was to raise funds for the purchase and preservation of forest that would otherwise be lost or severely degraded by agricultural expansion. The land purchased would soon become known as the Children's Eternal Rainforest (CER), today Costa Rica's largest privately-owned reserve. The 22,600-hectare forested expanse traverses seven geopolitical districts and three provinces, bridges an elevational range of >1,200 m, and spans the Continental Divide that separates Atlantic and Pacific watersheds. As the centerpiece of the Monteverde Reserve Complex, the CER is a vital nexus for natural habitats and populations.

The CER (known locally as "Bosque Eterno de los Niños") was purchased and protected thanks to donations from children, adults, and organizations in more than 40 countries around the globe. In addition to its key role in biodiversity conservation, the CER also benefits Costa Ricans through the conservation of five major watersheds that provide a continuous supply of clean water for human consumption, agriculture, and hydroelectric production; opportunities in the ecotourism sector; and via innovative outreach services such as facilitating participation by neighboring landowners in national PES programs. The MCL was also instrumental in early reforestation efforts on private farms in the Monteverde region (see Bosques en Fincas, Section 3.3.1, below), and has maintained an active environmental education program since 1986. In this way, the reach of the CER extends beyond the borders of

[4]Mechanisms for the Costa Rican Payment for Environmental Services (PES) program and the National Forestry Financing Fund (FONAFIFO) were established in Costa Rica's Forestry Law 7575 in 1996 (Asamblea Legislativa de la República de Costa Rica 1996). FONAFIFO is the administrative entity for the national program. See Sect. 4 for further discussion of PES as a tool for conservation in Monteverde.

the Monteverde Reserve Complex, creating the human and natural connections needed to ensure the welfare of human and nonhuman communities in the future.

As is the case for many conservation organizations, the quest for economic stability over time has been one of the MCL's main challenges. Currently, about half of the MCL's total gross income comes from PES, including participation in Costa Rica's national program with FONAFIFO, and contracts with two private hydroelectric companies in recognition of the ecosystem services (abundant, clean water throughout the year) provided by thousands of hectares of protected forest upstream of their dams. Unfortunately, the cooperative spirit that led to the original signing of the private PES contracts did not last, and the MCL has had to fight to defend both agreements—including one that is still in the appeals process in the Costa Rican court system.

The MCL also receives important income from visitation at its field stations and trails. Though most of the CER is not open to the public, there are four visitation centers, including the Bajo del Tigre Reserve, which receives the most visitation (approximately 9,000 visitors in 2019). Two field stations, San Gerardo and Pocosol, offer rustic lodging, meals and trails to student groups and ecotourism visitors. Finca Steller, on the eastern border of the CER, is home to the MCL's environmental education program and native tree nursery, and also has a small trail system.

Donations and grants continue to provide crucial funding as well, although the increase in environmental crises on a global scale—NOAA (the United States Department of Commerce's National Oceanic and Atmospheric Administration; (2020)) reports that droughts, flooding, freezing, severe storms, tropical cyclones, wildfires, and winter storms caused $531.7 billion in damage between 2015 and 2019[5]—combined with changes in US tax law increasing the threshold for deductions for charitable giving (many of the CER's donors are US-based), have brought new challenges to the nonprofit financing landscape.

10.3.1.3 Santa Elena Cloud Forest Reserve

The Santa Elena Reserve (SER) is another example of a unique idea for biodiversity conservation piloted in Monteverde. The Santa Elena Technical-Professional High School (CTPSE, Colegio Técnico Profesional de Santa Elena)—the public high school which serves students from communities throughout the Monteverde region—provides technical skill training in areas relevant to the local economy. As tourism's influence grew to a substantial portion of the local economy, preparing local youth for careers in the tourism sector became a priority. The CTPSE had

