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Waterbird Biodiversity and Conservation Threats in Coastal Ecuador and the Galapagos Islands

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1. Introduction

Within the context of the Convention on Biological Diversity (CBD) of the United Nations Environment Programme, the conservation of biodiversity is one of the major goals devoted to minimize and mitigate significantly the existing rate of biodiversity loss at the global, regional and national scales. At this level, birds are exemplary sentinels and bioindicators for the conservation and monitoring of biodiversity and ecosystem health. While 1226 bird species are considered globally threatened with extinction due to small and declining populations or ranges (BirdLife International, 2008), a substantial number of seabird populations are declining and threatened with extinction at the global level because of several conservation threats both on land and at sea, including fishery interactions, predation by invasive species and habitat loss due to coastal development (BirdLife International, 2010). The Pacific is an important area for threatened seabirds, where their ranges span multiple Exclusive Economic Zones (EEZs) as well as many areas beyond National Jurisdictions (ABNJs). Although seabirds represent only 3% of the total number of bird species in the world, about 28% (over 130 species) are listed as threatened on the IUCN red list for birds, under which 10% of seabirds are Critically Endangered (BirdLife International , 2010).

Under the CBD, Ecuador is a signatory country (1992) and ratified the Convention in 1993 with the aim to pursue and establish conservation efforts and action plans to preserve the national biodiversity, including birds. Despite of being one of the smallest countries of the world (i.e., 0.19% of the terrestrial surface of the Earth) with 256 370 km^2 and a human population close to 14 millions inhabitants, Ecuador is one of 17 world's megadiverse countries due to its rich biodiversity and high degree of bird endemism (Mittermeier et al., 1997; Stattersfield et al., 1998). Of the 151 wetlands identified as key habitats for Neotropical waterbirds in Ecuador, 40% are present on the continental coast (i.e., 59 wetlands), while 14 exist in the Galapagos (Santander et al., 2006). There, a total of 1640 species of birds are geographically distributed into four well defined geographical zones: the coast (coastal

Ecuador), the Andean region (highlands), the Amazon jungle (eastern region) and the UNESCO Heritage site, the Galapagos Islands. Of the total number of bird species recorded in Ecuador, 13.6 % or 223 species (Granizo et al., 2002; Santander et al., 2006a) are represented by aquatic and seabirds dwelling diverse habitats including oceanic-offshore environments, nearshore habitats, intertidal zones, islands, coastal lagoon, mangroves, shrimp farms, salt ponds and continental freshwater systems.

However, several environmental stressors and human activities threaten the population and survival of waterbirds in both continental Ecuador and the Galapagos. While habitat fragmentation and deforestation, urban sprawl, agriculture, current use pesticides, marine pollution and wetland degradation are the major impacts identified on the Ecuadorian coast, invasive species and pathogens, bycatch (long-line/gillnets) and the regional climate variability are the major threats in the Galapagos Islands. While these conservation threats have been recognized to some degree, most of their impacts have been scarcely identified and assessed. This is critical under the paradigm of conservation biology and preservation of wildlife, depending on science sound data and baseline information intended to support environmental management plans and conservation efforts.

Therefore, the aim of this chapter is to contribute with a review focused on the conservation status of the biodiversity of aquatic birds and an overall environmental impact assessment of current and looming threats in Ecuador, with special emphasis in the Galapagos Islands. To accomplish this goal, a revision of waterbird species and abundance of seabirds, shorebirds and aquatic birds of freshwater systems will be conducted. The chapter will also include a section describing major features of the natural history and conservation status of priority species, including threatened and endemic species (e.g., Waved Albatross, Galapagos Petrel, Galapagos Penguin, Flightless Cormorant, Horned Screamer, Brown-wood Rail, among others), as well as key species for the functioning and health of aquatic ecosystems. This section will be followed by the identification and assessment of current anthropogenic impacts and emerging conservation threats jeopardizing their survival in critical habitats and protected areas. Finally, the chapter will conclude with a section portraying mitigation strategies, recommendations for waterbird conservation and environmental stewardship.

2. Regions and study areas

Under the National Protected Areas System (SNAP, created in 1976), there are currently 40 protected areas, of which 37 are continental (18% of Ecuador); one is insular, The Galapagos National Park (693,700 ha); and, two are exclusively marine, including the Galapagos Marine Reserve (GMR) with 14,110,000 ha. In addition, Ecuador possesses 107 areas designated as Important Bird Areas (IBAs) and 12 Ramsar sites (i.e., wetlands of international importance) for the conservation of biodiversity and protection of threatened species, including critically endangered species (Santander et al., 2009). A review of all sites and areas for waterbirds conservation in Ecuador are out of the scope of this chapter; therefore, for the purpose of this review, only regions and areas in which the authors have been directly involved in censuses, banding, field work and research in southern Ecuador and the Galapagos Islands, described as follows.

2.1 Guayaquil Gulf Estuary Basin

The Gulf of Guayaquil is the largest estuary of the Pacific coast in South America with surface area of approximately 13,701 km and 230 km of length (Fig. 1). The entrance of the

Gulf is located at 3ºS of Ecuador and it goes 204 km from north to south, and enters a distance of 130 km. This estuary is located on the edge of the Guayas River and the city of Guayaquil. It is part of the Guayas Ecosystem, a large tropical area covering the Gulf of Guayaquil, the Guayas River Basin, the Guayas River Estuary and the city of Guayaquil. This ecosystem is home to 45% of the national human population, and articulates 12 provinces and 88 municipalities. Several watersheds drainage into the Guayas River Basin, including a vast geographical area with a hydrological system of 34 000 km^2, which captures the effluents coming from the Daule, Vinces and Babahoyo rivers. The Guayas River Estuary begins on at the Puná Island, across the Jambelí and Del Morro channels, and extends as far as the influence of the tide and salinity, which ends about 100 km within the continent at the confluence of the Daule and Babahoyo rivers. The depth of The Guayas River Estuary ranges from 20 to 180 m.

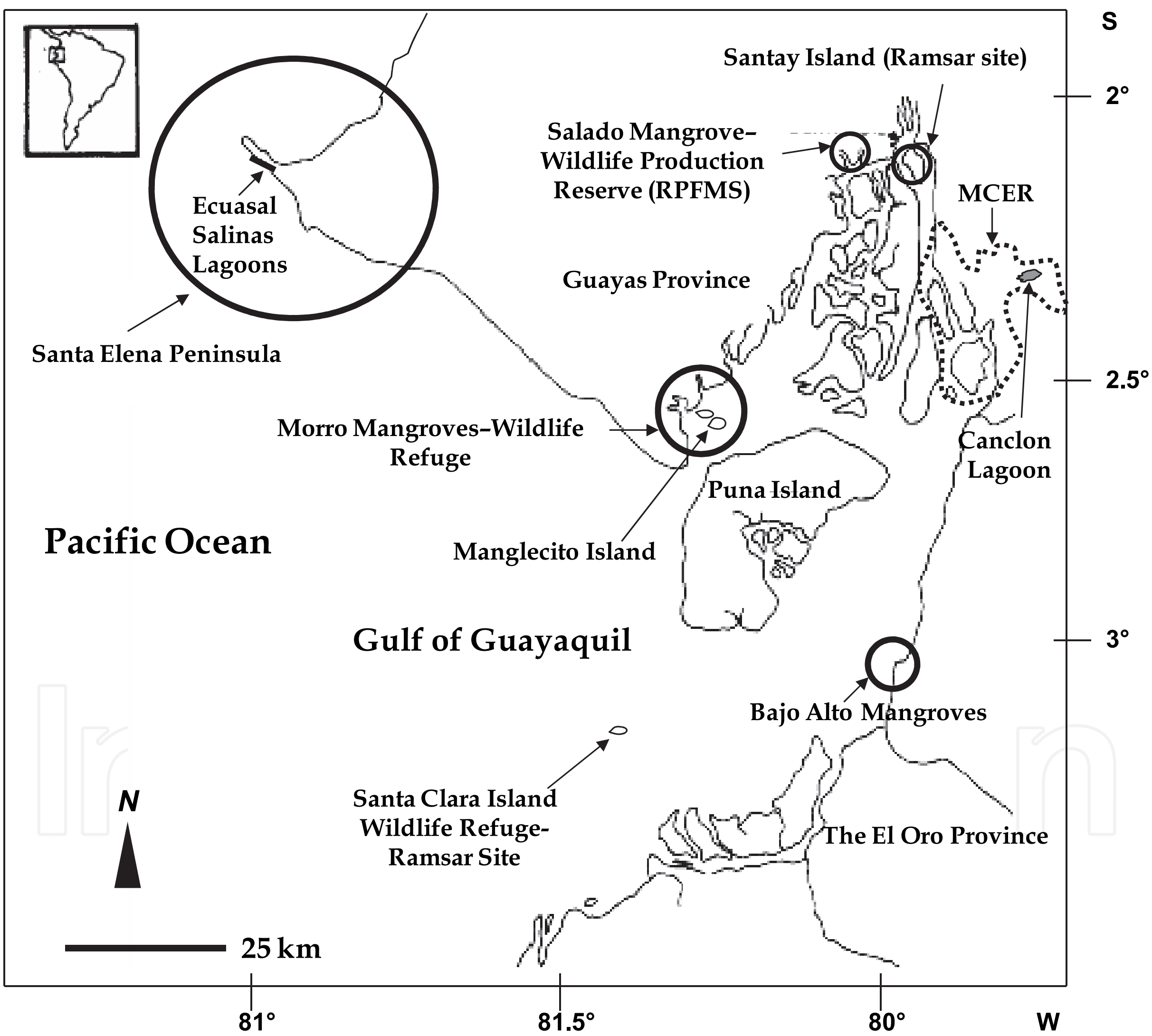

Fig. 1. Study areas on the southern coast of Ecuador, including mangrove-estuarine areas (as indicated by black rings) in the Guayaquil Gulf and Guayas River Basin and several other coastal sites, including the Ecuasal lagoons in the Santa Elena Peninsula (Santa Elena Province), Canclon Lagoon, located in the Manglares Churute Ecological Reserve (MCER); and Santa Clara Island (The El Oro Provi nce).

The Guayaquil Gulf Estuary contains approximately 81% or 121 hectares of the total area of Ecuadorian mangroves, encompassing about 148,000 hectares (CLIRSEN 2007)., and is suitable habitat for vast populations of different species of herons and egrets, shorebirds and frigatebirds, (Alava et al., 2005, Carvajal et al., 2005, Carvajal & Alava, 2007).

2.2 Churute Mangrove Ecological Reserve and El Canclon Lagoon

The Manglares Churute Ecological Reserve (MCER) (02°30'S, 79°42'W; Fig. 1) is located in the Guayaquil Gulf Estuary Basin (INEFAN & Fundación Natura, 1997; Briones et al., 2001) of the Guayas province. El Canclon Lagoon is one of the 32 wetlands identified in the Ecuadorian coastal region and was declared as a Ramsar site in 1996. The surrounding floodplain has an area of 800 ha, and is situated in the northern part of in the northern part of the MCER. Moreover, the El Canclon Lagoon is part of one of the most important endemic bird areas (EBA) in the Neotropics for biodiversity conservation, the Tumbesian region, which extends from southwest Ecuador to northwest Peru (Best et al., 1995; Stattersfield et al., 1998). Its lentic bodies of water and surrounding wetland ecosystem constitute a unique riparian habitat and refuge for Neotropical migrants as well as resident breeding birds. Among the tropical plant species representatives of the area are floating and emergent water plants such as duckweed (*Lemna minima*), water hyacinth (*Eichornia crassipes*), sleeping-beauty waterlily (*Nymphaea blanda*), water lettuce (*Pistia stratoites*), flat sedge (*Cyperus odoratus*) and cattails (*Thypa latifolia* and *T. dominguensis*) (Sierra et al., 1999). In addition, riparian vegetation, lowland bushes, and tropical dry and humid forest remnants border the southeast, east and northeast edges of the lagoon, which lies adjacent to the mountainous watershed of the El Mate, Perequete Chico, Perequete Grande, Cimalon, Pancho Diablo and Masvale hills. The area's unique habitat types, as well as its high level of bird endemism (~ 40%) (Alava et al., 2002), warrant the publication of all ornithological observations of the area, which may prove useful to future conservation efforts. The aquatic species recorded in and around El Canclon Lagoon include mainly waterfowl such as Fulvous Whistling Duck (*Dendrocygna bicolor*) and Black-bellied Whistling Duck (*D. autumnalis*), Neotropical Cormorant (*Phalacrocorax brasilianus*), Purple Gallinule (*Porphyrula martinica*), Wattled Jacanas(*Jacana jacana*), and herons such as Great Egret (*Ardea alba*) and Cattle Egret (*Bubulcus ibis*) egrets (Briones *et al.* 2001; Alava et al., 2002; Alava et al., 2009). A representative threatened species residing year-round in this wetland is the rare Horned Screamer (*Anhima cornuta*), a bird locally known "canclon" (Alava et al., 2007).

2.3 Reserva de Producción de Fauna Manglares el Salado-RPFMS (El Salado Mangrove–Wildlife Production Reserve).

The RPFMS is a wildlife refuge confining 9,748 hectares of remnant mangroves in southeast Guayaquil City (2º10'S, 79º56'W), Guayas Province. About 3% of the total area of this reserve is occupied by shrimp farms (<200 ha), of which 100 ha have been abandoned. Three thermoelectric facilities, a water pump station and sewers also occur within its boundaries. Small-scale clearing of mangrove trees (i.e. timber extraction for coal production) occurs at specific locations, while pollution from solid wastes and water contamination are environmental issues of concern being close to human urbanization and industrial parks (Carvajal et al., 2006). Artisanal fisheries are subsistence activities practiced by communities residing within the RPFMS. Although the RPFMS has a moderate level of fragmentation in some locations, and severe in others, some pristine mangroves in isolated patches are still well conserved and act as biological corridors and provide suitable habitat for local waterbird populations (e.g., heron nesting sites) and mammals. Mangroves around this area, including the Puerto Hondo Mangroves Sanctuary, are roosting habitat for about 214 individuals of the Red-lored Amazon (*A. autumnalis lilacina*) (Berg & Angel, 2006). Five of the six species of mangrove trees recorded for Ecuador are found in this reserve: red mangrove (*Rhizophora mangle*), hybrid red mangrove *(Rhizhopora harrisonii)*, black mangrove (*Avicennia germinans*), white mangrove (*Laguncularia racemosa*) and *jeli* or button mangrove (*Conocarpus erectus*).

