Chapter 12
Pollution as an Emerging Threat for the Conservation of the Galapagos Marine Reserve: Environmental Impacts and Management Perspectives

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Abstract The Galapagos Marine Reserve (GMR) is one of the most fragile marine ecoregions to be preserved to benefit global biodiversity. Ongoing continentalization and increasing human population diminish the degree of isolation of the Galapagos, jeopardizing its socio-ecological system. While tourism and fisheries activities stand by the islands' economy, several anthropogenic stressors threaten the marine ecosystem. An environmental assessment and literature survey were conducted to characterize the coastal marine pollution impacts caused by human-made activities. The assessment revealed that municipal waste incineration of organic waste and plastics in open dump areas is a potential source of unintentionally produced persistent organic pollutants such as dioxins and furans. Plastic is one of the most abundant solid wastes at sea and shorelines, representing 25 % of the total marine debris. More than 50 % of current-use pesticides applied in the agriculture zone of the inhabited islands were identified as endocrine-disrupting chemicals, underlying potential health effects in the endemic fauna. Oil spills and traces of hydrocarbons threaten the long-term survival of marine species due to the current reliance on fuel transported from Ecuador's mainland coast. Concerted local and global management strategies are strongly needed into the decision-making processes to protect the GMR from chemical and biological assaults.

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Introduction

Since Charles Darwin wrote *On the Origin of Species* in 1859, the Galapagos Islands have become a living laboratory for the study of natural history. The roots of their unique nature can be attributed to their remote, oceanic geography. The Galapagos comprises an archipelago with 13 major volcanic islands, situated approximately 1,000 km from the Ecuadorian coast, between 01°40′N–01°25′S and 89°15′W–92°00′W. At present, over 2,900 marine species have been identified, of which close to 20 % are endemic to the Galapagos (Bustamante et al. 2002a, b).

Several ocean 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 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. 2002a). In addition, the Equatorial Undercurrent or Cromwell current, rich in nutrients (i.e., dissolved iron), flows from west to east enhancing upwelling conditions around the western platform of the Galapagos.

Only two seasons occur in this region, a warm, wet-rainy season from December to May or June and a cold, dry (*garúa*) season from June to November or December (Snell and Rea 1999; Banks 2002). Periodically, El Niño event can disrupt the Galapagos regional climate, where in the last 20 years it has become more intense, reflecting an increase in the magnitude and intense peak frequency (Snell and Rea 1999; Mendelssohn et al. 2005; Sachs and Ladd 2010).

The Galapagos National Park (GNP) and the Galapagos Marine Reserve (GMR) have been designated a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Natural Heritage Site and Biosphere of the Earth, containing a unique biodiversity and endemism that provides strong evidence of evolutionary theory such as natural selection, adaptation, speciation, and radiation processes. These tropical remote islands still conserving 95 % of its biodiversity were recently enlisted as a heritage in risk in 2007 due to the rising number of invasive species, emergent human population growth, and increasing tourism (Watkins and Cruz 2007). As a complex social-ecological system, the resilience of the Galapagos Islands might be still seriously at risk due to the unsustainable development model and the unresolved social-ecological crisis preventing the reorganization of the system and leading it towards an undesirable state despite predominant legal, political, and management decisions (González et al. 2008).

Under this premise, the human and ecological footprint on the Galapagos Islands is unraveled as the geographic opening of the islands in terms of continentalization, defined as an anthropogenic process reducing the degree of isolation of this fragile ecoregion due to the ongoing reliance on and massive influx of energy, fuel, and materials transported from continental Ecuador, jeopardizing the long-term preservation of the islands (Charles Darwin Foundation 2010; Grenier 2010). Thus, both the GNP and GMR are constantly facing the trade-offs between development and conservation in concert with the social dimensions and political climate triggered by regional economic interests and globalization.

History reveals that subsequent to the declaration of the Galapagos as a national park ($\approx$7,900 km^2 of the terrestrial Galapagos Islands) in 1959, Rachel Carson published her well-known publication *Silent Spring* in 1962 to draw global attention to the potential effects of man-made chemicals, in particular pesticides, on wildlife populations (e.g., raptors and songbirds) and human health (Carson 1962). Interestingly, two decades before the publication of Carson's famous book, the Galapagos were already a strategic location occupied by the US military forces between 1941 and 1946 during World War II (Woram 2005), establishing a military base on Baltra Island (adjacent to the semi-urbanized Santa Cruz Island) in 1943 (González et al. 2008). While it is a fact poorly documented, the implications of this military presence had a considerable anthropogenic pressure in the Galapagos environment, including impacts to the endemic vegetation and land iguanas (*Conolophus subcristatus*). In addition to this preceding human footprint, Americans used the organochlorine pesticide, DDT (dichlorodiphenyltrichloroethane), to eliminate introduced rats (e.g., black rats, *Rattus rattus*) in the islands (Alava et al. 2011a, b). Yet, this effort was unsuccessful as the invasive rodents were not eliminated, but the legacy of the past use of DDT still persists in the marine environment of the islands, as demonstrated recently by the biomagnification of this pollutant in the Galapagos sea lion food chain (Alava and Gobas 2012).

Coastal development, fisheries overexploitation, and chemical and biological pollution have been identified as the major threats to the world's oceans and marine protected areas (Boersma and Parrish 1999). In these islands, most of the resident population obtains their economic incomes either directly or indirectly from the ecotourism, which is the major economic activity, based on the observation of native fauna and flora of the islands, while others are benefited from exploitation of reef fishes, lobster, sea cucumber, and even illegal shark finning (Merlen 1995; MacFarland and Cifuentes 1996; Bensted-Smith et al. 2002; Carr et al. 2013). However, intentional (operational) and unintentional (accidental) releases of hydrocarbons (e.g., oil, diesel, gas) occur regularly around the islands from ships, with the former occurring in the long term causing chronic degradation and the latter resulting in acute impacts to the marine environment (Lessmann 2004). While oil spills offer perhaps the most visible example of pollutant impacts on sea life, less visible and more insidious global toxicants of concern involve persistent organic pollutants (POPs), which have recently been assessed in few organisms in the Galapagos (Alava 2011).

During the last 15 years, the Galapagos Islands Archipelago has undergone drastic economic, social, cultural, and ecological changes. The principal cause of these changes has been economic growth driven by tourism whose gross income has increased by an average 14 % each year (Watkins and Cruz 2007; González et al. 2008). Tourism and population growth stimulate the arrival of more flights and more cargo ships, diminishing the degree of isolation of these remote islands and, therefore, increasing the potential arrival of invasive species (Watkins and Cruz 2007) and augmenting the risk of pollution.

The coastal environment and food webs in the Galapagos are at risk due to anthropogenic impacts. Contamination by both chemical and biological pollutants is critical to the long-term conservation of Galapagos biodiversity and native wildlife. Coastal waters that are contaminated with persistent chemicals and pathogens can lead to human illness, reduced fisheries quality and quantity, and impacts on the health of marine wildlife, having serious obvious social and economic consequences. Conversely, coastal waters that are protected from environmental pollutants provide food to humans and wildlife and provide a foundation for biodiversity, the human population, and the ecotourism sector. In 2000, Ecuador's economy obtained US $210 million from Galapagos tourism alone (Fundación Natura and World Wildlife Fund 2002). For the Ecuadorian government and the people of the Galapagos, therefore, a rigorous evaluation of past, current, and potential environmental impacts is a crucial part of the social and economic integrity of the archipelago.

In this chapter, an environmental impact assessment and literature review was conducted to explore evidences of current environmental and marine pollution pressures that are threatening the conservation of the Galapagos Marine Reserve and its endemic wildlife. By identifying local and external pollution sources and their potential impacts to the health of wildlife populations, we aim to contribute with a new impact assessment baseline and recommend precautionary mitigation strategies to support the environmental management plan of the Galapagos Marine Reserve.

Declining Wildlife in Galapagos: Impact of Environmental Stressors

Several populations of endemic wildlife and marine species (e.g., marine mammals, seabirds, and marine iguanas) are being affected by both natural and anthropogenic factors in the Galapagos (Fig. 12.1). In general, the Galapagos wildlife is affected by different natural stressors, including density-dependent (i.e., predation, competition, food shortages, disease, territory) and density-independent factors (the El Niño–Southern Oscillation (ENSO) and natural disasters, i.e., volcanic activity and tsunamis), as depicted in Fig. 12.1. Thus, it is of particular importance to differentiate those human-made activities affecting wildlife from natural variation and regulatory forces (i.e., population regulation), keeping populations at balance (i. e., equilibrium) after facing drastic fluctuations. In addition, while there are several lines of evidences showing that anthropogenic pressures such as introduced species, chemical and biological pollution, solid waste, urban sprawl (i.e., habitat fragmentation), and illegal fishing are affecting native and endemic species, the impact of

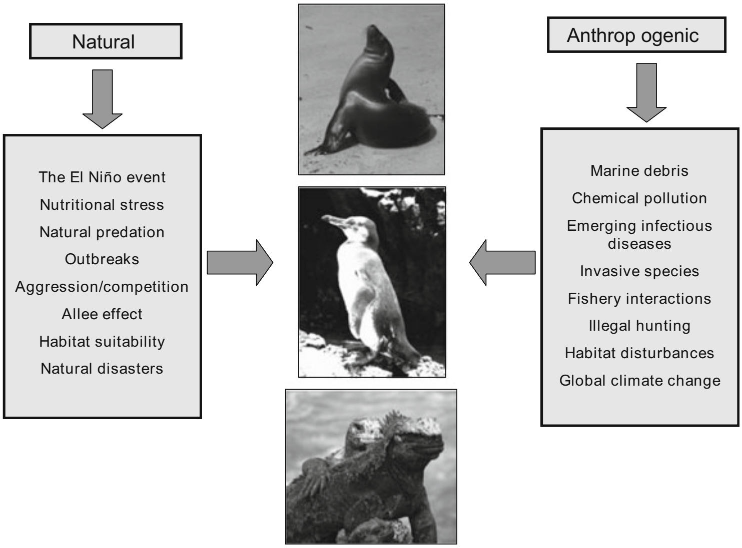

Fig. 12.1 Environmental stressors, including both natural and anthropogenic factors, influence the population dynamics of marine wildlife in the Galapagos Islands. In this illustration, three endemic species, including the Galapagos sea lion (*top*), Galapagos penguin (*middle*), and marine iguana (*bottom*), are shown as examples of organisms undergoing cumulative anthropogenic environmental impacts (*right box*) and affected by density-dependent factors (*left box*). Adapted and modified from Alava (2011). Photos: J.J. Alava

anthropogenic climate change cannot be ruled out as looming threat for these species in the long term.