[5]These NOAA (2020) figures do not account for other global environmental crises, including habitat loss due to large-scale Amazonian fires, the current Australian wildfires, world-wide coral reef decline, impacts of increasing plastic contamination in the world's oceans, melting glaciers and ice caps, and localized disruptions due to coastal zone flooding. Dollar values are based on losses which would not have been incurred had the event not taken place and include both insured and non-insured losses.

previously signed a long-term lease with the Costa Rican government for a 310-ha farm; however, using this farm for agricultural purposes did not prove successful (Burlingame 2000). In 1992, the Santa Elena Reserve was established as a training ground for ecotourism and gave students the opportunity to learn about park management and natural history guiding. The SER borders MCL's CER (see Fig. 10.1) and includes about 80% primary forest on the upper Atlantic slope (Burlingame 2000). In 2019, the SER received 51,164 visitors (Y Arias personal communication). Given its more remote location from the towns of Monteverde and Santa Elena, the SER receives fewer visitors than the MCFBP; however, this has made the SER an attractive alternative for birdwatchers and tourists who prefer less crowded environments. For researchers and ecology students, the SER also provides a good site for comparative research and study with respect to other reserves in the area.

10.3.1.4 Alberto Manuel Brenes Biological Reserve, Arenal Volcano National Park, and Other Surrounding Protected Areas

The Alberto Manuel Brenes Biological Reserve (RBAMB, Reserva Biológica Alberto Manuel Brenes), located contiguous to the CER and the north-eastern edge of the Bellbird Biological Corridor, spans 7,800 ha and is managed by the University of Costa Rica. Although very remote in terms of access via poorly-maintained roads from the nearest town, the RBAMB includes basic lab and dormitory space to support field research and field study courses.

The Arenal Volcano National Park (PNVA, Parque Nacional Volcán Arenal) spans 29,692 ha and includes its namesake, the Arenal Volcano, which was one of the hemisphere's most active volcanoes from the late 1960s through the first decade of the 2000s. Established in 1994, PNVA is an important buffer region on the Atlantic slope of the Monteverde Reserve Complex, extending forest connectivity to the north and east through lower elevations and protecting critical habitat and connectivity for migratory birds and large mammals requiring expansive ranges.

The Zona Protectora Arenal Monteverde[6] (Arenal-Monteverde Protected Zone) includes the MCFBP, CER, SER, Bosqueterno, RBAMB, PNVA, and a number of private farms, as well as a sizeable property to the north of Arenal Volcano National Park belonging to ICE, Costa Rica's electric utility (see Fig. 10.2). These are primarily located on the region's Atlantic slope. All of these additional protected areas have helped to expand the region's biodiversity island across the landscape.

[6] In Costa Rica, Zona Protectora is one of seven management designations for "protected wildlife areas." These also include National Parks, Forest Reserves, Biological Reserves, National Wildlife Refuges, Wetlands, and National Monuments. These are defined in Chapter VII, Article 32 of the Ley Orgánica del Ambiente, No. 7554, of October 4, 1995.

10.3.2 Sustainable Agriculture and Agroecology

Agricultural production in the earlier years of Monteverde's settlement was largely focused on subsistence because of the region's remote location and poor road access to external markets. Partly due to lack of access and partly because of personal values, many local farmers did not use agrochemicals, thereby contributing to more sustainable small-scale production (Griffith et al. 2000); nonetheless, agricultural expansion was a leading cause of deforestation in the Monteverde region through the 1970s.

Monteverde's Quaker settlers developed the nucleus of a large dairy production region, the "Monteverde milkshed," supplying the Productores de Monteverde S.A. dairy which, at its peak, grew into a large-scale producer of cheeses distributed throughout Central America (Griffith et al. 2000; Burlingame 2000). Due to low prices for milk, some of the pastures previously dedicated to dairy and mixed dairy-beef production have been abandoned and have returned to secondary growth forests (Stuckey et al. 2014).

Agriculture continues to be an important component of the local economy, but it does not currently contribute to continued deforestation. Instead, agriculture has moved toward a more sustainable model, particularly at higher elevations (Stuckey et al. 2014). Lack of support from extension agents is an ongoing challenge for local producers who have adopted organic and other sustainable farming methodologies (O Salazar personal communication).