2.4 Isla Santay (Santay Island - national recreation area)

Isla Santay is a Ramsar site (02º13'S, 79º51'W) with 4,700 ha located in the inner estuary of the Guayaquil Gulf (Guayas River Basin) and also close to the urban periphery of Guayaquil City (Delgado et al., 2000, Jaramillo et al., 2002, Santander & Muñoz, 2004). Isla Santay includes intertidal mud, sand or salt flats and intertidal forested wetlands, encompassing mangrove swamps, and tidal freshwater swamp forests. The total area of mangroves on is 2,224 hectares. The mangroves includes: *R. mangle, R. harrisonii*, *A. germinans, L. racemosa, C. erectus,* mangrove golden leatherfern (*Acrostichum aureum*)*, Salicornia fruticosa* and *Zizhypus thyrsiflora.* During the rainy season (i.e. late December to May) 60% of the island is flooded. The island is also inhabited by humans and several anthropogenic activities such as livestock farming (goats, pigs, and chickens), coal production from burning of trees and rice cultivation (Delgado et al., 2000; Jaramillo et al., 2002). Even though it has a considerable degree of human perturbation, Isla Santay is still a refuge for numerous species of terrestrial birds and waterbirds.

2.5 El Morro Mangroves Wildlife Refuge: Isla Manglecito (Manglecito Island)

The El Morro Mangroves Wildlife Refuge (2°39'S, 80°11'W) is a recent protected area encompassing 10,130 ha of mangrove forest, intertidal mudflats, estuarine channels and creeks in the El Morro Channel (Guayas Province), Gulf of Guayaquil. Manglecito Island, also known as the Frigatebirds' Island, is part of this Reserve and is habitat for a large breeding colony and year-round population of 2,000-6,000 Magnificent Frigatebirds (*Fregata magnificens*), which a large seabird population on the Ecuadorian coast Five species of mangrove trees occur in this island too, including red, hybrid red, black, white and button mangroves.

2.6 Santa Clara Island

Santa Clara Island (3º10' S, 80º 26' W) is a Ramsar site and a Wildlife Refuge in the Gulf of Guayaquil and influenced by the highly productive Peruvian upwelling system, delivering nutrient enriched water to the marine ecosystem of the island (Nixon and Thomas, 2001). With 5 hectares and 50-60 meters over the sea level, this refuge harbors the largest colonies of seabirds (15,000-20,000 seabirds), including one of the largest magnificent frigatebird population (5000-8000 frigatebirds) and about 6000−14000 blue-footed boobies and 3000−4000 brown pelicans, in coastal Ecuador (Valle, 1997; Valle, 1998; Suarez & Calle, 2005). The island possesses arid vegetation represented by *Capparis* and *Cordia* shrubs, as well as *Armathocereus* cactuses. Due to the large number of sea birds breeding on the island, the harvesting of "*guano*" has been recorded as an illegal activity, with a total extraction of 120 m^3 equivalent to 2000 sacs per season (Suarez y Calle, 2005). The Santa Clara Island is considered as one of the most important areas used as nesting and resting sites by blue-footed boobies in Ecuador's mainland coast (Miranda et al., 2010).

2.7 Bajo Alto Mangroves

The Bajo Alto mangroves is located in the El Oro Province (3ºS, 79.5ºW), and encompasses 555 ha, from which 357 ha are mangrove forests and 199 ha is represented by the adjacent estuarine water (Calle, 2003). Bajo Alto mangroves are not yet under any protected area or reserve status even though all the mangroves are protected by the Ecuadorian Mangrove Law. Mangrove remnants are still semipristine, and suitable for wildlife. The El Oro Province is typically characterized by a vast amount of banana plantations and shrimp farms. For instance, shrimp farm ponds are encroaching nearby mangrove habitat where mangrove hawks were sighted. The predominant mangrove tree species in this area is the red mangrove, followed by black and white mangroves (Calle, 2003).

2.8 Santa Elena Peninsula

The Santa Elena Peninsula is located in the southern coast of Ecuador (Fig. 1). This Peninsula is under the influence of the cold Humboldt Current, and, throughout the year, the environmental temperature fluctuates between 22ºC in summer (between June and November) and a maximum temperature of 33ºC in winter (between December and May). From June, when the southern winter sets in, the temperature of the sea surface decreases. Masses of relatively cold sea air enter the coastal strip, resulting in drizzly weather with very weak rain values, so this is an area of dry weather with a maximum average of 250 mm a year (WHSRN, 2009a). On the south east side of the Santa Elena Peninsula (southwestern tip of the mainland coast) there is a series of salt lakes owned by the ECUASAL Company and categorized as an IBA (see next subsection). In September 2007, a narrow coastal strip of coastal habitat and surrounding maritime stretch of ocean was declared marine protected area. It is located at the westernmost tip of the province of Santa Elena, and includes the beaches and several square miles of water around the Chocolatera. At present, a sea-watching project is being carried out. In order to know about the presence, migration and other behavior of the bird species, regular countings are done from the Chocolatera. The Santa Elena Peninsula is considered an important area and stopover for migratory birds (Haase, 1991; Haase, 2010). In 2010, the results of a total of 250 hours of sea-watching revealed that many poorly known species happen to occur more frequently near Salinas than previously thought. They include threatened species like Waved Albatross (*Phoebastria irrorata*), Galapagos Petrel (*Pterodroma phaeopygia*), Parkinson´s Petrel (*Procellaria parkinsoni*), Pink-footed Shearwater (*Puffinus creatopus*). Other species of concern like Elegant Tern (*Thalasseus elegans*) and Peruvian tern (*Sternula lorata*) are also observed at regular times. The Arctic Tern (*Sterna paradisaea*) and the Sabine's Gull (*Xema sabini*), as well as the six species of boobies occurring in coastal Ecuador (*Sula* spp.) have been also recorded from this area (Haase, 2010). This observation site directly within the Marine Protected area is located near a light house, at 6 meter above the sea level. This panoramic site offers a view of 280 ° of ocean, and is an extraordinary strategic location to watch sea- and coastal bird migration throughout the year. Within one year, 57 species of sea and coastal birds were recorded (Haase, 2010).

2.9 Ecuasal-Salinas Lagoons

The Ecuasal lagoons are located in the southwestern coastal region of Ecuador (Santa Elena Peninsula), including the Salinas (500 ha) and Pacoa (1000 ha) lagoons. The Ecuasal lagoons are man-made lakes situated less than 200 m from the coastline (Salinas: 02º 13´S 80º58´O; Pacoa: 02º 05´S 80º44´O), which were dug out in order to extract sea salt for commercialization by the Ecuadorian Salt and Chemical Products Company (ECUASAL) (WHSRN, 2009a). The Salinas lagoons are located 1 km southeast of the town of the same name and the Pacoa lagoons are 10 Km from Santa Elena (15 Km from Salinas) between San Pablo and Monteverde). The Salinas lagoons face the sea (towards the west) and are surrounded by different types of urban and industrial infrastructure, while the Pacoa lagoons are still mostly surrounded by an arid semi-desert area. Due to the dry, cold weather and scarce precipitation, this is one of the few areas in the country that facilitates salt production at industrial level. The lagoons are a suitable habitat for aquatic birds and currently home to thousands of resident and migratory water birds throughout the year (WHSRN, 2009a,b), and this already prompted its designation as Important Bird Conservation Areas (IBAs) (Santander et al., 2009). The lakes are an important stopover place for migratory birds, particularly during the months of August and September when they gather in large numbers. Systematic census work has been carried out since 1988, and a total of 95 species of aquatic birds have been registered, including 41 species of shorebirds, 9 gull species and 10 tern species (WHSRN, 2009a ; Haase, 2011a). An average of 4000 birds is counted per month. Each year the maximum number of birds is counted in September, when more than 30,000 individuals of the Wilson's phalarope (*Phalaropus tricolor*) have been counted in the area, representing more than 2% of the total population (Haase, 2011a). Additionally, the site is home to over 20,000 waterbirds per year. The Grey-hooded Gull (*Croicocephalus cirrocephalus*) breeds from February until October with over 700 pairs, and 400 pairs of Gull-billed Tern (*Gelochelidon nilotica*), in colonies spread out over the area (Haase, 1991; WHSRN, 2009b; Haase, 2011a). The Kelp Gull (*Larus dominicanus*) and South American Tern (*Sterna hirundinacea*) has also been found to breed and nest in this area for first time in Ecuador (Haase, 1996; WHSRN, 2009b). Other birds, among them some near threatened (NT) species, are regular visitors or permanently resident waterbirds of the site such as Peruvian Tern, (*Sternula lorata*), Chilean Flamingo (*Phoenicopterus chilensis*) and Elegant tern (*Thalasseus elegans*) (WHSRN, 2009b; Haase, 2011a).

2.10 Galapagos islands

The Galapagos comprises an Archipelago with 13 major volcanic islands, situated approximately 1000 km from the Ecuadorian coast, between 01°40´N-01°25´S and 89°15´W-92°00´W (Fig. 2). The roots of their unique nature can be attributed to their remote, oceanic geography. At present, 2,909 marine species have been identified, of which 18.2% are endemic to the Galapagos (Bustamante et al., 2002). Several oceans currents influence the regional climate and drive the population dynamics of native and endemic species. The most important oceanic surface currents are the Panama (El Niño) current, coming from the Northeast and bringing warm, nutrient-poor waters and, and the Peru (Humboldt) current, arriving from the Southern Ocean, and transporting cold, nutrient rich waters. Both current systems merge to form the South Equatorial Current (SEC), which drives surface marine waters to the west of the islands and which has been proposed as the major mean of transportation bringing species from mainland Ecuador to the Galapagos (Banks, 2002;

Bustamante et al., 2002). Remarkably, about 50% of terrestrial and waterbird species are endemic to the Galapagos either at the species or subspecies level (Jimenez-Uzcategui & Wiedenfeld, 2002; Wiedenfeld, 2006). The Galapagos and surrounding waters harbour between 88 and 111 species of seabirds and coastal-shorebirds, including native, breeding and regular migrant species.

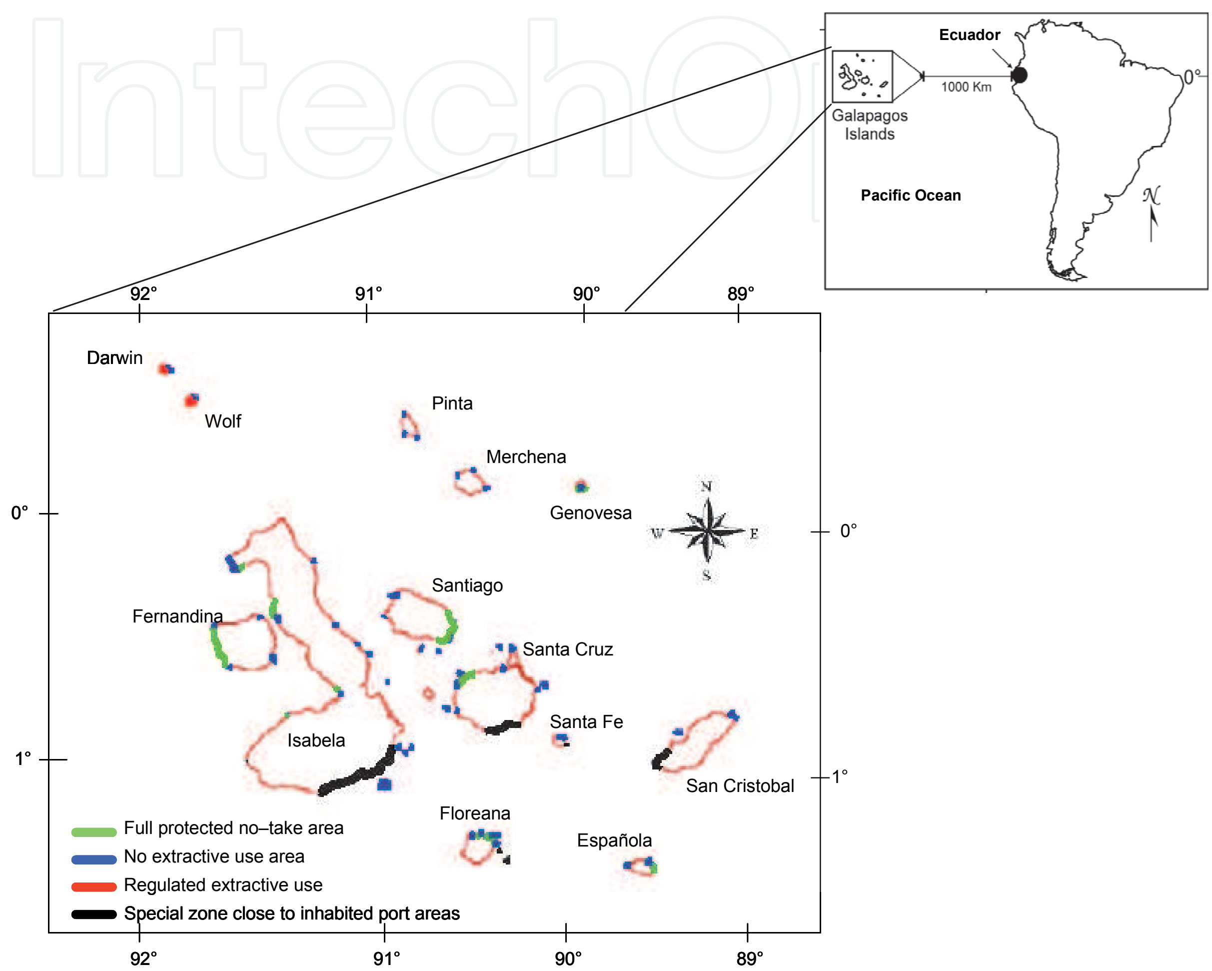

Fig. 2. Location of the Galapagos Islands relative to continental Ecuador, South America. The coastal zoning scheme for the Galapagos Marine Reserve (GMR) is also shown. The zones are fully-protected 'no-take' area, in green; non-extractive use areas, in blue; regulated extractive uses, in red; and, special zones nearby the inhabited port areas, in black. Adapted from Charles Darwin Foundation and World Wildlife Fund (2002).