The El Niño phenomenon has affected endemic seabird populations, including the flightless cormorants (*Phalacrocorax harrisi*) and Galapagos penguins (*Spheniscus mendiculus*). For instance, the 2004 penguin population (≈1,500 birds) was estimated to be less than 50 % of that prior to the strong 1982–1983 El Niño event (Vargas et al. 2005, 2006, 2007). Although the impact of climate change on several large-scale ocean-climatic fluctuations (i.e., ENSO episodes) is difficult to predict due to uncertainty, it has been suggested that global climate change may result in continued, more frequent, and intense El Niño events coupled with higher sea-surface temperature, increased precipitation, sea level rise, acidification, and reduction in upwelling in the Galapagos (Timmermann et al. 1999; Mendelssohn et al. 2005; Sachs and Ladd 2010). Therefore, it is likely that the most significant threat from climate change is its potential to affect the frequency and severity of ENSO events, impacting not only Galapagos seabirds and coastal waterbirds (Vargas et al. 2006; Wiedenfled and Jiménez-Uzcategui 2008) but endemic pinnipeds, including the Galapagos sea lions (*Zalophus wollebaeki*) and Galapagos fur seals (*Arctocephalus galapagoensis*) (Trillmich and Limberger 1985; Trillmich and Dellinger 1991; Alava and Salazar 2006; Salazar and Denkinger 2010), as well as the Galapagos marine iguana (*Amblyrhynchus cristatus*) (Laurie 1989; Laurie and Brown 1990; Wikelski and Thom 2000).

Bycatch and plastic threaten the critically endangered Galapagos albatross (*Phoebastria irrorata*) and Galapagos petrels (*Pterodroma phaeopygia*) in oceanic waters outside the limits of GMR (Alava and Haase 2011). Additional anthropogenic and catastrophic factors such as introduced predators (particularly rats, cats, and dogs), competition from fisheries, introduced diseases (i.e., emerging infectious pathogens), and oil spills could further contribute to population declines or accelerate the probability of extinction of Galapagos seabirds (Vargas et al. 2005, 2006; Wiedenfled and Jiménez-Uzcategui 2008; Alava and Haase 2011).

Typical examples of endemic marine mammals mostly affected by these factors are Galapagos sea lions and fur seals, which have declined from 40,000 and 30,000–40,000 to 16,000 and 6,000–8,000 animals, respectively, since the late 1970s, without showing signs of recovery in most of the islands (Alava and Salazar 2006). This implies a decline of 60 % for Galapagos sea lions and 80–85 % for Galapagos fur seals from the late 1970s to 2000 (Alava and Salazar 2006). As a result, these two species are listed under the IUCN endangered (EN) category (Aurioles and Trillmich 2008a, b).

Whereas the effects of oceanographic—climate episodes, including the El Niño events, are well known as a cause of declining in sea lions, fur seals, and seabirds, the role of marine pollution has not been fully investigated although it is among them. The best well-known case of mortality in an endemic species associated to marine pollution was the chronic toxic effects of the 2001 Jessica oil spill's residues that affected the vulnerable population of marine iguanas, as documented elsewhere (Wikelski et al. 2001, 2002; Romero and Wikelski 2002).

With a fair understanding of the distinction between natural forces acting and shaping the evolution in these species and those created by human activities, the following sections are focused on the anthropogenic impacts affecting wildlife populations, including marine fauna, and the GMR.

Pollution Sources and Impacts in the GMR

Anthropogenic Impacts: Characterization and Assessment

The fundamental source of this chapter is Alava (2011), complemented with information and data compiled and analyzed from the existing scientific literature, technical reports, and lines of evidences from field observations. A characterization matrix of anthropogenic impacts resulting in major conservation threats and environmental effects for marine and terrestrial components of the Galapagos Islands is available in Alava (2011). A synthesis focused on management implications for the GMR is also provided at the end of this assessment. Based on the identification of threats and impacts, the overall impact assessment is described as follows.

Table 12.1 Population and waste production in three islands of the Galapagos based on the last human census conducted in 2010

Island (years of surveys: waste production)	Population: 2010 census[a]	kg/day/person (1990s/2008)	% OM (1990s/ 2008)	2010 estimated range tonnes/year
Isabela (1998[b]/2008[c])	2,256	(0.6/0.6)	(≈70/86)	494
San Cristóbal (1997[b]/ 2008[c])	7,475	(1.3/0.6)	(>70/61)	1,637–3,547
Santa Cruz (1995[b]/2008[c])	15,393	(0.8/0.6)	(≈60/40)	3,371–4,495

Database for waste production per capita per day and organic matter (OM) composition was obtained and adapted from Fundación Natura and WWF (1999), Kerr et al. (2004), and De la Torre (2008)

[a] Database for the 2010 human population census for the Galapagos Islands was retrieved from INEC (2011)

[b] Data for 1995, 1997 and 1998 was obtained from Fundación Natura and WWF (1999) and Kerr et al. (2004)

[c] Data for 2008 was obtained from De la Torre (2008) cited by WWF and Toyota (2010)

Human Population Growth: Production and Incineration of Solid Waste

The human population has recently increased in the Galapagos, having approximately 25,800 people, without considering tourists, by 2010 (Table 12.1; Table 12.7 in Appendix) with an annual population growth rate of 6.4 % during the period 1990–1998 (Fundación Natura et al. 2000; Kerr et al. 2004; Epler 2007). Between 1974 and 1998, the population in Galapagos showed more than a threefold increase, from 4,078 to 15,311 inhabitants (Epler 2007), and nearly doubled during the period 1990–2001, from 9,785 to 18,640 inhabitants, according to the updated data retrieved from National Institute for Statistics and Censuses (INEC 2011), as shown in Table 12.7 in Appendix. Likewise, tourism has drastically increased with a rise in the number of visitors to Galapagos from 40,000 in 1990 to 145,000 tourists in 2006 (Watkins and Cruz 2007; Epler 2007). At this level, Santa Cruz is currently receiving the highest number of tourists per year in the Galapagos and exhibiting one of the highest levels of degradation in its vegetation because of the accelerated urban and rural development (González et al. 2008; Watson et al. 2010).

With a persistent increase in the human population growth in the Galapagos, the projected population in this decade will range from 26,570 in 2011 to 33,000 in 2020 (Table 12.7 in Appendix), as forecasted by INEC (2011). As population increases in these islands, the waste generation has been increasing in magnitude, resulting in increasing burning of solid waste and production of smoke. For instance, Santa Cruz has two landfills in the center of the island, where the first one is already closed and the second one was created in 2000 due to the rapid increasing volume of trash. Total human population in 2010 and waste production for three of the islands harboring urbanized centers are shown in Table 12.1.

From 1995 to 1997, the generation of solid waste in San Cruz and San Cristóbal ranged from approximately 0.8 to 1.3 kg/day/person (Table 12.1; Fundación Natura and WWF 1999), which exceeded the national waste production average of 0.4–0.7 kg/day/person for continental Ecuador at that time (Fundación Natura and WWF 1999; UNEP 2009). According to a recent survey, the waste production in both islands seems to have decreased to 0.6 kg/day/person by 2008 (De la Torre 2008), while the waste production in Isabela has not changed from 1998 to 2008, showing a constant production of more than 490 kg/day/person. It also appears that the proportion of organic matter (OM) estimated from the total waste production was higher in San Cristóbal (>70 % OM) when compared to Santa Cruz in the 1990s but showed a reduction (60 % OM) in 2008. On the contrary, the percentage of OM in Isabela changed from 70 % in 1998 to 86 % in 2008, underlying an increase in the consumption and disposal of organic waste and materials (Table 12.1).

Currently, San Cristóbal and Santa Cruz produce about 10–13 tonnes of waste per day, respectively (Fig. 12.2). Using the waste production per capita data reported in Table 12.1 and the population projections (Table 12.7 in Appendix) by INEC (2011), the maximum production of waste in the Galapagos is expected to be 30 tonnes/day by 2020, from which more the 50 % will be accounted by Santa Cruz and about 40 % by San Cristóbal (Fig. 12.2), if best management practices for solid waste are absent. Yet, the production of waste does not include the untreated trash from the daily arrivals of cruise ships (i.e., about 87 cruise ships around the islands) to Puerto Ayora (i.e., the capital city of Santa Cruz), where the waste is subsequently transported to and dumped at the landfill. It is estimated that the waste produced and disposed from tourism boats in Santa Cruz is 2 tonnes/day, while those arriving to San Cristóbal and Isabela disposed 0.8 and 0.3 tonnes/day, respectively (De la Torre 2008; WWF and Toyota 2010).