While coffee has long played an important role in the local agricultural sector, the focus of Monteverde's coffee sector has shifted toward organic/sustainable production and is marketed primarily toward tourism (Stuckey et al. 2014). This includes direct sales to tourists as well as agroecology tours of sustainable farms, which diversifies the income stream for the farmers and their families. Integrated sustainably-produced coffee and agrotourism projects represent a rapidly-growing segment of Monteverde's agricultural economy.

A recent study by the TSC found a growing local market for sustainably produced agricultural products, but insufficient organization to connect producers to consumers and promote this emerging market for locally and sustainably produced foods (Tropical Science Center 2018). Consequently, TSC has initiated a new program, Encadenamientos Productivos (or Agricultural Products Network), to link local farmers with restaurants and other consumers, particularly within the Bellbird Biological Corridor. Some local businesses have independently developed similar initiatives. For example, the University of Georgia Costa Rica Campus (UGA CR) implemented the policy of purchasing the majority of food from within a 400 km radius of the campus, with an emphasis on on-site organic production and purchasing from local farmers in the Monteverde area and in the nearby lowlands who also followed sustainable agricultural practices. The Hotel Belmar and several other Monteverde-based hotels and restaurants have established on-site food production and local food purchasing components to their operations. Weekly farmer's markets in Santa Elena and Guacimal offer outlets for connecting local farmers with local consumers.

10.3.3 Biological Corridors

> *"The main focus of conservation biology at Monteverde since 2000 has been on the role of landscape features in preserving biodiversity, particularly connectedness between habitats at different spatial scales".* (Wheelwright 2014: 2).

This section describes some of the ways in which Monteverde has integrated landscape-level conservation into the surrounding communities, functionally extending the limits of the Monteverde biodiversity island beyond the physical limits of the core protected areas.

10.3.3.1 Bosques en Fincas

In the mid-1990s, the MCL administered the program Bosques en Fincas (or Forests in Farms), which encouraged local farmers to maintain existing forest fragments and connect them by planting windbreaks. Dairy farmers realized the effectiveness of windbreaks at maintaining pasture productivity during the extremely windy season. Many of these windbreaks are now 20–30 years old. The Bosques en Fincas program set the stage for expanding forest connectivity across the privately-owned landscape surrounding the Monteverde Reserve Complex and spawned research suggesting the critical importance of remnant trees for biodiversity conservation (Guindon 1996; Harvey and Haber 1999). Brownson et al. (2019) describe Bosques en Fincas as an example of a successful local PES program, in which farmers were engaged by the MCL's outreach team and given the species of trees they were interested in planting on their farms. This program triggered a cultural shift toward reforestation in the region (K Brownson personal communication), which set the stage for other reforestation programs focusing on native species reforestation (see Sect. 3.3.4, below).

10.3.3.2 Enlace Verde

In the mid-1990s, the Monteverde Institute promoted a corridor program, Enlace Verde, aimed at protecting existing forests on individual farms within the town of Monteverde using conservation easements. This program intended to connect the Children's Eternal Rainforest with the Bajo del Tigre Reserve, both owned by the MCL. At the time, the San José, Costa Rica-based Environmental and Natural Resource Law Center (CEDARENA, Centro de Derecho Ambiental y de los Recursos Naturales) was introducing the concept of conservation easements within Costa Rica and partnered with the Monteverde Institute to support the Enlace Verde program. Three easements were signed in 1998, including unique reciprocal easement contracts. Despite multiple charrette exercises and individual meetings with landowners, including preparation of drafts of easement contracts and accompanying maps, the overall program did not expand as hoped across some fifty properties located in six neighborhood clusters (Scrimshaw et al. 2000:382).