3. Censuses and field methods

3.1 Ecuador mainland coast

Field observations and censuses were conducted from December 1998 to January 2002 to conduct inventories of waterbirds in mangrove areas of the Gulf of Guayaquil. A total of 22 field trips were deployed, including observations from a boat and an over-flight surveillance trip in an aircraft through mangrove conservation monitoring routes (Carvajal & Alava, 2007; Alava, 2005). Boat trips also followed line transects (n = 9) of 25 and 4 km established in three different areas (northwest, northeast and southeast) of the Gulf of Guayaquil to conduct the censuses (Alava, 2005). From February 2001 to January 2002, weekly bird inventories and 218 alternated field censuses to study aquatic birds were conducted simultaneously or sequentially during a study focused on a Horned Screamer population and habitat along 100m transects around the Canclon lagoon perimeter in five survey areas, showing different degree of perturbation, during the dry and wet seasons during 92 days (Alava et al, 2007; Alava et al., 2009). Daily observations lasted between 15 and 30 minutes at each transect using binoculars (7× 50). These observations were conducted in the morning and at noon (0730-0930 or 1000-1200 hr PDT), and during in the afternoon hours (1300-1500 hr PDT). In order to do the sea-watching from the Chocolatera in Salinas (Santa Elena Peninsula), powerful binoculars (16 x 70) were used to scan the stretch of water in front until the horizon to look for birds, during continued watching periods of 60 minutes (not necessarily on whole clock hours). Additionally, the local atmospheric conditions were also noted down. Most observations were done by one, and sometimes by three people. For the monthly census at the Ecuasal salt lakes one to three observers moved by bicycle or by car on the dikes that divide the pools, noting down the numbers of individuals per recorded species. During most visits a steady route was followed and most visits (90%) were done within the first four hours of daylight. The available optic material included a telescope (Swarovski 25 x60) and binoculars (16 x 70; 10 x 42). Between 1991 and the year 2000, the second author (B. Haase) conducted more than 240 systematic censuses of shorebirds and water birds (Haase, 2011a). As of 2004, two annual water bird census have been conducted (contribution by Wetlands International through the Ecuadorian non governmental organization, Aves & Conservación-Birds & Conservation), as part of the Neotropical Censuses of Water birds. Additionally, more than 2000 hours of shorebird banding has been carried out, with a total number of 6500 birds (smaller waders) captured with mistnets and banded. Basic biometric data were obtained before the birds were equipped with an aluminum band and according to the inter-american standard method, two color flags (for Ecuador: light green over red) were placed on the tibia (Haase, 2011a). Finally, data from Neotropical waterbird censuses conducted in Ecuador were also analyzed in this study and retrieved from published technical reports (Santander & Muñoz, 2005; Santander et al., 2006b; Santander et al., 2007; Santander & Lara, 2008).

3.2 Galapagos islands

Data on field surveys to determine the species and relative abundance and spatial distribution of seabirds in interior and exterior waters of the Galapagos Marine Reserve (GMR) were retrieved from the information and datasets collected by oceanographic expeditions aboard the R/V BAE Orion (INOCAR-Ecuadorian Navy) on August 2000 and April 2009, as well as on the R/V Roger Revelle (SCRIPPS Institution of Oceanography, University of California, San Diego, UCSD) from August to September 2001 (Cruz-Delgado, 2001; Alava, 2002; Jimenez et al., 2010; Alava et al., 2010). This study also includes data on censuses of Galapagos penguins and flightless cormorants reported elsewhere (Vargas et al., 2005; Jiménez-Uzcátegui et al., 2006; Jiménez-Uzcátegui & Vargas, 2007; Jiménez-Uzcátegui and Devineau 2009) and compared to time series of sea surface temperature (SST) anomalies to asses the impact of the El Niño-Southern Oscillation (ENSO), used here as a proxy to explore the effect of regional climate change. Data on SST anomalies were retrieved from the National Weather Service of the National Oceanic and Atmospheric Administration (NOAA, 2011):
(http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_change.shtml)

3.3 Richness and abundance of waterbird species

Several censuses of Neotropical waterbids have been conducted in Ecuador since 1995 (Santander & Lara, 2008). However, the censuses were not carried out each year, and census data is only available for 1995, 2004, 2005, 2006 and 2007, with a gap between 1995 and 2004, as reported elsewhere (Santander & Muñoz, 2005; Santander et al., 2006b; Santander et al., 2007; Santander & Lara, 2008). Censuses for 2008, 2009 and 2010 were not yet available at the time the present review was conducted. For the purpose of this study, the 2007-Neotropical waterbird census, including the coastal zone, highlands and Amazon region (Santander & Lara, 2008; retrieved online, http://lac.wetlands.org/), was used to measure waterbird biodiversity. The rationale to select this census is based on the fact that it represents the census with the highest records of both species and number of individuals in the history of Neotropical waterbird censuses undertaken in Ecuador since 1995. Under this premise, the total annual biodiversity of waterbirds for mainland Ecuador was estimated using the Shannon-Weaver and the Simpson biodiversity indices. The former was calculated using the equation (Krebs, 1999):

$$H' = -\sum pi \ln(pi) \qquad (1)$$

Where ***H'*** is the Shannon-Weaver diversity index, and ***pi*** is the relative abundance of each group of species. The Shannon-Weaver index is usually expressed as $e^{H'}$. Typically the value of the index ranges from 1.5 (i.e., low species richness and evenness) to 3.5 (i.e., high species evenness and richness), but values beyond this range can be found (McDonald, 2003). The latter was calculated using the Simpson's index (*D*) as follows:

$$D = \sum (pi)^2 \qquad (2)$$

Where equation (2) is subtracted from 1to yield 1-*D* (i.e., the Simpson's index of diversity), and *pi* is the fraction of all organisms which belong to the *i*-th species. The value of this index ranges between 0 and 1, with 1 representing infinite diversity and 0 representing no diversity (e.g., the greater the value, the greater the sample diversity). In this case, the index represents the probability that two individuals randomly selected from a sample will belong to different species. Additionally, seabird observations conducted in the Galapagos were sorted by species and relative abundances. For each threatened species identified in the present review, both the national (Ridgely & Greenfield 2001, Granizo et al., 2002) and global assigned categories by the IUCN Red List for birds (BirdLife International, 2011) are noted. Scientific names and English common names for waterbirds follow the South American Classification Committee (SACC) Classification (Freile, 2010).

4. Waterbird biodiversity

4.1 Richness and evenness

Both the number of species and abundances have increased since the first Neotropical census was deployed in 1995 in Ecuador (Table 1). This can be explained due to an increase in the observation efforts and number of sites visited for censuses. The maximum number of species was registered in February 2007, with a total abundance close to 40000 individuals.

At the Ecuasal lagoons, large numbers of shorebirds were recorded, with maximum counts for common and abundant species shown in Table 2. The most abundant shorebird species is the Wilson's Phalarope, followed by the Semipalmeated Sandpiper, Western Sandpiper and Least Sandpiper. The environmental conditions of the Ecuasal lagoons offer a suitable stopover and habitat for a substantial number of shorebird and seabird species.

	1995	2004	2005		2006		2007	
	February	July	February	July	February	July	February	July
Sites censused	11	22	23	25	29	26	27	21
Number of species	45	68	67	74	59	62	80	77
Number of individuals	3750	13759	21201	15533	17600	21509	39764	24704

Table 1. Data of Neotropical waterbird censuses conducted in Ecuador from 1995 to 2007. The censuses are generally conducted twice per year (February and July). In 1995 and 2004, the census was carried out only in February and July, respectively. Adapted from Santander & Lara (2008)

Abundant species	Maximum Counts
Snowy Plover (*Charadrius alexandrinus*)	221
Sanderling (*Calidris alba*)	> 1,000
Black-necked Stilt (*Himantopus mexicanus*)	1,500
Western Sandpiper (*Calidris mauri*)	1,500
Least Sandpiper (*Calidris minutilla*)	1,500
Semipalmated Sandpiper (*Calidris pusilla*)	2,000
Wilson's Phalarope (*Phalaropus tricolor)*	32,000

Source: WHSRN, (2009b). http://www.whsrn.org/site-profile/lagunas-de-ecuasal

Table 2. Major shorebird species and maximum abundaces recorded in Ecuasal lagoons.

During the oceanographic cruises conducted around the Galapagos Islands in 2000, 2001 and 2009, a total of 24 species of seabirds were recorded (Fig. 3), with abundances ranging from 830 individuals in 2001 to 2242 individuals in 2002. The Nazca Booby (*S. granti*) was the most abundant seabird accounting for 51% of the total abundance of species recorded (1560 seabirds) in 2009 (Fig. 3). Most of the sightings were aggregated in places southwestern Galapagos (0º-2ºS; 94-91ºW), where generally nutrient-enriched, upwelling areas are found (Jimenez et al. 2010; Alava et al., 2010). A high abundance of sea birds was also observed in areas exhibiting the highest values of primary production (0.5-1.7 mg/m^3 in 2000 and 0.46-0.50 mg/m^3 in 2009), southeast of the Galapagos (2-3ºS; 88ºW) (Alava et al., 2010). These observations underline the role of seabirds as eco-markers of primary productivity in a highly stochastic marine environment. Several seabirds, including critically endangered species such as the Waved Albatross (*Phoebastria irrorata*) and Galapagos Petrel (*Pterodroma phaeopygia*), were recorded in foraging areas (87°-84° W) off the GMR boundaries, implying the risk of bycatch in these unprotected areas. A reduction of 82% and 87% in the abundance of Waved Albatross and Galapagos Petrel recorded at sea (using similar tracks and cruises with the INOCAR Ecuadorian Navy for both years) is observed from 2001 to 2009, respectively (Fig. 3). In addition, large numbers of the Red-necked Phalarope (*Phalaropus lobatus*) were observed in several oceanographic cruises off Ecuador and around Galapagos waters (B. Haase, pers. obs.). On the contrary, a negative local population trend of this species has been reported at coastal Ecuador from 1991 to 2011 (Haase, 2011b). This species seems to be more oceanic, showing offshore habits compared to the Wilson's Phalarope, which is a more coastal species.

Several rare species of seabirds such as the Wandering Albatross (*Diomedea exulans*), Black-footed Albatross (*Phoebastria nigripes*), Gould's Petrel (*Pterodroma leucoptera*), Buller's Shearwater (*Puffinus bulleri*) and White-faced Storm-Petrel (*Pelagodroma marina*) have been registered for the Galapagos, but never at the Continent's mainland coast (Annex I).

Interestingly, the Parkinson's Petrel (*Procellaria parkinsoni*) is a locally common species found offshore of Ecuador's southern coast, where more than 100 individuals have been registered (B. Haase, pers. obs.), underscoring that this petrel is more frequent than previously thought.

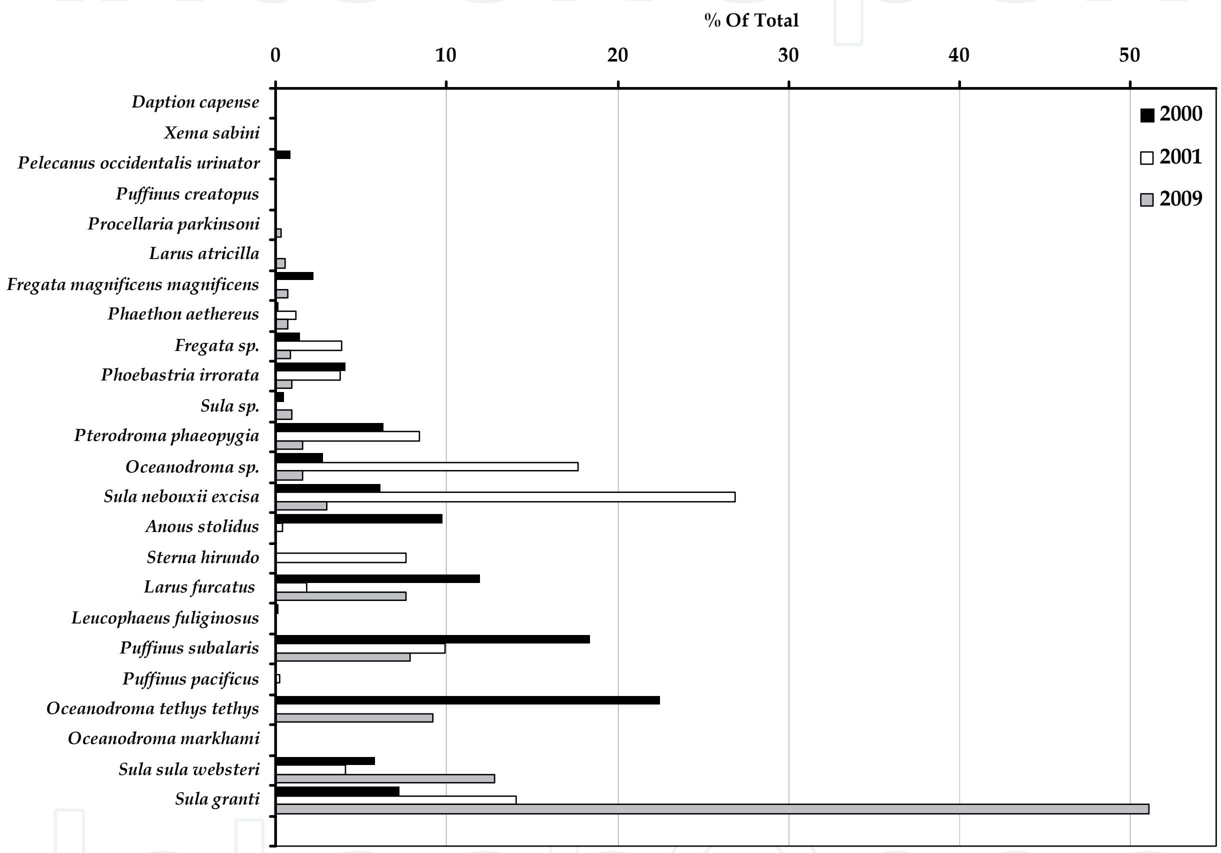

Fig. 3. Proportion of seabirds by species as a fraction of totals recorded around Galapagos waters aboard oceanographic cruises in 200, 2001 and 2009 (adapted from Alava et al., 2010).

The Masked Booby (*Sula dactylatra*) and the Brown Booby (*Sula leucogaster*) have recently been confirmed as booby species inhabiting the marine-coastal zone, including La Plata Island and Salinas, respectively (Haase, 2011a).

Based on the 2007 Neotropical census in Ecuador (Santander & Lara, 2008) and using both the Shannon-Weaver and Simpson indexes, a high biodiversity of waterbirds is found in Ecuador. The Shannon-Weaver index value was 3.50, while the Simpson biodiversity index value was close to 1.0 (Table 3). Although data for the Galapagos Islands was not present for the 2007 census, this still corroborates the high degree of richness and abundance of waterbird species in Ecuador, as previously reported (Santander et al., 2006a). A complete list of the waterbird species found and recorded for Ecuador and the Galapagos Islands, including the newest records, is available in Annex I.