The disposal of municipal waste in open dumps in rural areas close to coastal zones of urbanized islands of the Galapagos is an environmental issue of concern (Kerr et al. 2004). The leachate and incineration of local, municipal organic solid waste, polyvinyl chloride (PVC) plastics, and bleached paper without appropriate treatment represent an unquantified source of toxic POPs such as dioxins (i.e., polychlorinated dibenzo-*p*-dioxins, PCDDs) and furans (polychlorinated furans, PCDFs), which enter aquatic systems (Czuczwa et al. 1984; Czuczwa and Hites 1984). These are unintentional by-products and POPs generated from anthropogenic sources by incomplete combustion or thermal processes involving organic matter and chlorine. In continental Ecuador, the estimated total emission of dioxins and furans is about 98 g TEQ/year, from which uncontrolled combustion processes contribute approximately 51 % (Ministerio del Ambiente 2006). Therefore, as current practices do not prevent the by-production of PCDDs and PCDFs, an as yet uncharacterized risk exists to the terrestrial and aquatic biota in the human centers of the islands.

Most of the solid waste is organic matter, ranging from 60 to 70 % in the 1990s and from 40 to 86 % in 2008 (Table 12.1), and it is disposed of in open areas assigned for this purpose. These areas are a short distance from the main ports, 4 km

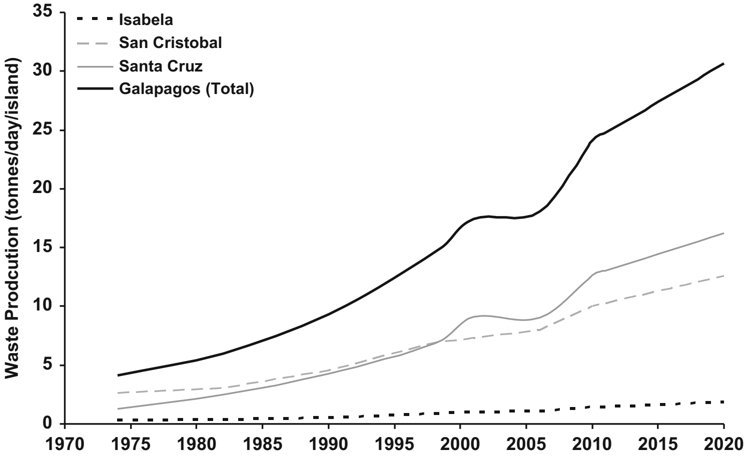

Fig. 12.2 Estimated and predicted production of solid waste in the Galapagos Islands, including the production per island for the three major islands harboring human centers (i.e., Isabela, San Cristóbal, and Santa Cruz), from 1974 to 2020. Predicted data for the period 2010–2020 were based on annual forecasts for the expected human population from 2010 to 2020 in the Galapagos, as projected by INEC (2011)

from Puerto Ayora and 3 km from Puerto Baquerizo Moreno (Kerr et al. 2004). Efforts have been carried out to improve the waste management of municipal organic waste to avoid the generation of dioxin and chronic accumulation of trash by implementing recycling programs (see WWF and Toyota 2010) and banning the burning of this kind of waste in open areas close to harbors and coastal zone, but there is still much to be done in this regard.

The Solid Tide: Marine Debris

Anthropogenic debris has become part of the oceanic environment, and it is now found from the poles to the equator and from shorelines, estuaries, and the sea surface to ocean bottom (STAP 2011). Not even the remotest places on Earth, with fewer people or without human presence, escape from this harmful environmental problem (Derraik 2002; UNEP 2009; STAP 2011). Marine debris is generated from both sea-based and land-based sources and is defined as "any persistent, manufactured or processed material used by humans and deliberately or unintentionally discarded, disposed of or abandoned in the marine environment, including the transport of these materials to the ocean by rivers, drainage, storm water and sewage systems or by winds" (UNEP 2005a, b, 2009; STAP 2011).

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, accounting for 25 and 28 % of the total (Fig. 12.3; Fundación Natura and

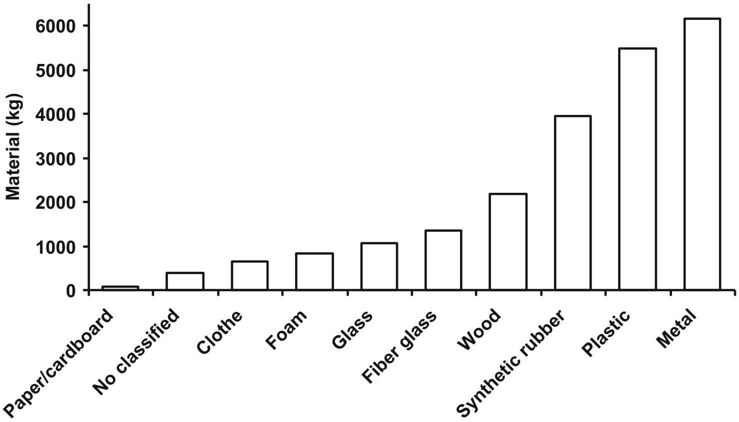

Fig. 12.3 Amount of marine and coastal debris collected in Galapagos during shoreline cleanups in 1999 (Data adapted from Fundación Natura and WWF 2000). See legends for definitions of items: plastics (bags, plastic wraps, containers, bottles, and plastic mesh); metals (cans and aerosol can containers); synthetic rubber (gum, waxes, gloves, shoes, tires, and toys); wood (boxes and tables); glass (bottles, containers, and light/fluorescent bulbs); foam (buoys, floaters, packing material, and disposable dishes); and paper/cardboard (boxes, cups, containers, and newspaper)

WWF 2000). At sea, the accidental or deliberate disposal of solid waste (e.g., plastic, fishing gear) from both tourism and fishing vessels represents a threat for marine vertebrates such as large pelagic fish, sea turtles, cetaceans, sea lions, fur seals, and seabirds (Alava 2011). For example, Galapagos sea lions have been found to interact with floating objects and debris on the sea surface, including hooks, plastic, nylon, and rope (Fig. 12.4; Alava and Salazar 2006). Fishhooks were the predominant object (22 %) affecting sea lions, followed by plastics, which represented almost 20 % of the total. Similarly, the impact of entanglement with debris and other items related to anthropogenic sources accounts for 20 % of environmental threats observed in sea lions residing in San Cristóbal (see Chap. 13).

Although plastic ingestion causes serious problems in some species of seabirds (i.e., albatrosses, petrels, and penguins) in other remote, oceanic regions of the world, including the Pacific Ocean (BirdLife International 2008a, b), this kind of pollution currently appears to pose a minor impact to Galapagos endemic species such as the Galapagos albatross (*P. irrorata*) and Galapagos petrel (*P. phaeopygia*) (Alava and Haase 2011). However, seabirds can mistakenly forage on plastic debris floating on the ocean's surface instead of normal prey and ingest it alongside diet items, causing intestinal damage and obstruction, malnutrition, and starvation (Cadée 2002; Derraik 2002; BirdLife International 2008a). For instance, more than 13,000 plastic pieces are floating per km^2 of ocean surface (UNEP 2005a, b). Thus, it is imperative to assess the impact of marine plastic not only on endemic and threatened seabirds residing in (e.g., Galapagos penguins, Galapagos petrels)

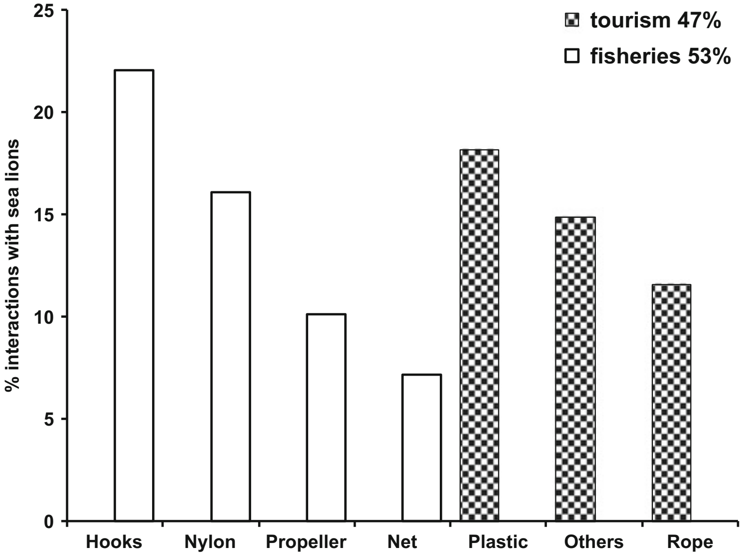

Fig. 12.4 Type and sources (tourism and fisheries) of the objects interacting with Galapagos sea lions in marine and terrestrial environments of the Galapagos (Data adapted from Alava and Salazar 2006; Merlen and Salazar 2007)

and/or foraging outside (i.e., Galapagos albatross) of the GMR boundaries but also on marine mammals, sea turtles, and marine iguanas with the aim to monitor potential health effects in these susceptible species in the long term.

The impact of marine debris, especially plastic materials, particularly causes concern because no appropriate solid waste management programs exists on board vessels (i.e., fishing boats, merchant-transportation ships, and recreational-tourism cruise ships), although the level of municipal waste collection is high and fairly organized in the islands. Finally, more local efforts are required to strengthen educational outreach addressed to human communities from the Galapagos' semi-urbanized centers to mitigate and avoid littering and ensure a low or zero impact on the marine environment. These programs and stringent regulations should be implemented on the local and incoming marine means of transportation, as well.