10.3.3.3 Reforestation Initiatives

Following in the footsteps of the MCL's Bosques en Fincas program, the Fundación Conservacionista Costarricense (FCC, or Costa Rican Conservation Foundation) was established in 2002 in response to the observed need to expand Pacific slope habitat for the Three-wattled Bellbird and other migratory species in this range. The FCC's reforestation program was started in 1998 as the "Bellbird Project" with the support of local organizations and funds provided by the British Embassy in San José, Costa Rica (D Hamilton personal communication). Following several years of project implementation, the formal non-profit foundation was established.

The FCC's tree nursery produces native forest species that provided free of charge to local landowners. The FCC has studied multiple areas where trees have been planted to understand and develop best practices that yield the greatest benefit-to-cost related to minimizing mortality rates and maximizing growth rates during establishment (D Hamilton personal communication). The FCC does not use formal agreements with recipient landowners to maintain the trees. To date, FCC has planted over 250,000 trees of more than 143 species and 42 families (D Hamilton personal communication).

The former University of Georgia Costa Rica Campus (UGA CR)[7] reforestation program was established in 2008 to offset University of Georgia students' emissions related to study abroad in Costa Rica, and ran for 11 years until 2019. In 2010 the FCC partnered with UGA CR, providing funding to expand the tree nursery. UGA CR's native species nursery primarily focused on species native to the San Luis Valley, where the campus was located. Planting was done both on-campus and on neighboring farms in San Luis, with saplings given to local landowners. UGA CR asked participant landowners to sign agreements which noted the numbers and species of saplings provided and stated that landowners agreed to maintain the saplings through establishment, however there was no enforcement. Beginning in 2011, UGA CR student groups and interns monitored planting sites to determine mortality and measure growth rates.

Between 2008 and 2016, the UGA CR program planted more than 35,000 trees representing over 90 species from the local forests (UGA CR unpublished data). For carbon offset estimates, mortality was estimated at 25%; however, at several sites, monitoring revealed high mortality due to cattle encroachment on one property and development of a housing lot on another. Other sites with effective protection for saplings during establishment had less than 5% mortality (UGA CR unpublished data).

Reforestation projects with non-binding agreements for landowner care of the trees planted are only as effective as the quality of the management provided until tree establishment. In their study of formal and informal payment for ecosystem services programs (see Sects. 3.4 and 4 for further discussion), Brownson et al.

[7]The University of Georgia sold this property in 2019. Long-term research and reforestation programs were not maintained by the current owner.

(2019) found that the more informal local reforestation programs in the Monteverde region promoted greater tree species diversity and more effectively engaged with less economically prosperous landowners than the formal national ecosystem services program.

10.3.3.4 Corredor Biológico Pájaro Campana (Bellbird Biological Corridor)

At the same time the Monteverde Institute was working on Enlace Verde, the TSC proposed the concept of a biological corridor following the Guacimal River watershed from Monteverde down the Pacific slope to the mangrove forests along the Gulf of Nicoya. As a step toward implementing this project, TSC acquired a 240 ha (593 acre) farm in the lower San Luis Valley, securing the largest remaining Pacific slope forest patch in the upper elevation of this watershed (Burlingame 2000). Further expansion of the corridor was not immediately put into place; yet the idea for a corridor initiative, like the seed of an *Ocotea monteverdensis* tree buried in the forest floor, was firmly planted and waiting for the right conditions to germinate.

The corridor initiative was revived in 2006, and in 2007 a group of local conservation and education organizations established the Local Advisory Committee for the Corredor Biológico Pájaro Campana (CBPC, or Bellbird Biological Corridor), including representatives from TSC, MCL, UGA CR, FCC, and the Monteverde Institute. The CBPC has been successful in large part due to common interests, shared vision, cooperative efforts, and commitment of time and funding by the organizations involved. The Local Advisory Committee successfully addressed differences in opinion, listened to and incorporated concerns from a wide body of stakeholder groups, and implemented the initiative in a professional manner.