Species	February	July	Total	(*pi*)	ln(*pi*)	(*pi*)*ln(*pi*)	$(pi)^2$
Podiceps occipitalis	69	134	203	0.00315	-5.7607	-0.0181	0.00001
Podilymbus podiceps	91	1093	1184	0.01837	-3.9973	-0.0734	0.00034
Tachybaptus dominicus	19	33	52	0.00081	-7.1227	-0.0057	0.00000
Pelecanus occidentalis	871	4970	5841	0.09060	-2.4013	-0.2176	0.00821
Pelecanus thagus	1546	1175	2721	0.04221	-3.1652	-0.1336	0.00178
Phalacrocorax brasiliensis	2272	1576	3848	0.05969	-2.8186	-0.1682	0.00356
Anhinga anhinga		34	34	0.00053	-7.5476	-0.0040	0.00000
Ardea alba	1374	887	2261	0.03507	-3.3504	-0.1175	0.00123
Tigrisoma fasciatum	4		4	0.00006	-9.6876	-0.0006	0.00000
Ardea cocoi	259	46	305	0.00473	-5.3536	-0.0253	0.00002
Ardea herodias	1		1	0.00002	-11.0739	-0.0002	0.00000
Butorides striatus	169	90	259	0.00402	-5.5171	-0.0222	0.00002
Egretta caerulea	630	390	1020	0.01582	-4.1464	-0.0656	0.00025
Egretta thula	1997	1539	3536	0.05485	-2.9032	-0.1592	0.00301
Egretta tricolor	43	94	137	0.00213	-6.1539	-0.0131	0.00000
Ardea ibis	1094	473	1567	0.02431	-3.7170	-0.0903	0.00059
Botaurus pinnatus	2	3	5	0.00008	-9.4645	-0.0007	0.00000
Botaurus spp	3		3	0.00005	-9.9753	-0.0005	0.00000
Nyctanassa violacea	50	128	178	0.00276	-5.8921	-0.0163	0.00001
Nycticorax nycticorax	94	96	190	0.00295	-5.8269	-0.0172	0.00001
Ixobrychus exilis	2		2	0.00003	-10.3808	-0.0003	0.00000
Eudocimus albus	27	52	79	0.00123	-6.7045	-0.0082	0.00000
Plegadis falcinellus	7		7	0.00011	-9.1280	-0.0010	0.00000
Theristicus melanopis	24	4	28	0.00043	-7.7417	-0.0034	0.00000
Mycteria americana	4		4	0.00006	-9.6876	-0.0006	0.00000
Phoenicopterus chilensis	738	264	1002	0.01554	-4.1642	-0.0647	0.00024
Anhima cornuta		24	24	0.00037	-7.8959	-0.0029	0.00000
Anas andium	426	111	537	0.00833	-4.7879	-0.0399	0.00007
Anas bahamensis	2103	511	2614	0.04055	-3.2053	-0.1300	0.00164
Anas discors	2896		2896	0.04492	-3.1028	-0.1394	0.00202
Anas clypeata	1		1	0.00002	-11.0739	-0.0002	0.00000
Anas georgica	888	371	1259	0.01953	-3.9359	-0.0769	0.00038
Dendrocygma bicolor	43	21	64	0.00099	-6.9150	-0.0069	0.00000
Dendrocygna autumnalis	389	60	449	0.00696	-4.9669	-0.0346	0.00005
Netta erythrophthalma	4		4	0.00006	-9.6876	-0.0006	0.00000
Cairina moschata		2	2	0.00003	-10.3808	-0.0003	0.00000
Oxyura ferruginea	177	176	353	0.00548	-5.2075	-0.0285	0.00003
Aramus guarauna		2	2	0.00003	-10.3808	-0.0003	0.00000
Laterallus albogularis	1	9	10	0.00016	-8.7713	-0.0014	0.00000
Rallus longirostris	5	4	9	0.00014	-8.8767	-0.0012	0.00000
Aramides axillaris		12	12	0.00019	-8.5890	-0.0016	0.00000
Neocrex erythrops		4	4	0.00006	-9.6876	-0.0006	0.00000
Porphyrio martinicus	40	35	75	0.00116	-6.7564	-0.0079	0.00000
Gallinula chloropus	454	98	552	0.00856	-4.7604	-0.0408	0.00007
Fulica ardesiaca	1157	1099	2256	0.03499	-3.3526	-0.1173	0.00122
Jacana jacana	126	87	213	0.00330	-5.7126	-0.0189	0.00001
Haematopus palliatus	31	32	63	0.00098	-6.9308	-0.0068	0.00000
Himantopus mexicanus	3379	1821	5200	0.08066	-2.5175	-0.2031	0.00651

Vanellus chilensis	2		2	0.00003	-10.3808	-0.0003	0.00000
Vanellus resplendens	153	176	329	0.00510	-5.2779	-0.0269	0.00003
Pluvialis squatarola	378	49	427	0.00662	-5.0171	-0.0332	0.00004
Pluvialis dominica	1		1	0.00002	-11.0739	-0.0002	0.00000
Charadrius alexandrinus	43	37	80	0.00124	-6.6919	-0.0083	0.00000
Charadrius collaris	169	35	204	0.00316	-5.7558	-0.0182	0.00001
Charadrius semipalmatus	244	181	425	0.00659	-5.0218	-0.0331	0.00004
Charadrius vociferus		4	4	0.00006	-9.6876	-0.0006	0.00000
Charadrius wilsonia	59	25	84	0.00130	-6.6431	-0.0087	0.00000
Charadrius spp.	227		227	0.00352	-5.6490	-0.0199	0.00001
Actitis macularius	213	53	266	0.00413	-5.4904	-0.0227	0.00002
Aphriza virgata		6	6	0.00009	-9.2822	-0.0009	0.00000
Arenaria interpres	238	123	361	0.00560	-5.1850	-0.0290	0.00003
Calidris alba	1005	31	1036	0.01607	-4.1308	-0.0664	0.00026
Calidris bairdii	365	6	371	0.00575	-5.1577	-0.0297	0.00003
Calidris mauri	1533	281	1814	0.02814	-3.5706	-0.1005	0.00079
Calidris melanotos	6	5	11	0.00017	-8.6760	-0.0015	0.00000
Calidris minutilla	786	552	1338	0.02075	-3.8750	-0.0804	0.00043
Calidris pusilla	1139	278	1417	0.02198	-3.8176	-0.0839	0.00048
Calidris spp.	253	47	300	0.00465	-5.3701	-0.0250	0.00002
Tringa semipalmata	292	140	432	0.00670	-5.0055	-0.0335	0.00004
Limnodromus griseus	239	160	399	0.00619	-5.0850	-0.0315	0.00004
Limosa haemastica	2	1	3	0.00005	-9.9753	-0.0005	0.00000
Micropalama himantopus	322	220	542	0.00841	-4.7787	-0.0402	0.00007
Numenius phaeopus	158	97	255	0.00396	-5.5327	-0.0219	0.00002
Phalaropus tricolor	1529	1642	3171	0.04919	-3.0121	-0.1482	0.00242
Tringa flavipes	472	56	528	0.00819	-4.8048	-0.0394	0.00007
Tringa melanoleuca	260	51	311	0.00482	-5.3341	-0.0257	0.00002
Tringa solitaria	4		4	0.00006	-9.6876	-0.0006	0.00000
Leucophaeus atricilla	2591	612	3203	0.04968	-3.0021	-0.1492	0.00247
Chroicocephalus cirrocephalus	1466	1143	2609	0.04047	-3.2072	-0.1298	0.00164
Larus dominicanus		3	3	0.00005	-9.9753	-0.0005	0.00000
Leucophaeus modestus	12	217	229	0.00355	-5.6402	-0.0200	0.00001
Leucophaeus pipixcan	44		44	0.00068	-7.2897	-0.0050	0.00000
Chroicocephalus serranus	179	74	253	0.00392	-5.5405	-0.0217	0.00002
Thalasseus elegans	67	121	188	0.00292	-5.8375	-0.0170	0.00001
Sterna hirundinacea		53	53	0.00082	-7.1036	-0.0058	0.00000
Sterna hirundo	4	19	23	0.00036	-7.9384	-0.0028	0.00000
Thalasseus maximus	1479	500	1979	0.03070	-3.4836	-0.1069	0.00094
Gelochelidon nilotica	37	140	177	0.00275	-5.8978	-0.0162	0.00001
Thalasseus sandvicensis	132	1	133	0.00206	-6.1836	-0.0128	0.00000
Sterna spp.	150	4	154	0.00239	-6.0370	-0.0144	0.00001
Rynchops niger	1	1	2	0.00003	-10.3808	-0.0003	0.00000
Total abundance	**39764**	**24704**	**64468**	**1.00**		**-3.5206**	**0.04128**
						***H*′ = 3.52**	**1-*D* = 0.960**

Table 3. Richness and evenness for waterbirds accounted during 2007 Neotropical census in Ecuador and measurements of biodiversity indices, including the Shannon-Weaver (*H*′) and Simpson (1-*D*) indices of biodiversity. The 2007 census also included water systems (e.g., lakes, lagoons and wetlands) from the highland and Amazon regions.

4.2 Accounts of priority species

4.2.1 Piping Plover (*Charadrius melodus*)

The Pipping Plover is a globally Near Threatened species and its population appears to be increasing (BirdLife International, 2011). However, this shorebird species is Critically Endangered in Ecuador (Granizo et al., 2002; Santander et al., 2006a). At present, the only record of this accidental visitor for South America has occurred in the Ecuasal lagoons (Santander et al. 2006a; WHSRN, 2009b).

4.2.2 Buff-breasted Sandpiper (*Tryngites subruficollis*)

A Near Threatened species also recorded in the Ecuasal lagoons (WHSRN, 2009b; B. Haase, pers. obs). The population of this species is globally declining due to overhunting in the past, habitat degradation and environmental contaminants (BirdLife International, 2011)

4.2.3 Waved Albatross (*Phoebastria irrorata*)

The Waved Albatross is an endemic, Critically Endangered species with almost the entire population breeding on a single island, Española Island, (Galapagos). Very few pairs breed in La Plata Island (Machalilla National Park) at coastal Ecuador. While the total population (i.e., breeders and non breeders) is currently estimated to be 15475 albatrosses, a population decline of 47% was observed from 1994 to 2007 (Anderson et al., 2008). It accounted for only 1% of the total abundance of seabirds observed in the 2009-INOCAR/Navy oceanographic cruise conducted in the Galapagos. Longline fisheries and targeted-direct fishing are the major threats in marine waters off Ecuador and Peru (Wiedenfeld and Jiménez-Uzcátegui 2008; Hardesty et al., 2010). In contrast to the serious problems that plastic ingestion causes in some other species of albatrosses, this pollution threat appears to pose a minor impact to this species.

4.2.4 Galapagos Petrel (*Pterodroma phaeopygia*)

The Galapagos petrel is an endemic, Critically Endangered species breeding on Santa Cruz, Floreana, Santiago, San Cristóbal, Isabela and possibly other islands in the archipelago, where the global population ranges from 10,000 to 19,999 individuals, based on an estimate of 4,500-5,000 active nests in 2008 (BirdLife International 2011; F. Cruz-Delgado, pers. comm.). Similar to the Waved Albatross, this species represented about 1.50% of the total number of seabirds recorded in the 2009-INOCAR/Navy oceanographic cruise. Long-line fishing in the southeastern Pacific is a major threat; however, long-lining within the GMR limits is particularly likely to affect foraging birds, while introduced species such as cats, pigs and rats are a major threat at the breeding grounds (Wiedenfeld and Jiménez-Uzcátegui 2008; BirdLife International 2011b).

4.2.5 Lava Gull (*Leucophaeus fuliginosus*)

This species is one of the rarest gulls in the world and widespread throughout the Galapagos Islands. With a very small endemic population of about 600-800 individuals, this gull only breeds in Galapagos and is considered Vulnerable by the IUCN (BirdLife International, 2011), which might understimate the conservation status risk for this species (Wiedenfeld and Jiménez-Uzcátegui 2008). Introduced predators such as cats and dogs as well as fishing activities (e.g., hooks and nets) are major conservation threats for this particular species (Cepeda & Cruz, 1994; Wiedenfeld and Jiménez-Uzcátegui, 2008).

4.2.6 Galapagos Penguin (*Spheniscus mendiculus*)

The tropical Galapagos penguin is an endemic and Endangered species breeding in the Galapagos Islands, where its decreasing population is estimated in 1,800 mature individuals, with approximately 95% of the population restricted to Isabela and Fernandina islands in the western part of the Galapagos (Vargas et al., 2005; Jiménez-Uzcátegui & Vargas, 2007; Vargas et al., 2007). The El Niño events driven by climate change is the primary threat, while oil spills, fishing activities, alien predators and emerging infectious diseases are categorized as looming threats impacting this unique population of penguins (Vargas et al., 2006; Vargas et al., 2007; Wiedenfeld and Jiménez-Uzcátegui, 2008; BirdLife International, 2011).

4.2.7 Flightless Cormorant (*Phalocrocorax harrisi*)

Similar to the Galapagos penguin, the flightless cormorant is an endemic and Endangered seabird breeding on Isabela and Fernandina in the Galapagos Islands, where its population has been estimated close to 1680 individuals (BirdLife International, 2011). The threats for this species are similar to that identified for Galapagos penguins, mainly the El Niño events, and oils spills, as well as flooding (Wiedenfeld and Jiménez-Uzcátegui, 2008; BirdLife International, 2011).

4.2.8 Horned Screamer (*Anhima cornuta*)

The Horned Screamer is threatened (i.e., Endangered) in Ecuador (Granizo et al., 2002) and categorized as a species of Least Concern at the global level (BirdLife International, 2011). The population (i.e. the El Canclon Lagoon population) is confined to the Manglares Churute Ecological Reserve (MCER). Studies on the Horned Screamer (*Anhima cornuta*) population, conservation status and habitat deterioration in the El Canclon Lagoon wetland have been documented elsewhere (Alava et al., 2002; Alava et al., 2007a; Alava et al., 2009). The most recent data indicate that the estimated overall mean number of screamers in the lagoon was 68 ± 48 birds (Alava et al., 2009). The extrapolated, absolute mean density is estimated in approximately less than 1 bird/ha for the whole lagoon wetland (68 birds /800ha) or a relative density of 0.7 individuals per transect. Recently, 24 individuals were recorded in the 2007-Neotropical census (Table 3; Santander & Lara, 2008). The abundance of screamers was lower (six-ten individuals) in more disturbed areas containing farms, agriculture fields and cattle ranching. Abundance was inversely associated with the presence of cattle and was not seasonally dependent during the dry and wet seasons. Screamers were significantly associated with vegetation coverage. Because the Horned Screamer strongly relies on the wetland vegetation, cattle overgrazing jeopardizes its habitat and survival in this Ramsar wetland.

4.2.9 Comb Duck (*Sakidiornis melanotos*)

This is a Vulnerable and rare species of waterfowl scarcely observed in coastal Ecuador (Granizo et al., 2002; Santander et al., 2006a). In December and January 2002, a total of three records of this species were made at the southeastern edge of the El Canclón Lagoon, where individuals were sighted on the water surface during normal flood conditions (Alava et al., 2007a). The sightings of Comb Ducks in Ecuador's costal regions have been sporadic and scattered, suggesting a marked rareness of this species in lowlands of southwest Ecuador. The first two specimens of this species were recorded on the slopes of the Cayambe Volcano in the Ecuadorian highlands during 1951–1952 (Norton *et al.* 1972). Additionally, flocks of about 15–25 individuals were observed in the early morning (06:30) along a mangrove channel of the MCER near the El Canclón Lagoon in November 1987 (Ortiz–Crespo 1988). At the extreme border of southern Loja and west Macara provinces, a few individuals, with a potential resident population, have been sighted along Rio Sabiango and Zapotillo area (Best *et al.* 1993, Ridgely & Greenfield 2001). Likewise, a total of 12 individuals were recently reported at the El Azúcar Dam, Santa Elena Peninsula (Guayas Province) in July 2004 during a Neotropical waterbird census (Santander & Muñoz 2004). Hunting and use of pesticides in rice fields are likely to be major threats for this species (Santander et al., 2006).