The Black Tide: Marine Pollution by Oil Spills and Hydrocarbons

Oil spills are one of the major threats to marine ecosystems, both in offshore and coastal zones. The transportation of crude oil or refined products results in the spill of an average estimated between 150,000 and 160,000 tonnes of petroleum worldwide annually (National Research Council 2003; ITOPF 2005). Biodiversity, fisheries, and ecotourism can be threatened when oil spills of severe magnitude occur. The use of fuels such as diesel, high-octane gasoline, and liquefied petroleum gas

Table 12.2 Consumption of diesel (17.6×10^6 L) and gasoline (4.4×10^6 L) by sector in the Galapagos in 2001 (Data adapted from Fundación Natura 2003)

Economic sector	Diesel in L (%)	Gasoline in L (%)
Tourism (inboard, outboard and bus engines, tourist hotels)	10.6×10^6 (60)	1.012×10^6 (23)
Fishing (outboard engines, truck motors)	0.704×10^6 (4)	1.364×10^6 (31)
Overland transportation (motorcycle/car/truck/bus engines)	0.352×10^6 (2)	1.804×10^6 (41)
Electricity (electric power facilities, diesel generators)	4.60×10^6 (26)	No usage (0)
Institutions (car engines and diesel generators)	1.41×10^6 (8)	0.220×10^6 (5)

transported from continental Ecuador has increased risks in the Galapagos. In 2000, a total of about 22 million liters of fuel (20 % gasoline and 80 % diesel) was delivered to the Galapagos (Fundación Natura 2003). Tourism and electric power generation are the major energy usage sectors for diesel consumption, whereas fishing (i.e., outboard motors) and motor vehicle transportation consume most of the gasoline in the islands (Table 12.2; Fundación Natura 2003).

During the last two decades, several oil spills have taken place in the Galapagos (Table 12.3). A major oil spill that threatened a significant part of the Galapagos Marine Reserve was the *MV Jessica* spill on 16 January 2001 at the entrance of Naufragio Bay (89°37′15″W, 0°53′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). 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 lions) due to the mitigation efforts conducted by the GNP and Charles Darwin Foundation/Research Station (CDF/CDRS). Other low-magnitude oil spill events have also occurred (Lessmann 2004).

In addition, the Galapagos sea lion (*Z. wollebaeki*) was an impacted species of concern within the CDF and in the GNP monitoring and management plans for marine fauna since some colonies were relatively close to the Jessica oil spill (Salazar 2003a). About 79 oil-affected individuals, showing different degree of oil presence on their bodies, were rescued, cleaned, and released, and one fatality was recorded. On the other hand, no significant declines in the numbers of individuals were observed in the rookeries monitored after the spill (Salazar 2003a).

Measurements of hydrocarbons in sedimentary shores of the Galapagos right after the *Jessica* oil spill showed low levels or no detectable concentrations (Fig. 12.5), ranging from 0.4 to 49.0 μg/g dry weight, with evidences of residual hydrocarbon contamination from sources other than the oil spill, and suggesting absence of heavy oiling contamination (Kingston et al. 2003). In general, concentrations of dissolved and dispersed oil hydrocarbons measured in water samples from five bays of the Galapagos Islands about 1 year before the aftermath

Table 12.3 Inventory of oil and diesel spills in the Galapagos from 2001 to 2006

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	7,571
MV Galapagos Explorer	13–14 September 2005	Academia Bay, Puerto Ayora, Santa Cruz Island	Not reported[a]

[a] 151,412 L of fuel was estimated to be contained in the boat, but actual volume spilled was not reported

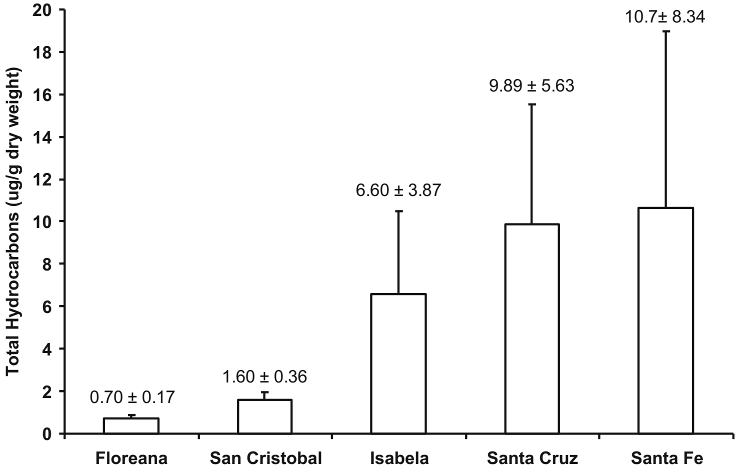

Fig. 12.5 Mean of total hydrocarbon concentrations measured in sediment samples collected from oil-impacted sandy shores of five islands of the Galapagos Islands after the 2001 Jessica oil spill. Error bars are standard errors (Data adapted from Kingston et al. 2003)

(Fig. 12.6) were below threshold levels, that is, 3–10 µg/L (Rodríguez and Valencia 2000).

Recent studies of the endemic Galapagos marine iguanas (*A. cristatus*) found elevated plasma corticosterone levels, impaired development (i.e., reduction of growth), and high mortality in individuals exposed to low levels or residual hydrocarbon traces during and/or after the *Jessica* oil spill (Wikelski et al. 2001, 2002; Romero and Wikelski 2002). This suggests that even low levels or traces of oil hydrocarbons have critical negative effects for marine endemic species of the Galapagos. Although no oiled seabirds were recorded at the time of this oil spill (Lougheed et al. 2002), researchers doing fieldwork in Española Island found five oiled Nazca boobies (*Sula granti*) in January 2001, one oiled Galapagos albatross (*P. irrorata*) in June 2001, and two oiled Nazca boobies in November 2001, confirming that these birds were polluted by spilled oil (Anderson et al. 2003).

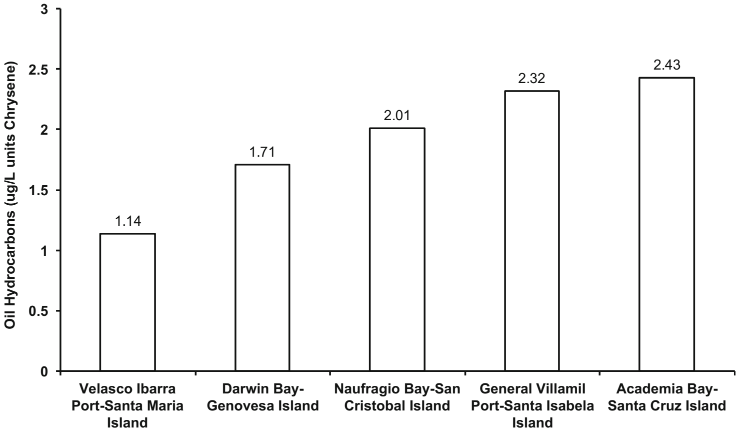

Fig. 12.6 Concentrations of oil hydrocarbons detected in marine water from fives sites of the Galapagos Islands (Data adapted from Rodríguez and Valencia 2000)

Fortunately, most of the populations of endangered seabirds such as Galapagos penguins and flightless cormorants were not affected by the direct impact of this spill; however, the chemical exposure of these birds to chronic residue levels of oil hydrocarbons in the long term is unknown.

The Silent Pollution: Impact of Persistent Organic Pollutants

The Galapagos Islands and surrounding ocean waters are susceptible to the global pollution by POPs, which are defined as "a set of organic compounds that: (a) possess toxic characteristics; (b) are persistent; (c) are liable to bioaccumulate; (d) are prone to long-range atmospheric transport and deposition; and (e) can result in adverse environmental and human health effects at locations near and far from their sources" (UNEP 2002). The set of pollutants listed as POPs by the Stockholm Convention on Persistent Organic Pollutants includes organochlorine pesticides (i.e., OC pesticides) such as aldrin, chlordane, dichlorodiphenyltrichloroethane (DDT), dieldrin, endrin, heptachlor, hexachlorobenzene (HCB), mirex, and toxaphene, as well as industrial chemicals, including polychlorinated biphenyls (PCBs), polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and HCB, which is a pesticide as mentioned above, but it can also be a by-product of pesticide manufacture (UNEP 2002, 2005a, b). New compounds have recently been added to the POP list, including emerging compounds such as polybrominated diphenyl ethers or PBDE flame retardants (i.e., treta-, penta-, hexa-, and heptabromodiphenyl formulations) and perfluorooctane sulfonate compounds or PFOS (i.e., perfluorooctanesulfonic acid and perfluorooctane sulfonyl fluoride).

It is likely that organic contaminants transported from Asian, South American, and Western industrialized countries are atmospherically delivered to these remote tropical islands. This implies the need of research and field studies to elucidate the fate and transport of POPs in the Southeastern Tropical Pacific region, where the Galapagos are located. In semi-urbanized centers (i.e., Santa Cruz and San Cristóbal), the presence of electric facilities/equipments and the grid electric wires' system containing transformers, capacitors, and cooling insulator fluid to provide energy to human settlements are likely to represent potential sources of PCBs. PCB-contaminated oil/dielectric fluid found in transformers and tanks of the grid electric system and facilities of human centers of the Galapagos are likely to be the minor, local sources of these contaminants, which need a management plan to treat and remove them from the islands (Ministerio del Ambiente 2006). To our understanding, Aroclor mixtures have not been yet identified.

In Ecuador, PCBs have never been produced for any chemical industry. Ecotoxicological and bioaccumulation studies on PCBs and DDTs have never been conducted at continental Ecuador, except for some recent measurements of these industrial compounds in oil/dielectric fluid used in transformers and capacitors/tanks of some electric station facilities of the Guayaquil's Electric Corporation (CATEG) (CEMA 2005). The PCB levels found are below 10 mg/L (CEMA 2005). More recently, the preliminary national inventory of PCBs in Ecuador reported a total volume of about 5,473,000 L of PCB-contaminated oil-fluid used in abandoned, unused, and used electric transformers by the electric corporations (Ministerio del Ambiente 2006). The global distribution of POPs, their persistence in the environment/biota, their risk to both human and biota, and, in some cases, continued production (deliberate or inadvertent) emphasize the need for an integrated approach to manage issues of POP production, waste, remediation, and exposure (Tanabe et al. 1994; Ross and Birnbaum 2003).