The CBPC spans 88,738 hectares within three adjacent watersheds which flow from the Monteverde cloud forest to the Gulf of Nicoya—the Aranjuez, Guacimal, and Lagarto River watersheds (see Fig. 10.2). Eleven of Costa Rica's 13 Holdridge Life Zones (Holdridge 1967) are represented within the corridor, and approximately 50% of Costa Rica's terrestrial vertebrate species are found within this region (Welch et al. 2011).

The CBPC was recognized by the Costa Rican government as part of the formal national network of biological corridors connecting Costa Rica's larger parks and reserves. The CBPC's Local Advisory Committee secured funding from the UNDP Small Grants Program to develop a strategic plan for the corridor (Welch et al. 2011). This strategic plan defined key areas of common interest, and sub-committees then developed sector-specific work plans from these broadly defined goals (J Welch personal communication). Over the course of the next decade, the Local Advisory Committee was able to secure additional grant funding from the UNDP Small Grants Program to develop promotional and educational materials, hold workshops in communities throughout the corridor region, and establish multiple community-based sub-committees throughout the three watersheds. The Local Advisory Committee was sensitive to the appearance of conservation initiatives being driven by the

organizations—both literally and figuratively—"at the top of the mountain" (and in the communities which received the most direct economic benefits from ecotourism), and worked to build broad common interest in the concept of maintaining and expanding habitat connectivity. Local concerns were incorporated into the strategic plan and, subsequently, continued UNDP Small Grant Program funding helped to establish sub-regional committees to generate locally driven initiatives (J Welch personal communication).

A growing number of PhD dissertations, master's theses, and undergraduate thesis projects have been completed related to the Bellbird Corridor (e.g., Brownson 2019; Camacho Céspedes 2019; Padgett-Vasquez 2019; O'Halloran et al. 2018; Powlen 2018; Allen 2016; Chinchilla Ramos 2015; Piedrahíta López 2013). The University of Georgia and Lynchburg College carried out a long-term water quality monitoring program in the region for 8 years, documenting the macroinvertebrate communities in the three watersheds (T Shahady personal communication).

The CBPC also is the focus of current land purchase priorities for the Monteverde Conservation League, whose goal is to increase ecological connectivity between the Children's Eternal Rainforest and forested areas at lower elevations on the Pacific slope. The MCL has purchased more than 100 hectares in the CBPC since 2014 and continues to raise funds for land purchase and conservation in the area.

10.3.4 Payment for Environmental Services (PES)

Costa Rica's national Payment for Environmental Services (PES, or Pago por Servicios Ambientales) program administered by the National Forestry Financing Fund (FONAFIFO, Fondo Nacional de Financiamiento Forestal) has been extensively studied by academics and practitioners alike. The early years of Costa Rica's PES program coincided with a noticeable trend of afforestation across the country, following decades where Costa Rica experienced some of the highest deforestation rates in the world (FONAFIFO 2001). The successes of PES in helping to protect privately-owned forest land in Costa Rica is highlighted by figures such as over 10% of the country having been protected via PES forest conservation contracts (Ringhofer et al. 2013).

Within the CBPC, 11 Holdridge life zones were represented by PES contracts issued between 2008 and 2012, with most of these PES contracts located in areas not represented by the Monteverde Reserve Complex (Padgett-Vasquez 2019). During this time period, 51 properties throughout the CPBC region were inscribed by FONAFIFO in the PES program (Padgett-Vasquez 2019). These properties ranged in size from 11 to 300 hectares (Padgett-Vasquez 2019). The majority of the 51 properties were located along or in very close proximity to rivers and streams, which suggests that the protection of these forested areas through PES contributes to maintaining the functional integrity of the region's ecological systems (Padgett-Vasquez 2019).