4.2.10 Muscovy Duck (*Cairina moschata*)

The Muscovy Duck is currently rare and locally uncommon in lotic, lentic, and wetland (e.g., marshes) ecosystems in both east and southwest Ecuadorian lowlands, even though it was probably an abundant waterfowl in the past (Ridgely & Greenfield 2001). The species is Endangered in Ecuador (Granizo et al., 2002). In the El Canclon laggon, this species was seldom recorded, with 7 sightings at the beginning of the rainy season from December 2001 to January 2002 (Alava et al., 2007a). All observed individuals showed the typical feather coloration of wild birds. These are the second most recent sightings of this species in the MCER after more than a decade since about 25 birds were recorded in MCER in March 1998 by J. C. Matheus (as cited by Ridgely & Greenfield 2001). This species has also been sighted in the Yaguachi marshes since 1980 (Ridgely & Greenfield 2001). Recently, one individual of this species was recorded at the Santay Island during the 2004–Neotropical waterbird census (Santander & Muñoz 2004), while two individuals were recorded in the 2007- Neotropical census (Table 3; Santander & Lara, 2008). As with the Comb Duck, sightings of this species are extremely rare along the Ecuadorian coastal, and has been suggested that hunting pressure is the major cause of its population decline in recent years (Ridgely & Greenfield 2001).

4.2.11 Southern Pochard (*Netta erythrophthalma*)

This is a very rare and Critically Endangered species in Ecuador (Granizo et al., 2002), but considered as a species of Least Concern globally (BirdLife International, 2011). Only four individuals were recorded in the 2007 Neotropical census (Santander & Lara, 2008). Major threats include hunting, aquatic habitat degradation and wetland transformation due to agricultural encroachment (Santander et al., 2006a; BirdLife International, 2011). Conservation efforts for this species need to be focus on habitat protection.

4.2.12 Great Blue Heron (*Ardea herodias*)

The great heron blue is found in the Ecuadorian coast and Galapagos inhabiting mangroves and coastal wetlands. The great blue heron recorded for the Galapagos is an endemic subspecies (*A. h. cognata*), breeding in the islands (Jackson, 2001; Jiménez-Uzcátegui et al., 2007). This heron is not as abundant as other species of herons and its population number is probably declining due to habitat loss.

4.2.13 Roseate Spoonbill (*Platalea ajaja*)

Research and conservation aspects on the Roseate Spoonbill population of the Gulf of Guayaquil were documented by Alava (2005). The mean number of recorded birds was 40.5

birds (95% CI: 16.0–64.8), ranging from 1 to 100 individuals. Censusing of birds based on the Hayne model yield a number of 662 individuals in an area of 48,000 ha (i.e., 2000 birds/1350 km^2), with absolute and relative abundances of 0.7 birds/km and 0.014 birds/ha, respectively (Alava, 2005). Individuals were mainly aggregated in the northwestern and northeastern areas of the Guayaquil Gulf Estuary, and followed by the southeastern part. Wetlands destruction such as mangrove areas, agriculture, urbanization and non-controlled hunting have negative impacts on Roseate spoonbills. On the short term, the Roseate Spoonbill population may become threatened because of habitat loss.

4.2.14 Greater Flamingo (*Phoenicopterus ruber*)

This charismatic species is mainly found in saline and brackish coastal lagoons of the Galapagos Archipelago, mainly in Isabela, Santiago, Rábida, Floreana and San Cristobal islands. Although the flamingo population found in the Galapagos is not endemic to the islands and it is not threatened at the global level, the native population breeding in the islands is considered as threatened with approximately 320-520 individuals (Granizo et al., 2002; Wiedenfel & Jiménez-Uzcátegui, 2008). Sea level rise due to climate change has been identified as a potential conservation threat for flamingos in the Galapagos (Granizo et al., 2002; Jiménez-Uzcátegui, 2006; Jiménez-Uzcátegui et al., 2007). Flamingos are very sensitive to human perturbations and predation of nests by introduced species such as pigs (Jackson, 2001; Wiedenfel & Jiménez-Uzcátegui, 2008).

4.2.15 Brown Wood-Rail (*Aramides wolfi*)

The Brown Wood-rail is categorized as Vulnerable globally and as Endangered in Ecuador (Granizo et al., 2002; BirdLife International, 2011), where it is one of the rarest birds and, during the last two decades, seldom recorded, mainly in mangrove (Taylor, 1996; Ridgely & Greenfield, 2001). Most sightings have been in either the north-west or south-west, from: north of Quinindé; pristine humid forest at Paraíso de Papagayos ranch; secondary forest and disturbed wetlands at Jatun Sacha-Bilsa Biological Reserve (within Mache Chindul Ecological Reserve) (Esmeraldas province); forest remnants at Río Palenque Research Station, (Los Ríos province; and mangroves in Manglares Churute Ecological Reserve (MCER), (Guayas province) (Alava et al., 2007b). On 29 June 2001, a bird was seen on a dirt road bordering disturbed riparian vegetation and secondary foothill forest on the east side of El Canclon lagoon (02°30'S 79°42'W) (Alava et al., 2007b). Coloration of the head, neck and body identified it as *A. wolfi* (i.e., ashgrey head and cinnamon-rufous neck, with the rest of the upperparts and underparts pale olivaceous-brown). This observation is the first at El Canclon (a Ramsar site) and in the entire MCER for over a decade, following that of two birds in mangrove on 28 December 1989 (Ridgely & Greenfield, 2001). Unconfirmed sightings were made in 2005–2006 at Puerto Hondo, a mangrove relatively close to Cerro Blanco Protected Forest. Attempts are underway to verify these observations as Rufous necked Wood-rail *Aramides axillaris* is frequent there and juveniles have similar plumage to adult *A. wolfi* (Alava et al., 2007b). The two are locally sympatric in mangrove, but *A. wolfi* seems to be more frequent inland (Ridgely & Greenfield, 2001). It has been suggested that *A. wolfi* is capable of surviving in fragmented or deteriorated habitats (Taylor, 1996; Ridgely & Greenfield, 2001). On the other hand, it is perhaps less tolerant of habitat perturbation than Grey-necked Wood-rail *A. cajanea* (Ridgely & Greenfield, 2001), and is definitely much more sensitive than *A. axillaris* (Vulnerable in Ecuador). The latter is commonly found close to disturbed or human modified mangroves, including in Guayas (Puerto Hondo) and El Oro (Bajo Alto) provinces (J.J. Alava, pers. obs.). Additional studies of *A. wolfi* are urgently required to increase knowledge of its natural history.

4.2.16 Galapagos Rail (*Laterallus spilonotus*)

As an endemic bird to the Galapagos, this a rare species of rail occurring in several islands, mainly those offering suitable habitat with humid zone vegetation as that found in Pinta, Fernandina, Isabela, San Cristobal, Santa Cruz, Floreana, and Santiago (Rosenberg, 1990), as well as Wolf, Drawin and Alcedo (BirdLife International, 2011). This rail is threatened (i.e., Vulnerable) with a decreasing population, estimated on 5000-10000 mature individuals (BirdLife International, 2011). The threats for its conservation include continuing conversion of highland habitat to agriculture, invasive plants (quinine tress, *Cinchona pubescens*, and black berries, *Rubus niveus*), overgrazing by exotic mammalian herbivores (e.g., feral goats, cattle and horses) and predation by introduced cats, pigs and rats (Rosenberg, 1990; Gibbs et al., 2003; Wiedenfel & Jiménez-Uzcátegui, 2008; BirdLife International, 2011).

5. Environmental impacts and conservation threats

5.1 Habitat loss, degradation and fragmentation

Birds are closely associated with forests, and approximately 30% of the world's species of birds are highly restricted to tropical forests used as either winter grounds or year-round habitats (Myers 1992). In Ecuador, Western and Tumbesian forests of Ecuador are being cleared by farming and ranching and are highly threatened by browsing and trampling of domestic livestock, with about 4% of the original forest coverage remaining by 1998 (Dodson & Gentry, 1991; Best & Kessler, 1995). For instance, uncontrolled cattle grazing of the native vegetation, deforestation, and agricultural sprawl (rice crops and farms) have negatively impacted the El Canclon Lagoon at the MCER, jeopardizing its conservation and affecting the local population of the Horned Screamer (*A. cornuta*) and several other waterbirds depending on this wetland (Alava et al., 2007; Alava et al., 2009). Likewise, it is estimated that about 55,400 hectares (27% of the original total area: 203,625 hectares) of mangrove forests has been lost in coastal Ecuador from 1969 to 2006 due to uncontrolled clear-cutting of mangroves (Fig. 4), not only for construction of illegal shrimp farms (aquaculture), but for agriculture, illegal extraction of timber and urban sprawl (CLIRSEN, 2007; Carvajal & Alava, 2007). The decrease of slat flat areas is also of concern with a reduction of 93% since 1969 (Fig. 4). Extensive banana plantations are found in southwest Ecuador, and are primarily located in coastal provinces such as Los Rios, El Guayas and the El Oro (INEC 2007). A total area averaging 232,235 ha is dedicated to the production of bananas at the national level. About 79% of this total are located on the coastal zone, mainly in the El Guayas and the El Oro provinces (an average of 51,183 and 44,607 ha, respectively), which are relatively close to mangrove areas. Presence of solid wastes (i.e., plastic bags and bottles) and illegal camp fires are signs of human activity in mangrove areas, as well. There, it has been suggested that deforestation and fragmentation in mangrove habitats have affected the local and nesting population of Roseate Spoonbills (*P. ajaja*) in the Guayaquil Gulf Estuary (Alava, 2005), as well as the declining population of the Brown Wood Rail (*A. wolfi*), which is endangered and less tolerant to habitat deterioration in Ecuador (Alava et al., 2007).

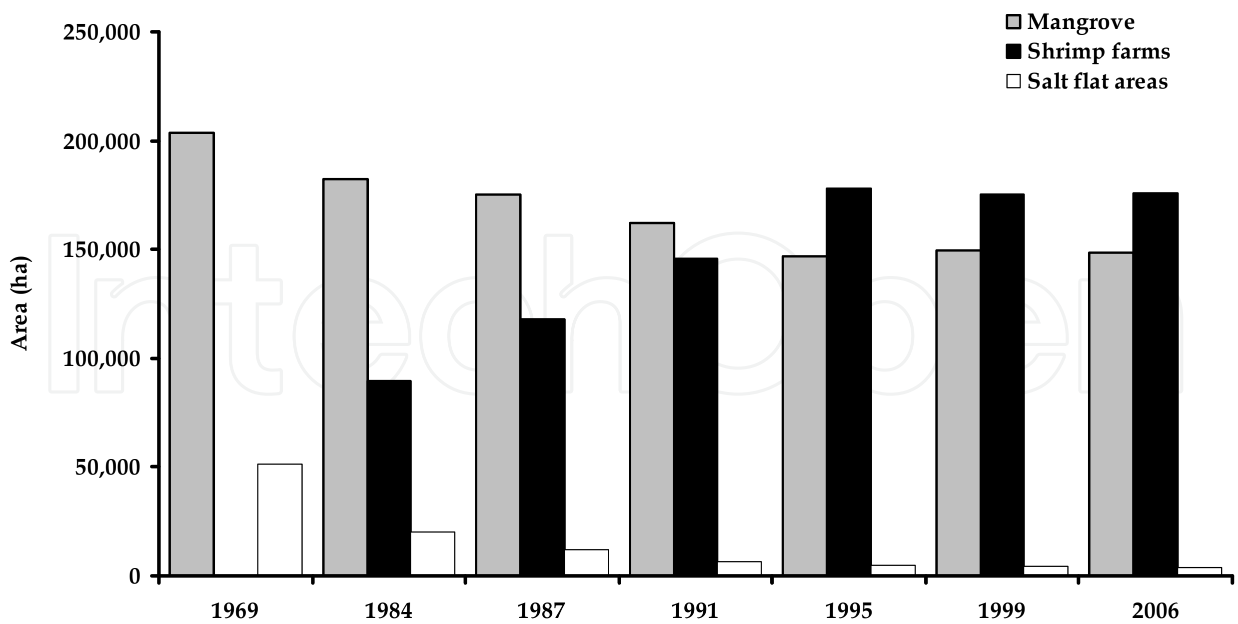

Fig. 4. Temporal and spatial evolution of mangroves, shrimp farming and salt flat areas (ha) on the continental coast of Ecuador from 1969 to 2006 (CLIRSEN, 2007).

5.2 Fishery interactions

Fishery bycatch, including longline fisheries, is categorized as the single major threat affecting many seabird populations and on the order of hundreds of thousands of seabirds, especially albatrosses, are caught and killed each year (BirdLife International, 2008; BirdLife International, 2009; Brothers et al., 2010). Industrial and artisanal fisheries, including commercial longline, gillnet and trawl fisheries, cause a significant mortality of seabirds (i.e., hundreds of thousands) each year around the global ocean, and in some cases, the effort of fishing activities (e.g., longline) overlaps with foraging grounds for seabirds (BirdLife International, 2008). Fishing activities outside of the boundaries (unprotected areas) of the Galapagos Marine Reserve possess a looming threat for seabirds such as albatrosses, petrels and shearwaters foraging frequently in these areas close to the continent (Jiménez-Uzcátegui & Wiedenfeld, 2002; Wiedenfeld & Jiménez-Uzcátegui 2008; Anderson et al., 2008). Among these, the waved albatross is probably the most affected seabird by fisheries interactions (e.g., longline fisheries) in the region. For instance, about 9-13 waved albatrosses were observed bycaught in longlines (i.e., 155 longline sets; 350 hooks per set) during a field study conducted with the artisanal fishing community of Santa Rosa in coastal Ecuador (Hardesty et al., 2010; J. Hardesty, pers. comm.). The bycatch incidence has been preliminary estimated in 0.11 albatrosses/1000 hooks, and most of the interactions are associated with artisanal longline fishing gears to capture hake (*Merluccius gayi*) (Arteaga et al., 2010). The bycatch assessment of pelagic longlining (High Seas Experimental Pilot Plan) conducted around water of the Galapagos Marine Reserve (GMR) in 2003 (Murillo et al., 2004) to evaluate the impact on epipelagic species and top predators did not report seabirds (e.g. albatrosses) as victims of bycatch, although it underscored the potential risk of bycatch for seabirds (Murillo et al., 2004). In contrast, a local artisanal tuna fishery, using single-hook lines with live sardines as bait within the GMR, reported catches up to five waved albatrosses per boat per day, indicating that a serious bycatch risk exists within the GMR if longlining occurs there (Anderson et al., 2003). In marine waters off northern Peru, thousands of waved albatrosses were estimated to be bycaught in small-scale longline fisheries (Jahncke et al., 2001). Mortality of adult albatrosses due to incidental and intentional (i.e., targeted fisheries for human consumption) in the artisanal Peruvian fishery possesses a serious threat for its conservation and remains as one of the stressors influencing the population dynamics of this species in recent years (Awkerman et al., 2006; Anderson et al., 2008).