In the past, the biomonitoring and ecotoxicological risk assessment of POPs was never conducted in the Galapagos; therefore, data on concentrations, patterns, distribution, and fate is scarcely available for these contaminants. Despite of the potential conservation impact and risk in the Galapagos Islands, environmental pollution by POPs has not fully been characterized in wildlife from this archipelago. Given that it is well documented that marine mammals are key biological compartments to assess the concentrations, fate, distribution, and toxic effects of POPs (Ross and Birnbaum 2003; O'Shea et al. 2003), the Galapagos sea lion, which is a resident species and top predator of the Galapagos marine food web, was previously proposed as a potential coastal sentinel to biomonitor and investigate marine pollution and bioaccumulation by POPs in the Galapagos (Alava and Salazar 2006), as illustrated in Fig. 12.7.

Within this context, some recent studies assessing the concentrations of PCBs, PBDE flame retardants, DDTs, and several other OC pesticides in the Galapagos revealed that Galapagos sea lions are not exempt from the global contamination by POPs, as reported in Table 12.4. The dominant pollutant of concern found in Galapagos sea lions was DDT with mean concentrations of 281 μg/kg lipid, ranging from 16.0 to 3,070 μg/kg lipid in 2005 and 525 μg/kg lipid (range 16.3–1,666 μg/kg

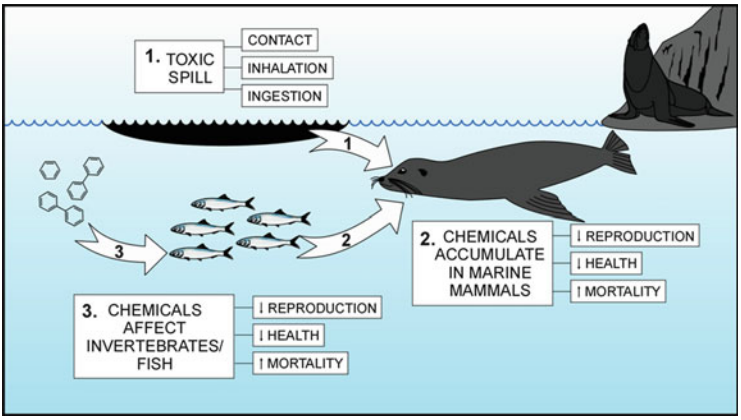

Fig. 12.7 Galapagos sea lions and several other species of epipelagic marine organisms (e.g., cetaceans, seabirds, marine iguanas, sea turtles) can be exposed to chemical assaults, including oil spills, which can possess acute and chronic toxic effects, and persistent organic pollutants (1), which can be accumulated mainly through dietary ingestion and by inhalation, causing potential health effects (2) due to contamination of diet items (fish preys) in the food chain (3). The prey can be also affected by contaminants (3). Adapted from Alava (2011) and Alava et al. (2011b)

lipid) in 2008 (Alava et al. 2011a), while PCBs measured in Galapagos sea lion pups were relatively lower and exhibited mean concentrations of 104 μg/kg lipid, ranging from 49 to 384 μg/kg lipid, in 2005 (Alava et al. 2009), and 113 μg/kg lipid, ranging 16.0–380 μg/kg, in 2008 (Alava and Gobas 2012).

POPs were also found in two fish prey species of Galapagos sea lions (thread herrings, *Ophistonema berlangai*, and mullets, *Mugil* sp.; Table 12.4), underscoring the biomagnification of these contaminants in the food chain of the Galapagos sea lions, as recently demonstrated by Alava and Gobas (2012). The presence of POPs in this endemic marine mammal was of particular importance, as a considerable weight of evidence in toxicological research indicates that environmental pollution by POPs is affecting and jeopardizing the health and survival of pinnipeds (e.g., harbor seals, California sea lions) and cetaceans (e.g., killer whales and belugas) (Ross 2002; Ylitalo et al. 2005; Loseto and Ross 2011; Buckman et al. 2011).

For instance, the exposure to POPs has been linked to effects on the immune (impairments in T-lymphocyte proliferation/count and phagocytosis) and endocrine systems (i.e., disruption of vitamin A and thyroid hormones) in harbor seals (Ross et al. 1995, 1996; Simms and Ross 2000; Tabuchi et al. 2006; Mos et al. 2006), in grey seals (Hall et al. 2003; Jensen et al. 2003), and in California sea lions (Debier et al. 2005). Recently, the deleterious effects of high levels of POPs (PCBs and DDTs) have been significantly linked to high prevalence of neoplasms and carcinoma, associated with mortality, in California sea lions (Ylitalo et al. 2005).

While threats associated with oil spills are visible and unlikely to cause a long-term decline of the Galapagos sea lion population due to their metabolic capacity to biotransform polycyclic aromatic hydrocarbon (PAHs) or nonhalogenated

Table 12.4 Concentrations (mean and ranges) of POP compounds (µg/kg lipid weight) measured in Galapagos sea lion pups and fish in the Galapagos Marine Reserve

		Galapagos sea lion				
POPs	Year	Males	Females	Thread herring	Mullet	Source
DDTs	2005	293 (51.0–1,200)	274 (16.0–3,070)	NC	NC	Alava et al. (2011a)
	2008	533 (16.3–1,666)	516 (71.2–1,230)	4.00 (0.70–6.05)	3.00 (0.82–6.80)	Alava and Gobas (2012)
Mirex	2005	3.20 (0.55–7.70)	3.22 (0.11–13.0)	NC	NC	Alava, unpublished
	2008	6.40 (0.85–24.0)	8.60 (2.50–21.0)	0.33 (0.25–0.40)	0.04 (0.03–0.1)	Alava and Gobas (2012)
Dieldrin	2005	15 (1.30–60)	11 (1.15–103)	NC	NC	Alava, unpublished
	2008	22.0 (9.00–63.0)	31.0 (9.00–83.0)	0.60 (0.01–0.90)	0.88 (0.40–1.30)	Alava and Gobas (2012)
β-HCH	2005	ND	ND	NC	NC	Alava, unpublished
	2008	26.0 (7.75–78.0)	34.2 (18.3–52.0)	0.44 (0.23–0.62)	0.50 (0.04–0.65)	Alava and Gobas (2012)
Chlordanes	2005	45.5 (16–123)	38 (2.35–382)	NC	NC	Alava, unpublished
	2008	90.5 (19–255)	107 (48–180)	1.70 (0.48–2.50)	0.87 (0.37–1.50)	Alava and Gobas (2012)
PCDFS	2005	ND	ND	NC	NC	Alava et al. (2009)
	2008	NA	NA	NA	NA	
PCDDs	2005	ND	ND	NC	NC	Alava et al. (2009)
	2008	NA	NA	NA	NA	
PCBs	2005	122 (49–384)	93 (53.2–353)	NC	NC	Alava et al. (2009)
	2008	91.0 (16.0–282)	136 (50.0–384)	9.35 (5.40–14.0)	28.0 (1.20–138)	Alava and Gobas (2012)
PBDEs	2005	35.0[a]	ND	NA	NA	Alava et al. (2009)
	2008	NA	NA	NA	NA	

NC: samples for this species were not collected; ND: chemical compound was not detected in the organism; NA: chemical compound was not analyzed

[a] Only one sample exhibited PBDE concentrations

hydrocarbons, the possible negative impacts (e.g., long-term chronic toxicity and sublethal effects) of POPs and other contaminants on health endpoints of this species are becoming more evident (Alava et al. 2009, 2011a, b; Alava and Gobas 2012; Fig. 12.7). For instance, the impact of antifouling paints (e.g., tributyltin, TBT) in marine fauna from major ports and marinas harboring vessels in the Galapagos has not yet been assessed. This also implies the need of baseline research on POPs for other marine species (e.g., sea turtles, marine iguanas, and seabirds) in the Galapagos.

Interestingly, a new eco-toxicological study based on skin biopsies collected from sperm whales (*Physeter macrocephalus*) inhabiting Galapagos waters revealed the highest expression levels for cytochrome P450 1A1 (CYP1A1), an enzyme used as a biomarker to assess exposure to organic pollutants such as PAHs and PCBs, relative to other studied regions of the Pacific (Godard-Codding et al. 2011), although questions linger to whether the chemical exposure to pollutants in this stock of sperm whales originates from local/regional sources or represents a global signature. Meanwhile, the Galapagos sea lion represents a novel marine mammal to be used as a potential biological compartment and eco-marker of coastal pollution by assessing the concentration and effect of POPs (i.e., measurements of POPs in blubber or blood samples and biomarker endpoints of the immune/endocrine systems).

Agriculture and Pesticide Use

In the Galapagos, agriculture occurs on all four human-inhabited islands (Santa Cruz, Santa Cristóbal, Floreana, and Isabela), mainly in the highlands, where the highly biodiverse humid zone has largely been cleared (Table 12.5; Snell et al. 2002). Currently, approximately 3.96 % (23,400 ha) of land area has been dedicated for agricultural use in the Galapagos, and the proportion of humid zones is diminishing (Kerr et al. 2004). While organic agriculture is partially practiced in the Galapagos (Dr. Alan Tye, pers. comm., former Head Scientist of the Department of Plant and Invertebrate Science, Charles Darwin Research Station), conventional agriculture is the norm, where farmers use insecticides, herbicides, fungicides, and fertilizers to control pests, which can lead to runoff and the contamination of coastal food webs.