10.3.5 The Monteverde-Arenal Bioregion Initiative (MABI)

One of the characteristics that makes Monteverde unique is the number of research scientists that have settled in the area and continued to study the region over multiple decades. The Monteverde-Arenal Bioregion Initiative (MABI) was initiated in 2014 by several of Monteverde's long-term research scientists and educators to coordinate and expand research, teaching, and outreach collaborations in support of biodiversity conservation. Given the ongoing observations and growing collective understanding about changing climate conditions in the Monteverde region and the likely impacts for biodiversity conservation (e.g., Pounds et al. 1999; Pounds et al. 2006; Nadkarni and Solano 2002; Eaton et al. 2012), MABI was created to develop shared database resources and coordinate regular conferences which serve to share information, define research priorities for the region, develop coordinated research proposals, and support each other's research, teaching, and outreach. To date, funding limitations have limited new region-wide collective research efforts, however the multiple MABI conferences held during 2014–2016 served to share information and build new relationships among the many scientists and educators working in the region (N Nadkarni personal communication).

10.3.6 The Monteverde Commission for Resilience to Climate Change (CORCLIMA)

The same capacity for community mobilization and organization and deeply-rooted environmental values that led to the creation of the Monteverde Reserve Complex and more recently the Bellbird Biological Corridor has also spawned a new initiative, The Monteverde Commission for Resilience to Climate Change (CORCLIMA). Promoting Costa Rica's National Strategy for Climate Change, local residents and institutions have joined forces and are coordinating across sectors and scales with the goal of leading the Monteverde Zone to become carbon neutral and develop climate resilience strategies for the region (Brenes et al. 2019, corclima.org). While the carbon balance benefits are global in scale, the adjustments Monteverde seeks to achieve in meeting carbon neutral goals and implementing climate change resilience will enhance the quality of life for local residents, help further protect habitat to support the region's biodiversity, and promote Monteverde's reputation as an authentic, sustainable tourism destination. CORCLIMA's actions serve as a demonstration for other communities seeking to implement similar plans.

10.4 Challenges for the Future

How to sustain the local economy, improve quality of life for a growing local population, and continue to protect the region's natural capital while adapting to changing climate conditions is the biggest overarching challenge facing Monteverde today. Should the projected changes in climate impact the cloud forest habitat to the extent that it further threatens the populations of quetzals, bellbirds and other iconic species which draw many tourists to the region, what impact will that have on tourism and thus the local economy? Long-term biodiversity conservation is tied to economic stability, and economic downturn can lead to increased pressure on forests and forest resources. How can Monteverde diversify the local economy and also find alternative funding mechanisms for biodiversity conservation to balance fluctuations in tourism?

Addressing the challenges requires both top-down and continued grass-roots leadership. Coordinated strategic visioning with an alignment of national policies integrating environmental conservation, agricultural production, and continued development for sustainable tourism, sustainable manufacturing, and service sectors are also needed. Costa Rica's national law recognizing biological corridors as regions where such integrated conservation and development takes place provides a broad legal framework and national administrative structure to support local initiatives. Yet as Padgett-Vasquez (2019) notes, one of the challenges in landscape-level conservation is to establish functional wildlife corridors within these broadly declared conservation regions spanning privately-owned property. The accomplishments of the Bellbird Biological Corridor reflect how local leadership capacity and coordination is critical to implement such broad national conservation plans. The challenge of funding staff and administrative overhead to support the ongoing coordination of the CBPC reflects the common economic struggle faced by grass-roots conservation initiatives around the world. Volunteer boards comprised of dedicated representatives of local NGOs can only carry conservation initiatives so far, particularly in small communities.

Planning and zoning is of critical importance as populations grow and small rural towns like Santa Elena undergo rapid urbanization. Of the 82 cantons in Costa Rica, 40 have developed zoning plans, 21 have comprehensive environmental planning regulations, and only four have completed studies of hydrological vulnerability and established guidelines regarding water resource protection (INVU 2019). While the springs emanating from the protected reserves supply clean water for the region, wastewater management and contamination of local waterways continues to threaten public health as well as Monteverde's aquatic diversity outside of the protected areas.