5.3 Invasive species and emerging diseases: The Galapagos case

Biological invasions are considered a leading cause of extinctions in terrestrial and marine ecosystem of marine protected areas (Boersma & Parrish, 1999; Bax et al., 2003). The introduction of exotic marine species and pathogens (viruses, bacteria and parasites) represents major threats for biodiversity and ecosystem functions, with potentially serious implications for fisheries resources, tourism, human health in marine protected areas and biosphere reserves (Carlton, 1989; Carlton & Geller, 1993; Carlton, 1996; Bax et al., 2003). Furthermore, emerging marine diseases in marine organisms have been linked to anthropogenic factors (Harvell et al., 1999). The Hawaiian Islands represents an extraordinary example of the negative effects of the biological invasion on endemic and native species (Vitousek et al., 1987). This is supported by the fact that Hawaii contains a large proportion of the imperilled USA endemic birds (43%) and plants (40%) threatened by alien species (Gurevitch & Padilla, 2004). The Galapagos Islands are facing a similar fate unless control and conservation strategies take place to mitigate biological invasion. Terrestrial invasive species, including mammalian predators and plants, significantly jeopardize native and endemic species inhabiting these remote islands (Snell et al., 2002).The number of registered introduced species in the archipelago has increased 10 times from 112 species in 1900 to 1321 in 2007 (Watkins & Cruz, 2007). Yet, this does not include introduced pathogens. Among the invasive pathogens, viruses, bacteria and parasites are the ones possessing serious risk to the endemic fauna.

Introduced plants including berries (*Rubus* spp.; black berry *Rubus niveus*) and quinine trees (*Cinchona pubescens*) have caused habitat loss and alteration for endemic species of birds such as the Galapagos Petrel and Galapagos Rail (Wiedenfeld & Jiménez-Uzcátegui, 2008). Introduced vertebrates are mainly predators affecting bird populations by killing many species of adult birds (cats *Felis catus*) and flightless or nesting species (dogs *Canis familiaris* and pigs *Sus scrofa*); and by destroying nests and young (cats, dogs, black rat, *Rattus rattus*) (Jiménez-Uzcátegui & Wiedenfeld, 2002; Wiedenfeld & Jiménez-Uzcátegui, 2008). Some introduced viral diseases from domestic animals such as avian virus or avipoxvirus by domestic birds, fowlpox virus infecting chicken have threatened endemic species of birds (e.g., Darwin's finches) in the Galapagos (Wikelski et al., 2004). Thiel et al., (2005) has recently found presence of canarypox-like viruses in pox-like lesions of endemic passerine birds (Yellow Warblers, *Dendroica petechia*; finches, *Geospiza* spp.; and Galápagos mockingbirds, *Nesomimus parvulus*) from the inhabited islands of Santa Cruz and Isabela. A seroprevalence of 66% (29/44) to adenovirus group 1 has been found in waved albatrosses (*P. irrorata*) inhabiting Espanola Island (Padilla et al., 2003). Newcastle disease, Marek's disease virus (herpes) and mycoplasmosis detected in domestic chickens farmed on the islands (Vargas & Snell, 1997), has the potential to cause declines of the Flightless Cormorant (*P. harrisi*), Lava Gull (*L. fuliginosus*), and Galapagos Penguin (*S. mendiculus*), species with small population sizes. West Nile Virus (WNV) is expected to reach Ecuador

anytime and there is a high probability risk of its introduction into Galapagos unless strict control and preventive strategies are implemented prior to the arrival of the disease (GGEPL, 2004). The incidental transport of mosquitoes by boat or of infected vertebrate hosts is also significant risks for WNV invasion. If WNV is introduced in to Galapagos it is likely to cause catastrophic mortality of endemic birds, reptiles and mammals, leading to irreparable ecological and economic damage to the islands (GGEPL, 2004). The introduction of this disease is most likely to occur through the human transport of infectious mosquitoes, particularly via inadvertent transport in airplanes. Recently, several kinds of bacteria have already been detected in endemic sea bird and pinnipeds of the Galapagos. For example, while antibodies to avian adenovirus type 1 and *C. psittaci* were found in 31% (21/68) and 11% (7/65) of flightless cormorants, respectively, seventy-five of 84 (89%) Galapagos penguins had antibodies to *Chlamydophila psittaci,* but chlamydial DNA was not detected via polymerase chain reaction in samples from 30 birds (Travis et al., 2006a; Travis et al., 2006b). Waved albatrosses showed a seroprevalence of 9% (4/44) to avian encephalomyelitis; however, cloacal swabs were negative for *C. psittaci*-DNA. (Padilla et al., 2003). *Salmonella* sp. was reported in domestic pigeons (introduced rock doves, *Columba livia*) on San Cristóbal and may cause severe disease in species such as Galapagos doves (*Zenaida galapagoensis*) and other native birds (Harmon et al., 1987; Wikelski et al., 2004; Padilla et al., 2004). Among parasites, *Haemoproteus* sp., the only hemoparasite identified, was found in 89% of the Galapagos doves sampled but not in the rock doves (Padilla et al., 2004).
Currently, the major parasitic disease that could cause widespread mortality of native, endemic birds is the avian malaria, if it is introduced into Galapagos ecosystems. This parasite has caused severe mortality and decimation of a significant proportion of Hawaiian's endemic birds since it was introduced at beginning of 20th century (Wikelski et al., 2004). At present, despite its vector, the mosquito *Culex quinquefasciatus* (Diptera: Culicidae), is already established on the Galapagos Islands (Peck et al., 1998; Whiteman et al., 2005), there has been no report or detection of *Plasmodium relictum* (Wikelski *et al*. 2004; Thiel *et al*. 2005). A protozoan, *Trichomonas gallinae*, was reported in domestic pigeons (introduced rock doves, *Columba livia*) on San Cristóbal and may cause severe disease in species such as Galapagos doves (*Zenaida galapagoensis*) and other native birds (Harmon et al., 1987; Wikelski et al., 2004; Padilla et al., 2004). Because endemic species of birds of the Galapagos were not exposed to alien parasites transmitted by invasive species prior human occupation of the islands, they are more susceptible to the pathogenesis generated by parasitic diseases with potential risk at the population health level.

5.4 Anthropogenic pollution

Pollution coming from agriculture, forestry and industry significantly affects birds' population. Marine oil spills and persistent organic pollutants (POPs) can have a significant impact on population of seabirds (BirdLife International, 2008a). In Ecuador, the Guayaquil Gulf Estuary Basin has become the sink receiving point and non point sources of contamination over the last 80 years. As agriculture is the fundamental base for the Ecuador economic activity, the predominant crops are banana plantation, rice fields, sugar cane and cocoa in the Gulf of Guayaquil. In 2005, the total land used/harvest area for banana, coffee, rice, maize and cocoa ranged from 1,269,775 to 1,652,600 ha (INEC, 2007; FAO, 2007). In the past, farmers conducted both extensive and intensive use and application of fertilizers, herbicides and pesticides, including some organochlorine pollutants banned in others countries such as DDTs, chlordanes, heptachlor, dieldrin, aldrin, mirex, and lindane

(Solórzano, 1989). For example, banana plantations and agricultural lands use a broad spectrum of synthetic pesticides transported via run off and aerial dispersion to the estuaries and mangrove forests. However, the negative effects of chemical pollution on the coastal-estuarine environment have been scarcely characterized. The demand of pesticide usage for agricultural area is reflected by the importations of fungicides, insecticides and herbicides from January to May for both 2002 and 2003, with a total of 2,494 and 3,254 metric tonnes, respectively (SICA-MAG, 2003)

The Salado Estuary, harboring the El Salado Mangrove–Wildlife Production Reserve, has been receiving about 60% from domestic use and 40% from industrial use, causing degradation of the water and sediment conditions of this estuary. Several studies from the Municipality of Guayaquil, National Fisheries Institute, and the Polytechnic School of the Litoral have reported low dissolved oxygen (DO) levels at the Salado Estuary, ranging from 0.74 mg/L to 2.4 mg/L, and pH as low as 5.7 over the surface sediment (Calle & Alava, 2009). A recent study on pollution by pesticides on the Taura River Basin, Gulf of Guayaquil, revealed the presence of several organochlorine (OC) and organophosphate (OP) and pyrethroid pesticides in samples of water, sediment and aquatic organisms (Montaño & Resabala, 2005). Some industrial and agricultural POPs such as PCBs and DDT were used in Ecuador after they were banned in the 1970s in developed countries, and therefore released to soil and water bodies. In continental Ecuador, DDT was applied inside houses (intra-domiciliary applications) between 1957 and 1999 (Ministerio del Ambiente & ESPOL-ICQ , 2004), and a massive use of DDT was carried out during the 1980s to control the malaria vector-mosquito (Dr. Hugo Jurado, pers. comm.). The huge scale use of DDT culminated in 1988. At that time, however, DDT was also distributed without any control and used illegally for the agricultural sector to control crop pests (Dr. Hugo Jurado, pers. comm.). DDT was used, overused or misused, and therefore released to the soil and water bodies. To date, it has been pointed out that the only country still using DDT during the mid-1990 in South America was Ecuador; ironically, it was also the only country that experienced a significant decline in malaria (Mangu-Ward, 1997). DDT concentrations were reported on the Taura River Basin, Gulf of Guayaquil, in sediment (1.36 ug/kg wet weight) and aquatic organisms (2.87 ug/kg wet weight). The DDE/DDT ratio for these samples indicate relatively recent contamination by DDT-parental compound in sediment (ratio DDE/DDTs = 0.66) and fish (ratio DDE/DDTs=0.14) from the Taura River. The environmental implications and health effects of DDT use in aquatic birds and raptors is poorly understood and assessed in this country. The current levels, distribution, fate and effects of these POPs in environmental matrices (e.g., water, sediments, soil, fish and birds) have received scant attention.

Relatively high metal concentrations in sediment were reported for Hg (2.89 mg/kg dw), Pb (112 mg/kg dw), Cu (250 mg/kg dw), and Zn (550 mg/kg dw) exceeding the Effects Range Low (ERL) and the Effects Range Medium (ERM) sediment quality guidelines for Hg (0.71) and for Zn (410) (Calle & Alava, 2009). Organic (i.e., pesticides) and inorganic (metals) chemicals contaminants are a major problem not only for waterbirds, but for raptors associated to aquatic environments and several other species of wildlife. It is likely that individuals of Mangrove Black Hawk inhabiting mangroves close to commercial banana cultivation (i.e. the El Oro Province) might be facing exposures to chemicals and lethal effects both in the long and short terms (Alava et al., 2011), similar to that suggested for the Snail Kite (*Rosthramus sociabilis*) inhabiting and foraging in zones of vast rice fields and flooded areas of coastal Ecuador (e.g., Guayas, Los Rios and the El Oro provinces) where pesticides are broadly used (Alava et al., 2007). Ecotoxicological research is strongly encouraged in Ecuador to determine the levels, food web bioaccumulation and effects of insecticides and herbicides (e.g., organochlorines, organophosphates, carbamates, bipiridyls) in top predator birds, including water birds and raptors.

Marine pollution by debris in Galapagos waters is emerging as a significant concern for biota. A beach-shoreline cleanup program around the Galapagos in 1999 retrieved 22,140 kg of debris, with plastics and metals being the predominant objects at 25 and 28% of the total (Fundación Natura & WWF 2000; Alava, 2011). At sea, the accidental or deliberate disposal of solid waste (e. g., plastic, fishery gear) from both tourism and fishing vessels represent a threat for marine vertebrates such as large pelagic fish, sea turtles, cetaceans, sea lions, fur seals and sea birds (Alava, 2011). Likewise, both intentional (operational) and unintentional (accidental) fuel and oil releases occur around the islands from ships, with the former occurring in the long-term causing chronic degradation and latter resulting in acute impacts to the marine environment (Lessmann, 2004). Oil spills offer perhaps the most visible example of pollutant impacts on sea life. During the last two decades, several oil spills have taken place in the Galapagos (Table 4). A major oil spill that threatened a significant part of the GMR was the *MV Jessica* spill on 16 January 2001 at the entrance of Naufragio Bay (89 37'15"W, 053'40"S), San Cristóbal Island. The oil tanker released almost 100% of its total cargo consisting of 302,824 L of IFO 120–bunker fuel (Fuel Oil 120) and 605,648 L of Diesel oil # 2 (DO#2) (Lougheed et al., 2002; Edgar et al., 2003). Although no oiled seabirds were recorded at the time of this oil spill (Lougheed et al., 2002), researcher doing field work in Española Island found five oiled Nazca boobies (*Sula granti*) in January 2001, one oiled waved albatross in June 2001, and two oiled Nazca boobies in November 2001, confirming that these birds were polluted by spilled oil (Anderson et al., 2003). In early July 2002, a second oil spill took place in the Galapagos, when a small tanker (*BAE/Taurus*) sank and spilled diesel fuel in waters off the coast of Puerto Villamil, Isabela Island. Fortunately, no sign of fuel was found on the beaches or on marine animals (including sea birds), due to mitigation efforts conducted by the GNPS and Charles Darwin Foundation. Other low magnitude oil spill events have also occurred (Lessmann, 2004). The chronic toxic effects of the 2001−Jessica oil spill's residues on unique vulnerable population of Galapagos marine iguanas (*Amblyrhynchus cristatus*) has been well documented elsewhere (Wikelski et al., 2001; Wikelski et al., 2002). Less visible and more insidious global toxicants of concern involve POPs (i.e., PCBs, DDTs and several other organochlorine pesticides), which have recently been detected and assessed in fish collected from Galapagos waters and in Galapagos sea lions (*Zalophus wollebaeki*) (Alava et al., 2009; Alava et al., 2011; Alava, 2011), but these contaminants still need to be investigated in seabirds endemic to the Galapagos.

Boat/Tanker	**Date**	**Site**	**Quantity (L)**
Motor Yacht Iguana	June 1988	Santa Cruz Island	189,265
MV/Jessica	16 January 2001	Naufragio Bay, San Cristóbal	908,472
BAE/Taurus	4-7 July 2002	Puerto Villamil, Isabela Island	7571
MV/Galapagos-Explorer	13-14 September 2005	Academia Bay, Puerto Ayora, Santa Cruz Island	Not reported*

Table 4. Inventory of oil and diesel spills in the Galapagos from 2001 to 2006. *151,412 L of fuel were estimated to be contained in the boat, but actual volume spilled was not reported (adapted from Alava, 2001).

5.5 Regional climate variability

Increasing emissions of greenhouse gases, including carbon dioxide (CO_2) due to fossil fuel, and increases in global average air and ocean temperatures are the major forces driving global warming in the last century and in recent times (IPCC, 2007). A warming (global surface temperature) of about 0.2 °C per decade is projected for the next two decades according to scenarios of the Intergovernmental Panel on Climate Change (IPPC, 2007). Warming is larger in the Western Equatorial Pacific than in the Eastern Equatorial Pacific over the past century, suggesting that the increased West-East temperature gradient may have increased the likelihood of strong El Niños, such as those of 1983 and 1998 (Timmermann et al., 1999; Hansen et al., 2006). It has been predicted that anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if greenhouse gas concentrations were to be stabilized (IPPC, 2007). Global warming of more than ≈1°C, relative to 2000, will constitute dangerous climate change due to likely effects on sea level and extinction of species (Hansen et al., 2006).