As seen in Appendix Table 12.8, some current-use pesticides (CUPs) are applied to agricultural areas (highlands) in islands with human centers (MIT 2008). According to this list, no legacy organochlorine pesticides (OC pesticides such as DDTs, dieldrin, mirex, heptachlor, and chlordanes) are currently used in the Galapagos. However, DDT was used in significant amounts by military personnel from the US Navy (former American Air Force and Naval Base in Baltra, Santa Cruz Island, during the World War II) to eliminate introduced rats in human housing from urbanized areas and into the islands between 1940s and 1950s (M. P. Harris, Centre for Ecology and Hydrology, Banchory Research Station, Banchory, UK, pers. comm.; M. Cruz, GGEPL-Galapagos National Park, pers. comm.). More recently, a pyrethroid, the insecticide deltamethrin, is being used to control the dengue mosquito vector (*Aedes aegypti*) in the Galapagos (Dr. Hugo Jurado, pers. comm., National Center for Tropical Medicine, University of

Table 12.5 Total areas for agricultural and habitat (humid and transition[a]) zones in km^2 and the proportion of clearance affected by agriculture occupancy in humid and transition zones in four islands of the Galapagos (Adapted from Snell et al. 2002)

Island	Agriculture	Humid zone	% Affected	Transition zone	% Affected
Santa Cruz	122	118	74	127	26
San Cristóbal	82	83	93	40	9
Floreana	5	31	15	39	2
Isabela	52	641	8	1,323	0
Sierra Negra[b]	52	370	14	460	0

[a] Transition zone: woodland communities dominated by *Pisonia floribunda*, *Psidium galapageium* (Guayabillo woodland), and *P. galapageium* and *Scalesia* tree spp. (Scalesia–Guayabillo forest)
[b] This is a specific site represented by a volcano on Isabela Island where the human settlements are located

Guayaquil, and Technical Director of the National Malaria Eradication Service Centre (SNEM), Guayaquil, Ecuador).

Many of these pesticides have been identified as causing reproductive and endocrine-disrupting effects (see EDC in pesticides listed in Table 12.8 in Appendix) in both wildlife and human populations (Colborn et al. 1993; Colborn 1998; WWF Canada 1999; Lyons 1999). Furthermore, chlorothalonil and its metabolites are highly toxic to fish, aquatic invertebrates, and marine organisms. Levels lower than 1 mg/L can cause negative effects in rainbow trout, bluegill, and channel catfish (see review by Verrin et al. 2004). Similarly, malathion is extremely toxic for aquatic invertebrates, to some species of fish (<1 mg/L), and to some aquatic life stages of amphibians, whereas carbaryl is moderately toxic to fish (1.3−10 mg/L) (Verrin et al. 2004). There are also two herbicides of concern including glyphosate (commercially known as Rodeo or Roundup) and paraquat (Gramoxone). Glyphosate is a broad-spectrum nonselective herbicide to control grasses, broadleaf weeds, and woody plants, inhibiting amino acid biosynthesis (Ecobichon 2001), while paraquat is a widely used, nonselective contact herbicide, inhibiting photosynthesis in plants (Ecobichon 2001; Sedigheh et al. 2011). If both herbicides were extensively used in agricultural land and rural areas in the Galapagos, these substances might have eliminated and caused deleterious damage to native and endemic species of plants.

The application of pesticides in the agricultural zones of these human-inhabited islands may also introduce dioxins (i.e., PCDDs) and furans (i.e., PCDFs) to the marine environment, as these have been found as contaminants in a number of pesticide products. While no risk assessments have been carried out to elucidate on the levels and potential health effects of CUPs in the Galapagos, there are reasons for urgent concern and research in this subject.

Biological Pollution and Invasive Pathogens

Biological invasions are considered a leading cause of extinctions in terrestrial and marine ecosystems of marine protected areas (Boersma and Parrish 1999; Bax et al. 2003) as emerging marine diseases in marine organisms have been linked to anthropogenic factors (Harvell et al. 1999). For the purpose of this review, biological pollution is defined as the "accidental or deliberate introduction of viruses, bacteria and parasites, as well as terrestrial, exotic species of vertebrates, invertebrates and plants." Information on terrestrial exotic species (i.e., animals and plants) is not discussed in this review since it has been well reported elsewhere (Snell et al. 2002).

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, and human health in marine protected areas and biosphere reserves (Carlton 1989, 1996; Carlton and Geller 1993; Bax et al. 2003). For example, both ballast water and hull fouling are the major pathways releasing alien organisms from transportation or recreational ships and tankers in threatened and fragile ecosystems (Carlton and Geller 1993; Bax et al. 2003). The Hawaiian Islands represent 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 US endemic birds (43 %) and plants (40 %) threatened by alien species (Gurevitch and Padilla 2004). Similarly, alien pathogens represent 34 % of the birds affected by aliens of all kinds (Coles et al. 1999), and 91 of approximately 400 marine species present in Pearl Harbor are aliens (Gurevitch and Padilla 2004). The Galapagos Islands are facing a similar fate unless control and conservation strategies take place to mitigate biological invasion. The number of registered introduced species in the archipelago has increased 10 times from 112 species in 1900 to 1,321 in 2007 (Watkins and Cruz 2007). This does not include introduced pathogens. Among the invasive pathogens, viruses, bacteria, and parasites are the ones possessing serious risk to the endemic fauna.

Some introduced viral diseases from domestic animals such as avian virus or avipoxvirus by domestic birds, fowlpox virus infecting chicken, and canine distemper virus (CDV) epidemic in domestic dogs have threatened endemic species of birds (e.g., Darwin's finches) and marine mammals (e.g., Galapagos sea lions) in the Galapagos (Wikelski et al. 2004; Salazar et al. 2001; Cruz et al. 2002). For instance, a serological survey and DNA screening assessment for infectious disease pathogens conducted in Isabela Island revealed that domestic dogs and cats are exposed to many pathogens, including parvovirus, parainfluenza virus, adenovirus, distemper virus, *Dirofilaria immitis*, *Wolbachia pipiens*, *Bartonella* sp., *Ehrlichia*/*Anaplasma* spp., and *Mycoplasma haemocanis* in dogs and panleukopenia virus (67 %), *Toxoplasma gondii* (63 %), calicivirus (44 %), and herpesvirus 1 in cats (Levy et al. 2008).

Thiel et al. (2005) has recently found the 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 Galapagos albatrosses (*P. irrorata*) inhabiting Española Island (Padilla et al. 2003).

In the Galapagos, a CDV outbreak killed about 400 domestic dogs on Santa Cruz and Isabela Islands accounting for 69.2 and 31 %, of the CDV cases, respectively (Cruz et al. 2002). In San Cristóbal Island, only one case of CDV was found.

A serological survey determined the seropositive response of antibodies against CDV (50 % or 7/14), parvovirus (14 % or 1/7), and adenovirus (canine hepatitis virus, 100 % or 1/1) in the canine population of Santa Cruz during 2001–2002 (Cruz et al. 2002).

Newcastle disease, Marek's disease virus (herpes), and mycoplasmosis detected in domestic chickens farmed on the islands (Vargas and Snell 1997) have the potential to cause declines of the flightless cormorant (*P. harrisi*), lava gull (*Larus 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). If WNV is introduced into 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). One of the three mosquito species found in the Galapagos, the black salt marsh mosquito (*Aedes taeniorhynchus*) (Bataille et al. 2009a), has been recognized as a vector of the WNV and other diseases in other regions of America (see Bataille et al. 2009a for references) and thus a potential threat to Galapagos wildlife and humans. Disease introduction is most likely to occur through the inadvertent human transport of infectious mosquitoes or infected vertebrate hosts, particularly by airplanes or boats, as that occurred in the Galapagos with *Culex quinquefasciatus* (Bataille et al. 2009a, b) or in Socorro Island off the Mexican coast (Carlson et al. 2011). The incidental transport of mosquitoes by boat or of infected vertebrate hosts is also significant risks for WNV invasion.

A serological survey of sea lions from different colonies of the Galapagos Islands in 2001 revealed that no CDV antibodies were present in this species (Salazar et al. 2001; Alava and Salazar 2006). This indicates that they have not had any recent infection by morbilliviruses and that they are vulnerable to infection by this genus of viruses. Mortalities among pinnipeds caused by morbilliviruses CDV and phocine distemper virus (PDV) have been documented in harbor (*P. vitulina*), grey (*H. grypus*), Baikal (*Phoca sibirica*), and Caspian *(P. caspica*) seals in industrialized regions (Osterhaus et al. 1988, 1989, 1990; Dietz et al. 1989; Visser et al. 1991; Kennedy et al. 2000). For instance, about 10,000 Caspian seals died due to CDV in 2000, and more than 23,000 and 30,000 harbor seals died in 1988 and 2002, respectively (Härkönen et al. 2006).

Recently, several kinds of viruses and bacteria have already been detected in endemic seabirds 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, 75 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, b). Galapagos 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*) in 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).

A serological survey determined that five out of six domestic dogs were seropositive (83 %) to *Leptospira* on Santa Cruz in 2001–2002 (Cruz et al. 2002). This implied that Galapagos pinnipeds may be at risk of infection by this bacterial pathogen. Shortly after, health surveys showed that Galápagos sea lions were susceptible to nine strains of the bacterium *Leptospira*, whereas Galápagos fur seals were susceptible to two strains, but there was no immunological response to brucellosis (Salazar 2002, 2003b). Using PCR analysis, the presence of *Leptospira* DNA was confirmed in 70 % of tissue samples (i.e., kidney and placenta) collected from dead sea lions, including three newborn pups, in San Cristóbal (Guevara 2011).

Recently, a conjunctivitis associated with bacillococci bacteria, with a 60–100 % prevalence in Galapagos sea lion pups, appears to be related to the presence of a new species of ocular parasite (*Philophthalmus zalophi*) (Dailey et al. 2005). 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). In marine mammals, ectoparasites such as lice (*Antarctophthirius microchir*) and nasal mites (*Orthohalarachne diminuata*) were identified in various individuals of pinnipeds (Salazar 2002, 2003b). Domestic and feral animals introduced from the continent poses a major threat as potential sources for horizontal transmission of ecto- and endoparasites to local endemic species.