A growing body of literature through the first two decades of the twenty-first Century describes the shortcomings of public land conservation programs to provide sufficient habitat to address long-term biodiversity conservation concerns (Norton 2000; Chacón 2005; Mayer and Tikka 2006; Pasquini et al. 2011; Kamal et al. 2015). In particular, there is growing recognition that connectivity across a wider landscape

is critical to provide sufficient habitat to support migratory species through an increasingly more densely human-dominated landscape, and to support long-term ecological resiliency and both floral and faunal adaptation to changing global climate conditions (Zamzow et al. 2018). Yet for privately-owned projects and conservation initiatives led by non-governmental organizations to be successful, there must be supportive public policy in place to encourage and support conservation practices (Pasquini et al. 2011). Private nature reserves and those owned by non-governmental organizations have some advantages compared to public protected areas—management flexibility, ability to make decisions more rapidly, and broader economic opportunities (Pasquini et al. 2011). Indeed, in the case of Monteverde, initial government designation of the region as a Zona Protectora was ineffective and led to the local establishment of NGOs to fill the conservation gap. Private land conservation—including NGO-owned conservation reserves—cannot exist in a vacuum, however, and requires lock-step coordination with the public sector and the long-term public sector commitment to establish and maintain such policy. Comprehensive conservation policy supporting private land conservation must address ecological, economic, and social aspects, including public education required to embed the value and importance of biodiversity conservation as core to the human condition. From the local to global-scale, there must be coordination and commitments from the public sector reflecting that biodiversity conservation is a priority beyond partisan politics.

For private land conservation programs to successfully meet conservation goals, there is a need for thoughtfully designed, contextually-appropriate incentive programs to encourage private land conservation that address both ecosystem conservation goals as well as economic productivity which is considered a right of private land ownership (Mayer and Tikka 2006). The ability of farmers to adopt more sustainable agricultural practices is largely influenced by broader socio-economic trends, national-level rural development policies, and institutional capacity of agencies, such as the Ministry of Agriculture, to provide technical support for organic and other forms of sustainable agriculture (Wegner 2016). Conversations with coffee farmers in Monteverde reveal the complete absence of Ministry of Agriculture extension support for farmers practicing organic agriculture (O Salazar personal communication), despite the growing international demand for certified organic products.

As a tool in the biodiversity conservation toolbox, payment for ecosystem services has been employed in Costa Rica since the mid-1990s. While studies of the earlier years of the PES program found that PES was effective at increasing forest cover within biological corridors in Costa Rica (Morse et al. 2009; Newcomer 2007), most evidence in Costa Rica, however, points toward PES not being particularly helpful in changing landowner decision-making, and there is mixed evidence at best about whether PES payments broadly contribute to avoided deforestation (Allen 2018, K Allen personal communication). In the case of private landowners in the Monteverde area, PES subsidizes land abandonment and/or protection of forests which are not necessarily in imminent threat (K Allen personal communication) and, in general across Costa Rica, has favored larger landowners (Zbinden and Lee 2005;

Newcomer 2007). Furthermore, individuals have expressed a lack of trust with the government (Newcomer 2007; Allen and Padget-Vasquez 2017), in part driven by restrictions placed on properties in PES during and following the termination of PES contracts (S Padgett-Vasquez personal communication). Thus, local PES programs, such as the reforestation programs described in Sect. 3.3.3, are effective ways to build trust relationships with smaller local landowners, increase tree species diversity across the landscape, and provision ecosystem services (Brownson et al. 2019).