Seabirds are key indicators of the impact of climate change on the global ocean (BirdLife International, 2008b). Although the impact of climate change on several large-scale oceano-climatic fluctuations, including the El Niño-Southern Oscillation, (ENSO) is difficult to predict, it has been suggested that global warming may result in more frequent and intense

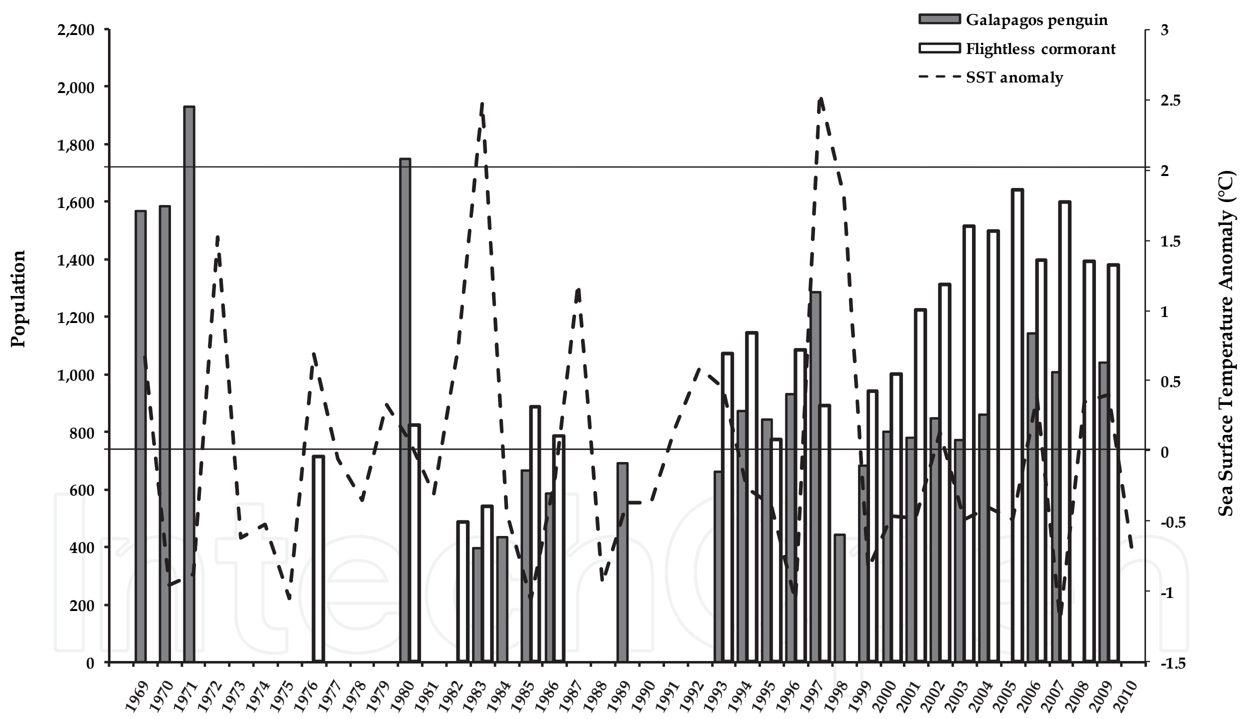

Fig. 5. Time series data of Galapagos penguin (grey bars) and Flightless cormorant (white bars) populations and sea surface temperature (SST) anomalies (dashed line) for El Niño regions 1 and 2, which engulf the Galapagos Archipelago in the Southeastern Tropical Pacific Ocean region. The positive temperature anomalies exceeding 2°C (solid, black line) indicate strong El Niño events (i.e., 1982-1983; and, 1997-1998). SST anomalies are good indicator of El Niño events; thus, SST anomaly data was collected between 1969 and 2009. SST anomalies were available from the NOAA National Weather Service (NOAA, 2011): (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_change.shtml).

El Niño events (Timmermann et al., 1999). Therefore, it is likely that the most significant threat from global climate change is its potential to affect the frequency and severity of ENSO events and the associated to lack of primary productivity, impacting endemic Galapagos seabirds and coastal waterbirds (Vargas et al., 2006; Wiedenfeld & Jiménez-Uzcátegui, 2008). Increases in sea surface temperature deplete primary production disrupting the bottom of marine food webs, and therefore top predators. El Niño may severely affect marine species especially small population of seabird such Galapagos penguins and Flightless cormorants (Wiedenfeld & Jiménez-Uzcátegui, 2008; Vargas et al., 2006). For instance, the 2004 penguin population (858 penguins) was estimated to be less than 50% of that prior to the strongest 1982–1983 El Niño event, including the population counted in the early 1970s, when the total number was 1931 penguins (Vargas et al., 2005; Vargas et al., 2006; Vargas et al., 2007), as shown in Fig 5. This underlines that the strong El Niño events of 1982-1983 and 1997-1998 were followed by population declines of more than 60% from which the species has yet to recover (Vargas et al., 2007). The censuses for Galapagos penguin and Flightless cormorants conducted in the last decade (2000-2010) appear to show a moderate positive or stable trend for both species (Jiménez-Uzcátegui et al., 2006; Jiménez-Uzcátegui & Vargas, 2007; Jiménez-Uzcátegui & Devineau, 2009), underscoring the potential recover during cold La Niña episodes (Vargas et al., 2006), but above all the ecological resilience of these endemic seabirds to overcome the environmental change and. In addition, sea level rise and shift in suitable climatic conditions attributable to global warming may damage coastal habitats such as mangroves and lagoons (Wiedenfeld & Jiménez-Uzcátegui, 2008; BirdLife International, 2008b).

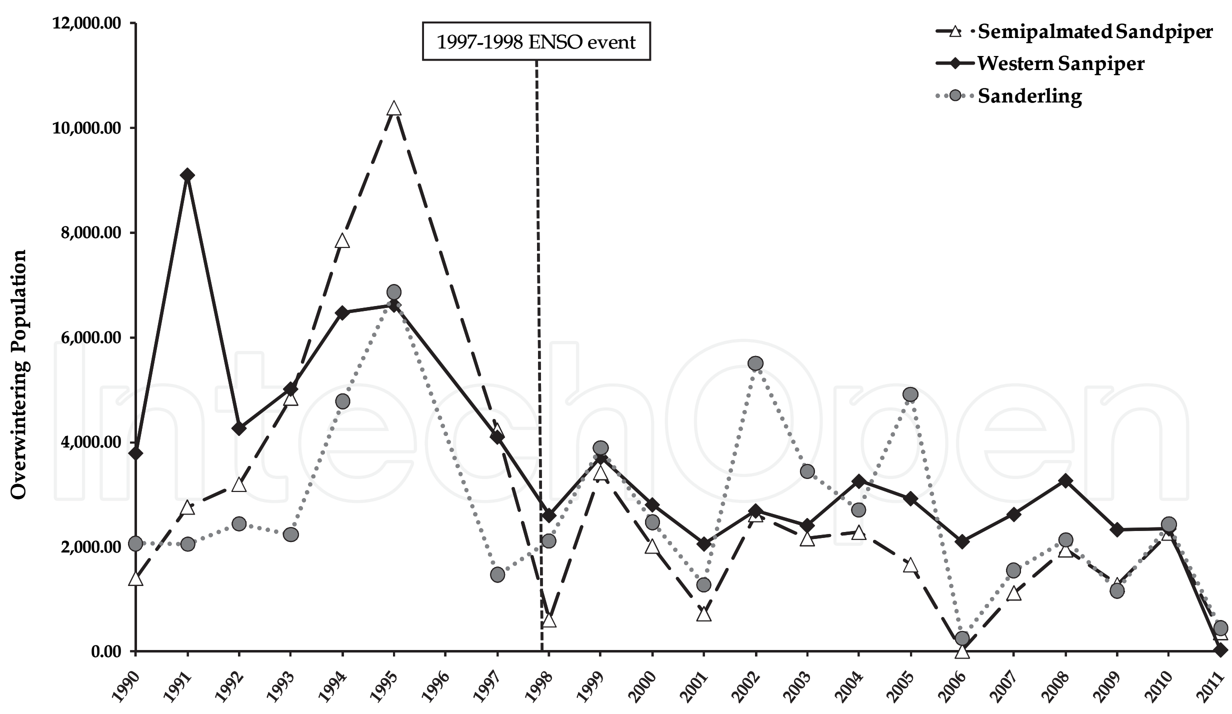

Fig. 6. Local population trends of migratory sandpipers observed at Ecuasal lagoons on coastal Ecuador from 1990 to 2011 (data adapted from Haase, 2011b).

Similarly, negative trends have recently been observed for local populations of several migratory shorebird species overwintering at coastal Ecuador from 1991 to 2011 (Haase, 2011b). Some of the species include the Western Sandpiper (*C. mauri*), Semipalmated Sandpiper (*C. pusilla*) and Sanderling (*C. alba*). The decline is more evident after the El Niño event of 1997-1998 (Haase, 2011b), as shown in Fig. 6.

6. Conservation and management implications

Several international conventions aimed to conserve and protect the biodiversity and environment as well as cultural and natural heritage within the country have been signed and ratified by the Ecuadorian government. These include the Convention on Biological Diversity (CBD, ratified in 1993), World Heritage Convention (signed in 1973), Convention on Migratory species (ratified in 2004), Convention on International Trade in Endangered Species of Wild Fauna and Flora (signed in 1974), Ramsar Convention on Wetlands (ratified in 1990). Ecuador has also signed bilateral environmental agreements with Peru and Colombia. Despite of Ecuador's commitment to internalize and pursue the goals of these agreements and the existence of several environmental laws, regulations and acts at the National level, lack of law empowering is observed at the local and regional levels and violations are scarcely sanctioned. Empowerment and enforcement of regulations and laws are necessary to accomplish legal protection of threatened species and conservation of critical habitats for waterbirds. Best management practices and effective land-use zoning, utilizing buffer zones between agricultural (plantations and farms) areas and the mangrove wetlands would ensure protection of local biodiversity. Best framing practices and the establishment of buffer zones (i.e., 100m) are needed to mitigate the agriculture expansion and cattle ranching in some areas such as those found around the El Canclon lagoon and Santay Island. Community-based conservation and environmental awareness might be undertaken by building capacity of local stakeholders (e.g. farmers and ranchers) in sustainable aquaculture/agriculture and nature tourism in areas that have received scant attention. At the Ecuasal lagoons, for instance, the owner and manager (Ecuasal Company) of the two production plants (Salinas and Pacoa lagoons) has lent its facilities to local ornithologists for the study of the birds and has shown great interest in supporting bird conservation and ecotourism during the last 10 years. Likewise, the Control and Surveillance System of the Mangrove Clear-Cutting Project conducted by Fundacion Natura and the National Chamber of Aquaculture hampered significantly the deforestation of mangrove forests on the Ecuadorian continental coast between 1998 and 2002 (Carvajal & Alava, 2007). Yet, field research is necessary for studying the relationship between the abundance waterbird species, including common and rare species, and disturbed and undisturbed mangrove areas.

Introduced plants and animals represent one of the greatest threats to the ecosystems of Galapagos**.** The invasive species eradication and control program of the Galapagos National Park Service and the Galapagos Inspection and Quarantine System (SICGAL) promise the avoidance and restriction of alien species to the islands. A recent triumph in this arena was the successful eradication of introduced and feral goats in Santiago Island (Cruz et al., 2009); yet, goats from other island still need to be removed. Similarly, industrial longline fishing activities have continued within Galapagos waters and several illegal vessels have been confiscated since the GMR was established. It has been suggested that the reduction of adult mortality of albatrosses in the coastal fishery of Ecuador and Peru appears to be the most effective means to stabilize this threatened species (Anderson et al., 2008). Currently, the ongoing institutional cooperation and surveillance system involving the Galapagos National Park Service, The Ecuadorian Navy Forces and non-governmental organizations assure in somehow the control and enforcement of fishing prohibitions to mitigate the bycatch problem within the GMR.

7. Acknowledgements

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Order: Family/common name	Species	Remarks/**Global conservation status**
ANSERIFORMES: Anhimidae		
Horned Screamer	*Anhima cornuta*	**Least Concern**
ANSERIFORMES: Anatidae		
Black-bellied Whistling-Duck	*Dendrocygna autumnalis*	
Fulvous Whistling-Duck	*Dendrocygna bicolor*	
Comb Duck	*Sarkidiornis melanotos*	
Orinoco Goose	*Neochen jubata*	**Near-threatened**
Muscovy Duck	*Cairina moschata*	**Near-threatened**
Torrent Duck	*Merganetta armata*	
Blue-winged Teal	*Anas discors*	
Cinnamon Teal	*Anas cyanoptera*	Extirpated
Northern Shoveler	*Anas clypeata*	Rare/Accidental
White-cheeked Pintail	*Anas bahamensis*	
Yellow-billed Pintail	*Anas georgica*	
Andean Teal	*Anas andium*	
Southern Pochard	*Netta erythrophthalma*	**Least Concern**
Lesser Scaup	*Aythya affinis*	Rare/Accidental
Masked Duck	*Nomonyx dominicus*	
Ruddy Duck	*Oxyura jamaicensis*	
PODICIPEDIFORMES: Podicipedidae		
Least Grebe	*Tachybaptus dominicus*	