Avian malaria (i.e., *Plasmodium relictum*), the major parasitic disease that caused severe mortality and decimated a significant proportion of Hawaiian's endemic avifauna since it was introduced in the early twentieth century (Wikelski et al. 2004), was reported for the first time in the blood of 19 Galapagos penguins sampled between 2003 and 2005 in five islands of the archipelago (Levin et al. 2009). Although the vector was not confirmed in that study, the line of evidence pointed to its only possible vector, the mosquito *C. quinquefasciatus*, recently established on the Galapagos Islands (Peck et al. 1998; Whiteman et al. 2005).

Despite the fact that there were no reports or detection of *P. relictum* in the islands (Wikelski et al. 2004; Thiel et al. 2005), Miller et al. (2001) suggested a connection between this mosquito and the absence of penguins in the shores of one of the islands where this parasite was later found in penguin samples. Another protozoan, *Trichomonas gallinae*, was reported in domestic pigeons on San Cristóbal and may cause severe disease in species such as Galapagos doves (*Z. galapagoensis*) and other native birds (Harmon et al. 1987; Wikelski et al. 2004; Padilla et al. 2004). Because the Galapagos endemic species were not exposed to alien parasites transmitted by invasive species prior to human occupation of the islands, they are more susceptible to the pathogenesis generated by parasitic diseases with potential risk at the population health level.

Long-term assessments and monitoring of marine water quality in coastal and maritime environments are scarce in the Galapagos Islands (Walsh et al. 2010; Stumpf et al. 2013). Yet, overflow from rudimentary septic tanks (i.e., latrines or cesspools) and runoff of sewage waters around the islands threaten the water quality near urbanized centers and increase the risk of fecal contamination in coastal waters (Okey et al. 2004; Moir and Armijos 2007; Walsh and McCleary 2009;

Table 12.6 Values of fecal and total coliforms (colony-forming units (CFU)/100 mL) at coastal marine sites, Galapagos (Data from Rodríguez and Valencia 2000), relative to the current recreational marine water quality standards (US Environmental Protection Agency 1986)

Sites	Fecal coliform	Total coliform	US EPA (1986) fecal coliform standard (200 CFU/100 mL)	US EPA (1986) total coliform standard (1,000 CFU/100 mL)
Academia Bay (Las Ninfas Lagoon), Santa Cruz Island	15	240	Not exceeded	Not exceeded
Naufragio Bay, San Cristóbal Island	8.8	16	Not exceeded	Not exceeded
Santa Maria, Isabela, and Genovesa Islands	5.0	2.0	Not exceeded	Not exceeded

Stumpf et al. 2013). In 1999, a microbiological survey of total and fecal coliform bacteria conducted in several coastal marine sites of the Galapagos reported concentrations ranging from 2 to 240 CFU/100 mL and from 5 to 15 CFU/100 mL, respectively (Table 12.6; Rodríguez and Valencia 2000). At that time, these levels were below the Ecuadorian Water Quality Guidelines for the Prevention and Control of Environmental Contamination passed out in 1989.

However, recent water quality monitoring in Las Ninfas Lagoon conducted in 2005, 2007, and 2008 revealed that the contamination of marine water by fecal coliform bacteria has changed from 15 FCU/100 mL in 1999 (Rodríguez and Valencia 2000) to 480 CFU/mL in 2008, with a maximum peak of 1,458 CFU/mL in 2007 (López and Rueda 2010), exceeding both the Ecuadorian national environmental legislation to protect public health (TULAS 2003) and the fecal coliform guideline of the Environmental Protection Agency (US EPA 1986), as illustrated in Fig. 12.8. This trend underlines the health risks by bacterial contamination in recreational marine waters for public health and aquatic biota in this site. More recently, the use of molecular methods in a small-scale study has determined the presence of elevated levels of fecal contamination ($>$104 cell equivalents (CE)/100 mL) by *Enterococcus* spp. (i.e., mean, 1.38×10^2 CE/100 mL) and *Bacteroides* spp. (i.e., mean, 4.74×10^5 CE/100 mL) in Puerto Baquerizo Moreno (San Cristóbal) and Puerto Ayora (Santa Cruz), as reported by Stumpf et al. (2013). Furthermore, the impact of spillover pathogens and antibiotic-resistant bacteria in endemic organisms inhabiting this remote area warrants further microbiological and pathological research.

Because of the presence of livestock, antibiotics are used for cattle ranching and domestic farms in rural zones (Francisco Torres, pers. comm., Centro de Estudios de Medio Ambiente, Escuela Superior Politécnica del Litoral, Guayaquil, Ecuador). Antibiotic resistance results from the broad and indiscriminate use of antibiotics, both in humans and in animals (Pruden et al. 2006). Residual antibiotics from animals' feces as well as from of septic tank overflow and sewage effluents may enter coastal marine areas. This may had antibiotic resistance in both human-introduced pathogens and natural strains of bacteria (i.e., antibiotic-resistant pathogens). Recently, antibiotic resistance genes (ARGs) from tetracycline and sulfonamide have been categorized as

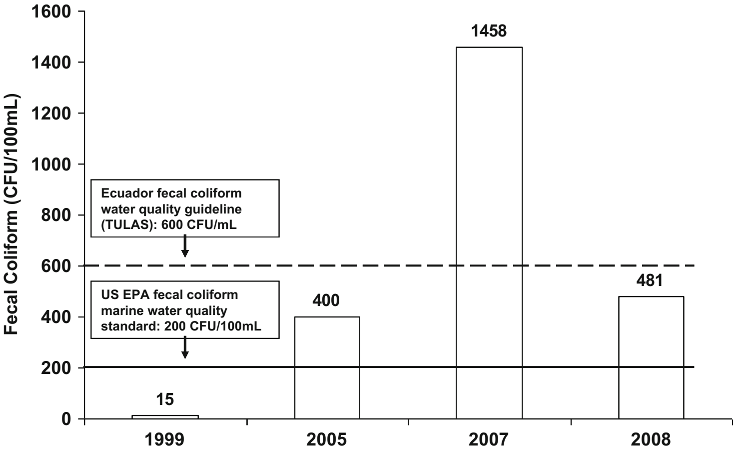

Fig. 12.8 Trends of fecal coliform levels (CFU/mL) measured in Las Ninfas Lagoon (Santa Cruz) for 1999, 2005, 2007, and 2008 (Rodríguez and Valencia 2000; López and Rueda 2010). The *dashed line* represents the fecal coliform benchmark for Ecuador according to the Ecuadorian national environmental legislation to protect public health (TULAS 2003). The *solid line* indicates the US EPA fecal coliform standard for marine waters

emerging contaminants, showing higher concentrations in urban/agricultural impacted river sediments (Pruden et al. 2006).

The threat and development of emerging infection diseases and microbial invasions can be further exacerbated in endemic fauna exposed to immunotoxic and endocrine disruptor chemicals (e.g., POPs, CUPs, xenoestrogens) causing impairments in the immunological (e.g., decreased proliferation of white cells) and endocrine (e.g., disrupted regulation of thyroid hormone) systems and making them more susceptible to pathogens. Likewise, new studies on ecological immunology in Galapagos sea lion pups found evidences of changes in the immune activity (i.e., humoural and cellular immune activities), which was negatively correlated with life history and health endpoint parameters in a sea lion colony exposed to anthropogenic environmental impacts (Brock et al. 2013). Sea lions in the human impacted colony exhibited higher antibody concentration changes and were under greater immunostimulatory pressure than those in the comparison colony, indicating implication risks for individual fitness, colony stability and emerging infectious diseases (Brock et al. 2012; Brock et al. 2013). This can be worsened in nutritional stressed animals due to the stress caused by more frequent and stronger climatic events such as the El Niño episodes. More recently, the massive die-off of small cetaceans (i.e., long-beaked common dolphins, *Delphinus capensis*, and Burmeisters porpoises, *Phocoena spinipinnis*) stranded along the Peru's northern coast was linked to cumulativeadditive anthropogenic impacts (e.g., pollution, underwater noise, pathogens) exacerbated by the El Nino event (Alava 2012). Thus, there is an urgent need to strengthen monitoring activities and preventive actions to reduce the Galapagos fauna exposure to some of these stressors.

Management Implications and Research Needs

Environmental pollution in the Galapagos has typically been described in the past as an aesthetic and minor issue of concern rather than a significant conservation problem (Snell et al. 2002; Bustamante et al. 2002a, b). However, human population growth due to migration and tourism, introduction of exotic and invasive species, solid waste generation, lack of sewage systems, and water pollution are some of the central degrading activities challenging the resilience of the Galapagos Marine Reserve and National Park in the last three decades (Merlen 1995; MacFarland and Cifuentes 1996; Watkins and Cruz 2007; González et al. 2008). The threats for the Galapagos conservation and mitigation strategies in terms of environmental pollution are summarized as follows.

Conservation Threats

The Galapagos is a heritage at risk not only because of the massive tourism, human migration, and invasive species but due to potential chemical assaults and the spreading out of pathogens, as described in this review. A series of major events in recent years, including oil spills, increased generation of solid waste, expansion of agriculture and tourism sector, and the emerging of new pathogens and other biological pollutants, should serve as a wake-up call for decision makers in the Galapagos.

Of important concern is the release of solid wastes (e.g., plastics) and leaking of hydrocarbons from tourism ships and the fishing industry, which are likely to be the major local sources of contamination in the Galapagos marine environment. Both large and small fuel spills take place on a regular basis in the islands during the transport and delivery of fuel to tourist boats (Lessmann 2004; Okey et al. 2004). The existence of localized sources (waste incineration in open dumps in the recent past) and atmospheric inputs (continental or global inputs) might be contributing to the migration and deposition of POPs to the Galapagos environment, as evidenced for the levels of PCBs found recently in Galapagos sea lion pups and fish.