Despite these noted issues, however, the national PES program is an important mechanism that provides critical funding for ongoing habitat protection and biodiversity conservation of large protected areas owned by NGOs such as MCL. Fundraising for the purchase of land for conservation purposes is challenging; fundraising for ongoing maintenance and protection of these properties is far more difficult. While Costa Rica's PES program promotes biodiversity conservation as one of the four primary ecosystem services recognized in all PES contracts, carbon sequestration and hydrological services are the primary services connecting buyers (e.g., those purchasing gasoline, those using water in manufacturing) to sellers (i.e., forest land owners). In the case of NGOs, including MCL, which own large tracts of land that serve as regional biodiversity islands, the service provision of biodiversity conservation is a high value-added contribution to the bundle of ecosystem services. Given FONAFIFO's ongoing struggles to fund the national PES program via gas taxes, water fees, and subsidies from international agencies (including the World Bank and the Global Environment Fund), a more coordinated, holistic national policy strategy might incorporate a small fee for the provision of biodiversity services as a mechanism to help support local NGOs' land conservation initiatives, such as the Monteverde Cloud Forest Preserve and the Children's Eternal Rainforest.

Efforts to integrate natural capital accounting into the national accounting structure can help Costa Rica better value and manage its natural resources. Providing such an overarching framework allows private industry, non-governmental organizations (NGOs), and individuals to then pursue innovative approaches toward achieving a more sustainable economic and ecological future for Costa Rica. Such a holistic approach toward national development policy would provide the framework for sustaining and expanding biodiversity islands such as Monteverde.

10.5 Conclusion

Monteverde reflects a unique conservation situation where the national government of Costa Rica recognized the importance of the region for biodiversity conservation but was not able to dedicate resources to establish a public protected area. International research scientists partnered with existing Costa Rican NGOs and established new local NGOs, filling the federal conservation gap by securing funds to purchase and manage large swaths of forest across the region. At the heart of the region's privately-held protected lands are 554 hectares of forest that Quaker settlers set aside

to protect their community's water source some 20 years prior to the establishment of larger protected areas.

Many of the international scientists studying the area's ecology decided to make Monteverde their home and/or have spent significant amounts of time in the region over decades. They helped to establish local NGOs that not only protect land and study the region's ecology, but also help to share this knowledge with the local community and teach local people about what they are studying. Over time, they have created a vast body of knowledge about Monteverde's biodiversity, some of which we have highlighted in Sect. 2 as representative of the Monteverde region. In turn, many local residents have subsequently committed their professional careers to support conservation initiatives, working as naturalist guides, park guards, research technicians, administrators, and educators. Together, this blended community established local schools that incorporate experiential learning and environmental stewardship into their curriculum, spreading conservation values among the younger generations. As described, the NGOs translate knowledge into outreach programs supporting local farmers and broader community interests, all the while maintaining a core mission of habitat protection. The local NGOs capitalized on the increased popularity of Costa Rica as an ecotourism destination and the region's charismatic species and were able to move more nimbly than many of the public parks, setting up infrastructure, administration, and support services to promote nature-based tourism. This grew the local economy and increased general prosperity in the region. As described in previous sections, the diversity of different types of initiatives—university partnerships, sustainable tourism, international fundraising campaigns, purchasing policies for sustainable products, carbon offsets, farmer and landholder outreach, technical school partnerships, etc.—have formed a patchwork quilt of biodiversity conservation that has endured for nearly 50 years. As some pieces of this quilt fray, the Monteverde community has remained dedicated to the long-term biodiversity conservation goals and has developed new initiatives to fill the gaps. From the initial successes of establishing the MVCFBP, the CER, and the SER, the scale of conservation initiatives has expanded from bounded protected areas focused on Monteverde's cloud forests to landscape-level protection spanning both Atlantic and Pacific slopes.

Changing climate conditions now make Monteverde an interesting place to study the impacts of these changes on the cloud forest ecosystem. How this biodiversity island will evolve, how biological corridors will support species migration, and how climate impacts and projected resource constraints will affect the region's socioeconomic conditions and how that, in turn, impacts biodiversity conservation remains to be seen. If there is a big-picture takeaway message from the case study of Monteverde, it is that biodiversity conservation—through a portfolio of private land conservation initiatives, public parks and reserves, and public-private partnerships—is a continuously evolving process made ever more challenging by changing climate conditions, yet made possible and successful by highly engaged, coordinated, cooperative private-sector, public-sector, and NGO-led initiatives.

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