Order: Family/common name	Species	Remarks/**Global conservation status**
Pied-billed Grebe	*Podilymbus podiceps*	
Great Grebe	*Podiceps major*	Rare/Accidental
Silvery Grebe	*Podiceps occipitalis*	**Least Concern**
PHOENICOPTERIFORMES: Phoenicopteridae		
American Flamingo	*Phoenicopterus ruber*	
Chilean Flamingo	*Phoenicopterus chilensis*	**Near-threatened**
SPHENISCIFORMES: Spheniscidae		
Humboldt Penguin	*Spheniscus humboldti*	Rare/Accidental/**Vulnerable**
Galapagos Penguin	*Spheniscus mendiculus*	Endemic/ **Endangered**
PROCELLARIIFORMES: Diomedeidae		
Black-browed Albatross	*Thalassarche melanophris*	Rare/Accidental
Wandering Albatross	*Diomedea exulans*	Rare/Accidental
Waved Albatross	*Phoebastria irrorata*	**Critically endangered**
Black-footed Albatross	*Phoebastria nigripes*	Rare/Accidental/**Endangered**
PROCELLARIIFORMES: Procellariidae		
Southern Giant-Petrel	*Macronectes giganteus*	Rare/Accidental/**Near-threatened**
Southern Fulmar	*Fulmarus glacialoides*	Rare/Accidental
Cape Petrel	*Daption capense*	Rare/Accidental
Galapagos Petrel	*Pterodroma phaeopygia*	Breeding endemic/**Critically endangered**
Gould's Petrel	*Pterodroma leucoptera*	Rare/Accidental
White-chinned Petrel	*Procellaria aequinoctialis*	Rare/Accidental/**Vulnerable**
Parkinson's Petrel	*Procellaria parkinsoni*	**Common/Vulnerable**
Pink-footed Shearwater	*Puffinus creatopus*	Accidental/**Vulnerable**
Wedge-tailed Shearwater	*Puffinus pacificus*	Rare
Buller's Shearwater	*Puffinus bulleri*	Rare/Accidental/**Vulnerable**
Sooty Shearwater	*Puffinus griseus*	Near-threatened; Common
Galapagos Shearwater	*Puffinus subalaris*	Endemic/Rare coastal
PROCELLARIIFORMES: Hydrobatidae		
Wilson's Storm-Petrel	*Oceanites oceanicus*	Rare/Accidental
Elliot's Storm-Petrel	*Oceanites gracilis*	Data deficient
White-faced Storm-Petrel	*Pelagodroma marina*	Rare/Accidental
White-bellied Storm-Petrel	*Fregetta grallaria*	Rare/Accidental
Polynesian Storm-Petrel	*Nesofregetta fuliginosa*	Vulnerable
Ringed Storm-Petrel	*Oceanodroma hornbyi*	Accidental/**Data deficient**
Leach's Storm-Petrel	*Oceanodroma leucorhoa*	Rare/Accidental

Order: Family/common name	Species	Remarks/**Global conservation status**
Ashy Storm-Petrel	*Oceanodroma homochroa*	Rare/Accidental **Endangered**
Band-rumped Storm-Petrel	*Oceanodroma castro*	Accidental
Wedge-rumped Storm-Petrel	*Oceanodroma tethys*	Common
Black Storm-Petrel	*Oceanodroma melania*	Common
Markham's Storm-Petrel	*Oceanodroma markhami*	Rare/Accidental/**Data deficient**
Least Storm-Petrel	*Oceanodroma microsoma*	Accidental
PHAETHONTIFORMES: Phaethontidae		
Red-billed Tropicbird	*Phaethon aethereus*	Coastal Accidental
CICONIIFORMES: Ciconiidae		
Jabiru	*Jabiru mycteria*	Rare/Accidental
Wood Stork	*Mycteria americana*	
SULIFORMES: Fregatidae		
Magnificent Frigatebird	*Fregata magnificens*	Common
Great Frigatebird	*Fregata minor*	Coastal rare
SULIFORMES: Sulidae		
Nazca Booby	*Sula granti*	Common
Blue-footed Booby	*Sula nebouxii*	Common
Peruvian Booby	*Sula variegata*	Common
Red-footed Booby	*Sula sula*	Coastal Rare
Brown Booby	*Sula leucogaster*	Hypothetical
SULIFORMES: Phalacrocoracidae		
Flightless Cormorant	*Phalacrocorax harrisi*	Endemic/**Endangered**
Neotropic Cormorant	*Phalacrocorax brasilianus*	Common
Guanay Cormorant	*Phalacrocoraxbougainvillii*	Rare/**Near-threatened**
SULIFORMES: Anhingidae		
Anhinga	*Anhinga anhinga*	
PELECANIFORMES: Pelecanidae		
Brown Pelican	*Pelecanus occidentalis*	Common
Peruvian Pelican	*Pelecanus thagus*	Common/**Near-threatened**
PELECANIFORMES: Ardeidae		
Pinnated Bittern	*Botaurus pinnatus*	**Least Concern**
Zigzag Heron	*Zebrilus undulatus*	
Least Bittern	*Ixobrychus exilis*	
Rufescent Tiger-Heron	*Tigrisoma lineatum*	
Fasciated Tiger-Heron	*Tigrisoma fasciatum*	
Great Blue Heron	*Ardea herodias*	
Cocoi Heron	*Ardea cocoi*	Coastal common
Great Egret	*Ardea alba*	Common

Order: Family/common name	Species	Remarks/**Global conservation status**
Little Egret	*Egretta garzetta*	
Snowy Egret	*Egretta thula*	Common
Little Blue Heron	*Egretta caerulea*	Locally common
Tricolored Heron	*Egretta tricolor*	Common
Cattle Egret	*Bubulcus ibis*	Common
Green Heron	*Butorides virescens*	
Striated Heron	*Butorides striata*	Locally Common
Agami Heron	*Agamia agami*	
Whistling Heron	*Syrigma sibilatrix*	Rare/Accidental
Capped Heron	*Pilherodius pileatus*	
Black-crowned Night-Heron	*Nycticorax nycticorax*	Common
Yellow-crowned Night-Heron	*Nyctanassa violacea*	Common
Boat-billed Heron	*Cochlearius cochlearius*	
PELECANIFORMES: Threskiornithidae		
White Ibis	*Eudocimus albus*	Locally Common
Scarlet Ibis	*Eudocimus ruber*	Rare/Accidental
Glossy Ibis	*Plegadis falcinellus*	
Green Ibis	*Mesembrinibis cayennensis*	
Bare-faced Ibis	*Phimosus infuscatus*	Rare/Accidental
Black-faced Ibis	*Theristicus melanopis*	**Least Concern**
Roseate Spoonbill	*Platalea ajaja*	Very locally common
GRUIFORMES: Rallidae		
Rufous-sided Crake	*Laterallus melanophaius*	
White-throated Crake	*Laterallus albigularis*	
Gray-breasted Crake	*Laterallus exilis*	
Galapagos Rail	*Laterallus spilonotus*	Endemic/**Vulnerable**
Clapper Rail	*Rallus longirostris*	**Least Concern**
Virginia Rail	*Rallus limicola*	
Brown Wood-Rail	*Aramides wolfi*	**Vulnerable**
Rufous-necked Wood-Rail	*Aramides axillaris*	**Least Concern**
Gray-necked Wood-Rail	*Aramides cajanea*	
Red-winged Wood-Rail	*Aramides calopterus*	
Uniform Crake	*Amaurolimnas concolor*	
Chestnut-headed Crake	*Anurolimnas castaneiceps*	
Russet-crowned Crake	*Anurolimnas viridis*	
Black-banded Crake	*Anurolimnas fasciatus*	
Sora	*Porzana carolina*	
Colombian Crake	*Neocrex colombiana*	**Data deficient**
Paint-billed Crake	*Neocrex erythrops*	
Spotted Rail	*Pardirallus maculatus*	
Blackish Rail	*Pardirallus nigricans*	

Order: Family/common name	Species	Remarks/**Global conservation status**
Plumbeous Rail	*Pardirallus sanguinolentus*	
Purple Gallinule	*Porphyrio martinica*	Locally Common
Azure Gallinule	*Porphyrio flavirostris*	
Common Moorhen	*Gallinula chloropus*	Locally Common
American Coot	*Fulica americana*	**Extirpated**
Slate-colored Coot	*Fulica ardesiaca*	Coastal Accidental
GRUIFORMES: Heliornithidae		
Sungrebe	*Heliornis fulica*	
EURYPYGIFORMES: Eurypygidae		
Sunbittern	*Eurypyga helias*	
GRUIFORMES: Aramidae		
Limpkin	*Aramus guarauna*	
GRUIFORMES: Psophiidae		
Gray-winged Trumpeter	*Psophia crepitans*	
CHARADRIIFORMES: Burhinidae		
Peruvian Thick-knee	*Burhinus superciliaris*	Locally common
CHARADRIIFORMES: Charadriidae		
Pied Lapwing	*Vanellus cayanus*	
Southern Lapwing	*Vanellus chilensis*	
Andean Lapwing	*Vanellus resplendens*	Rare
Black-bellied Plover	*Pluvialis squatarola*	Common
American Golden-Plover	*Pluvialis dominica*	Accidental
Pacific Golden-Plover	*Pluvialis fulva*	Rare
Collared Plover	*Charadrius collaris*	Locally common
Snowy Plover	*Charadrius alexandrinus*	Locally Common
Wilson's Plover	*Charadrius wilsonia*	Locally Common
Semipalmated Plover	*Charadrius semipalmatus*	Common
Piping Plover	*Charadrius melodus*	Rare/Accidental/**Near-threatened**
Killdeer	*Charadrius vociferus*	Locally Common
Tawny-throated Dotterel	*Oreopholus ruficollis*	Extirpated
CHARADRIIFORMES: Haematopodidae		
American Oystercatcher	*Haematopus palliatus*	Locally Common
CHARADRIIFORMES: Recurvirostridae		
Black-necked Stilt	*Himantopus mexicanus*	Common
American Avocet	*Recurvirostra americana*	Rare

Order: Family/common name	Species	Remarks/**Global conservation status**
CHARADRIIFORMES: Jacanidae		
Wattled Jacana	*Jacana jacana*	Locally Common
CHARADRIIFORMES: Scolopacidae		
Spotted Sandpiper	*Actitis macularius*	Common
Solitary Sandpiper	*Tringa solitaria*	
Wandering Tattler	*Tringa incana*	Locally Common
Greater Yellowlegs	*Tringa melanoleuca*	Common
Willet	*Tringa semipalmata*	Common
Lesser Yellowlegs	*Tringa flavipes*	Common
Upland Sandpiper	*Bartramia longicauda*	Coastal accidental
Whimbrel	*Numenius phaeopus*	Common
Hudsonian Godwit	*Limosa haemastica*	Accidental
Marbled Godwit	*Limosa fedoa*	Rare/Accidental
Ruddy Turnstone	*Arenaria interpres*	Common
Black Turnstone	*Arenaria melanocephala*	Rare/
Surfbird	*Aphriza virgata*	Locally common
Red Knot	*Calidris canutus*	Accidental
Sanderling	*Calidris alba*	Common
Semipalmated Sandpiper	*Calidris pusilla*	Common
Western Sandpiper	*Calidris mauri*	Locally Common
Least Sandpiper	*Calidris minutilla*	Common
White-rumped Sandpiper	*Calidris fuscicollis*	Coastal accidental
Baird's Sandpiper	*Calidris bairdii*	Accidental
Pectoral Sandpiper	*Calidris melanotos*	Accidental
Curlew Sandpiper	*Calidris ferruginea*	Rare/Accidental
Stilt Sandpiper	*Calidris himantopus*	Locally Common
Buff-breasted Sandpiper	*Tryngites subruficollis*	**Near-threatened**
Short-billed Dowitcher	*Limnodromus griseus*	Locally Common
Long-billed Dowitcher	*Limnodromus scolopaceus*	Rare
South American Snipe	*Gallinago paraguaiae*	
Noble Snipe	*Gallinago nobilis*	
Andean Snipe	*Gallinago jamesoni*	
Imperial Snipe	*Gallinago imperialis*	**Near-threatened**
Wilson's Phalarope	*Phalaropus tricolor*	Locally Common
Red-necked Phalarope	*Phalaropus lobatus*	Common
Red Phalarope	*Phalaropus fulicarius*	Accidental
CHARADRIIFORMES: Thinocoridae		
Rufous-bellied Seedsnipe	*Attagis gayi*	
Least Seedsnipe	*Thinocorus rumicivorus*	Rare/Accidental

Order: Family/common name	Species	Remarks/**Global conservation status**
CHARADRIIFORMES: Laridae		
Swallow-tailed Gull	*Creagrus furcatus*	Coastal accidental
Sabine's Gull	*Xema sabini*	Locally Common
Bonaparte's Gull	*Chroicocephalus philadelphia*	Rare/Accidental
Andean Gull	*Chroicocephalus serranus*	Coastal Accidental
Gray-hooded Gull	*Chroicocephalus cirrocephalus*	Common
Gray Gull	*Leucophaeus modestus*	Locally Common
Laughing Gull	*Leucophaeus atricilla*	Common
Franklin's Gull	*Leucophaeus pipixcan*	Common
Lava Gull	*Leucophaeus fuliginosus*	Endemic/**Vulnerable**
Belcher's Gull	*Larus belcheri*	Rare
Ring-billed Gull	*Larus delawarensis*	Rare
Lesser Black-backed Gull	*Larus fuscus*	Rare
Kelp Gull	*Larus dominicanus*	Common
Glaucous-winged Gull	*Larus glaucescens*	Rare
Brown Noddy	*Anous stolidus*	Rare
Sooty Tern	*Onychoprion fuscatus*	Not coastal/**Data deficient**
Bridled Tern	*Onychoprion anaethetus*	Locally Common
Yellow-billed Tern	*Sternula superciliaris*	Not Coastal
Peruvian Tern	*Sternula lorata*	**Endangered**
Large-billed Tern	*Phaetusa simplex*	Coastal Rare
Gull-billed Tern	*Gelochelidon nilotica*	Locally Common
Inca Tern	*Larosterna inca*	Near-threatened/Rare
Black Tern	*Chlidonias niger*	Accidental
Common Tern	*Sterna hirundo*	Accidental
Arctic Tern	*Sterna paradisaea*	Locally uncommon
South American Tern	*Sterna hirundinacea*	Locally Common
Royal Tern	*Thalasseus maximus*	Common
Sandwich Tern	*Thalasseus sandvicensis*	Common
Elegant Tern	*Thalasseus elegans*	Common /**Near-threatened**
Black Skimmer	*Rynchops niger*	Accidental/ Locally Common/Least Concern
CHARADRIIFORMES: Stercorariidae		
Pomarine Jaeger	*Stercorarius pomarinus*	Accidental
Parasitic Jaeger	*Stercorarius parasiticus*	Locally Common
Long-Tailed Jaeger	*Stercorarius longicaudus*	Rare
South Polar Skua	*Stercorarius maccormicki*	Rare

Annex I. List of waterbird species of Ecuador, including species of the Galapagos Islands Scientific and English names follow the South American Classification Committee (SACC) Classification, Version 31 March 2011 (Freile, 2010).

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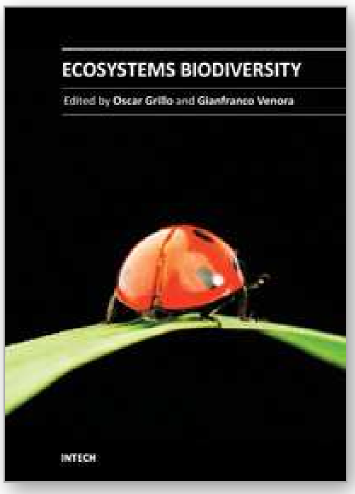

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Ecosystems can be considered as dynamic and interactive clusters made up of plants, animals and micro-organism communities. Inevitably, mankind is an integral part of each ecosystem and as such enjoys all its provided benefits. Driven by the increasing necessity to preserve the ecosystem productivity, several ecological studies have been conducted in the last few years, highlighting the current state in which our planet is, and focusing on future perspectives. This book contains comprehensive overviews and original studies focused on hazard analysis and evaluation of ecological variables affecting species diversity, richness and distribution, in order to identify the best management strategies to face and solve the conservation problems.