The cumulative ecotoxicological pressure coming from these threats can play a dramatic role as an unnatural or anthropogenic selection force shaping evolution in endemic species of the Galapagos. Unnatural selection has already been identified as a human environmental alteration that may be replacing natural selection or non-anthropogenic factors as the major driving force of evolution in Darwin's finches (Deem et al. 2010). If anthropogenic stressors continue contributing to the perturbation of natural habitats and behavior of species, the natural evolutionary forces normally ruling speciation and radiation can be lost in the long term and, therefore, difficult to characterize, monitor, and preserve in its genuine state unless management and mitigation strategies are urgently implemented to minimize and reduce anthropogenic factors in the Galapagos.

Management Actions and Mitigation Measures

Several laws, regulations, policies, and plans have been enacted recently by the Ecuadorian government in benefit of the conservation and management of both the GMR and GNP (e.g., Special Law for the Conservation and Sustainable Development of the Galapagos Province, 1998). However, the control and management of environmental pollution in the Galapagos warrants additional efforts. At continental Ecuador, efforts have already been undertaken through the Ecuadorian Guidelines for the Control and Management of Environmental Pollution.

Meanwhile, the lessons learned from the oil spill cleanups and from the remedial actions taken in response to them were a topic of particular importance for the Ecuadorian government and regional commissions involved with marine protected areas and environmental pollution. Because of this, regional authorities paid more attention and concern, and the Galapagos was recently designated as a Particularly Sensitive Sea Area (PSSA) by the International Maritime Organization (IMO) in 2005 under Resolution MEPC-135(53) to prevent marine pollution by spills and hazardous contamination coming from ships. At this level, the application of the precautionary principle would help to avoid and mitigate pollution in the Galapagos Archipelago.

More recently, the local waste management in the Galapagos is being improved by implementing an educational outreach camping and a recycling system, including an oil recycling program, to reduce waste through the Waste Management Blueprint initiative (WWF and Toyota 2010). Solid waste containing a substantial amount of OM needs to be treated appropriately by banning the incineration of this kind of waste in open areas close to harbors and coastal zone to avoid the generation of dioxins. Although the upgrade of a water treatment plant to improve the quality of domestic effluents and treatment of sewage discharged into coastal waters of Puerto Baquerizo Moreno was implemented in 2011, testing for fecal indicator bacteria is critical to verify the efficacy of the system (Stumpf et al. 2013). Further monitoring of coastal water quality is required in suspected hot spots of bacterial contamination and nonimpacted areas for comparison purposes around urban centers of the Galapagos.

Additionally, the implementation of an environmental impact assessment and monitoring program of current-use pesticides (CUP) and past-use pesticides in the urban centers should be a priority task to include in the regional management plan and environmental monitoring of the Galapagos Marine Reserve and National Park; the aim is to assess the levels and potential health effects of these chemicals to wildlife, aquatic/marine organisms, and humans. Local effluents need to be controlled to avoid biological pollution and spread of infectious diseases to local wildlife and native human. Alternative approaches to dispose and treat sewage water effluents and oil leaking are required at the domestic and economic sectors (fisheries and tourism). Local hotels and restaurants should incorporate best management practices (BMPs) through environmental management systems (EMS), which will promote green certification as an added value. The periodical maintenance and monitoring (i.e., environmental audits to fix irregularities) of outboard motors, boat engines, and oil tankers can contribute in the reduction of marine pollution by hydrocarbons.

The management of POPs (i.e., dioxin/furans generated from organic waste incineration, pesticides) and biological pollution so far analyzed in this review needs to be focused both at the local/regional and international levels regarding environmental and marine policy. Ecuador is a recent signatory country of the Stockholm Convention since May 2001 and ratified it on 7 June 2004. Since then, the National Plan for the Implementation of the POP Management in Ecuador was undertaken in this country by commencing with a national inventory of POPs, including PCBs, dioxins/furans, and OC pesticides (Ministerio del Ambiente 2006). Therefore, the use of international policy instruments such as the Stockholm Convention on Persistent Organic Pollutants and the Convention on Long-Range Transboundary Air Pollution (CLRTAP) POP protocol must be emphasized to protect this semi-pristine, remote area of the world.

We propose the use of endemic marine species such as pinnipeds (Galapagos sea lions and fur seals) and seabirds (e.g., Galapagos albatrosses, Galapagos penguins, and flightless cormorants) to assess and biomonitor the current exposure levels, patterns, fate, and effects of contaminants in the Galapagos. These charismatic, top predator species can be used potentially as regional sentinels of marine pollution and coastal health in these remote islands. For example, the ecotoxicological research on POPs (e.g., dioxins/furans, PCBs, DDTs, and other OC pesticides) can be focused in the measurement and assessment of these compounds in blubber biopsies and blood samples of sea lions, seabirds, and marine iguanas to elucidate both local and regional contamination.

In addition, biomarkers such as vitamin A, aryl hydrocarbon receptor (AhR), estrogen, and thyroid hormones can be evaluated through ecotoxicogenomics (i.e., assessment of toxicological gene endpoints related to stress response) to examine potential endocrine disruption, immunotoxicity, and associated health effects by POPs in the Galapagos sea lion and endemic seabirds. This needs to be accompanied by ecotoxicological and bioaccumulation modeling to predict and better assess these contaminants (i.e., toxicity, persistence, and bioaccumulation/biomagnification) in marine food webs. This should be coupled with the use of model bias and uncertainty analyses, as a tool to account for variability and uncertainty. In fact, the use and application of models has tremendously contributed to the progress of science in environmental toxicology and chemistry and contributed to the management of toxic chemicals by helping to understand their origin, behavior, distribution, fate, exposure, and toxic impacts on the environment (Gobas and Muir 2004).

Galapagos is the last remote, evolutionary natural lab to protect and conserve for future generations. While it is not too late to undertake international and local environmental stewardship and management strategies to mitigate and control pollution, the presence of anthropogenic stressors and coastal marine pollution is a sign that the GMR is not immune to contamination.

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Appendix

Table 12.7 Human population inhabiting three major islands in the Galapagos and total population

Year	Isabela	San Cristóbal	Santa Cruz	Galapagos (total)
1974	446	2,014	1,577	4,078
1982	630	2,377	3,138	6,201
1990	864	3,499	5,318	9,785
1998	1,427	5,295	8,512	15,311
2001	1,619	5,633	11,388	18,640
2006	1,780	6,142	11,262	19,184
2010	2,256	7,475	15,393	25,884
2011*	2,392	7,899	16,285	26,576
2012*	2,464	8,095	16,725	27,284
2013*	2,538	8,293	17,169	28,000
2014*	2,614	8,493	17,619	28,726
2015*	2,690	8,693	18,070	29,453
2016*	2,765	8,890	18,517	30,172
2017*	2,842	9,085	18,963	30,890
2018*	2,918	9,278	19,404	31,600
2019*	2,995	9,473	19,852	32,320
2020*	3,073	9,667	20,302	33,042

Bold years are real censuses conducted by the National Institute for Statistics and Censuses (INEC), while years with asterisks reflect predicted data from 2011 to 2020 forecasted by the INEC (2011)

Table 12.8 Current-use pesticides (CUPs) applied to agricultural lands in the Galapagos

Pesticide type	Chemical class	Chemical product (trade name)	EDC[a]	LOAEL or LEL[b] (mg/kg/day)
Insecticide	Mixture of avermectins[c]	Avermectin B1 (Abamectin)		0.40
	Neonicotinoid	Acetamiprid		N/A
	Pyrethroid	Cyhalothrin-lambda (Karate)	EDC	1.5
		Deltamethrin	EDC	N/A
	Carbamate	Carbaryl (Sevin)	EDC	15.6
	Thiourea	Diafenthiuron		N/A
	Organophosphate	Malathion	EDC	0.34
Herbicide	Chlorinated phenoxy compound	2,4-D Amine (Salvo)[d]	EDC	0.75
	Phosphanoglycine (glycine's aminophosphonic analogue)	Glyphosate (Rodeo, Roundup)	EDC	30.0
	Bipyridylium herbicide (quaternary ammonium)	Paraquat (Gramoxone)	EDC	0.93
	Pyridine[e]	Picloram (Grazon and Tordon)	EDC	35
Fungicide	β-Methoxyacrylates[f]	Azoxystrobin (Heritage)		N/A
	Chloronitrile	Chlorothalonil (Bravo, Ole)		3.0
	Dithiocarbamate[g]	Maneb	EDC	15
	Dithiocarbamate	Mancozeb	EDC	N/A
	Substituted dimethyl aniline	Metalaxyl		25
	Copper compound	Copper hydroxide		N/A
	Copper compound	Copper sulfate pentahydrate		N/A
	Nonmetal chemical element	Sulfur (micro-ionized)		N/A

Sources: Alava (2011), Massachusetts Institute of Technology (2008)

[a] EDC, endocrine-disrupting chemical according to Colborn et al. (1993), Colborn (1998), and WWF Canada (1999)

[b] LOAEL (lowest-observed-adverse-effect level), the lowest exposure level at which there are biologically significant increases in frequency or severity of adverse effects between the exposed population and its appropriate control group; LEL (lowest-observed-effect level), in a study, the lowest dose or exposure level at which a statistically or biologically significant effect is observed in the exposed population compared with an appropriate unexposed control group (Integrated Risk Information System (IRIS) Database. http://www.epa.gov/ncea/iris)

[c] Containing more than 80 % avermectin B1a and less than 20 % avermectin B1b. Avermectins are a family of macrocyclic lactones, including insecticidal or anthelmintic compounds derived from the soil bacterium *Streptomyces avermitilis*

[d] 2,4-Dichlorophenoxyacetic acid is a plant growth deregulator, interfering with auxin action (i.e., auxin herbicide)

[e] Chlorinated derivative of picolinic acid used in combination or formulations with 2,4-D or 2,4,5-T (Agent Orange) against perennials on non-croplands for brush control. Picloram is also a plant growth deregulator, interfering with auxin action

[f] Derived from the naturally occurring strobilurins

[g] Ethylene-(bis)-dithiocarbamate (EBDC) group of fungicides

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