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INTERPRETATIONS OF, AND AMENDMENTS TO, MARPOL AND RELATED INSTRUMENTS

Designation of an Emission Control Area for Nitrogen Oxides, Sulphur Oxides and Particulate Matter

Submitted by the United States

SUMMARY

Executive summary:	This document is submitted in support of the proposal to designate certain waters adjacent to the coasts of the United States territories of the Commonwealth of Puerto Rico and the U.S. Virgin Islands as an Emission Control Area for NO_X, SO_X, and PM, in accordance with regulations 13 and 14 and Appendix III of MARPOL Annex VI. It provides references and other information considered in developing the proposal.
Strategic direction:	7.3
High-level action:	7.3.1
Planned output:	7.3.1.1
Action to be taken:	Paragraph 3
Related document:	MEPC 61/7/3

Background

1 In document MEPC 61/7/3 the United States proposes to amend MARPOL Annex VI to designate certain waters adjacent to the coasts of the Commonwealth of Puerto Rico and the United States Virgin Islands as an Emission Control Area (ECA) for the control of nitrogen oxides (NO_X), sulphur oxides (SO_X), and particulate matter (PM) emissions. The Commonwealth of Puerto Rico and the U.S. Virgin Islands are unincorporated territories of the United States, and their residents are United States citizens. Consequently, the U.S. Government has a fundamental interest and responsibility in protecting public health and the environment in these areas and in ensuring that these citizens receive the same degree of protection from ship emissions as that which will be realized for people living under the protection of the recently designated North American ECA. The burden on international shipping as a result of the proposed ECA is expected to be small, while the improvements in air quality and associated health and environmental benefits resulting from designation of this ECA are expected to be significant both within in the proposed area and potentially in downwind areas.

2 Many in-depth technical analyses were conducted in developing the proposal for this ECA. annex to this document provides a description of those analyses. A lengthier Technical Support Document can be retrieved electronically from the following website: http://www.epa.gov/otaq/oceanvessels.htm.

Action requested of the Committee

3 The Committee is invited to note the information provided in this document and consider it during review of the United States proposal for an Emission Control Area.

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ANNEX

INFORMATION DOCUMENT FOR UNITED STATES PROPOSAL FOR DESIGNATION OF AN EMISSION CONTROL AREA FOR NITROGEN OXIDES, SULPHUR OXIDES AND PARTICULATE MATTER

CONTENTS

INFORMATION RESPONDING TO THE CRITERIA IN APPENDIX III TO ANNEX VI

1 Introduction

This Information Document supports the proposal by the United States (U.S.) to amend MARPOL Annex VI for the designation of an Emission Control Area (ECA) to prevent, reduce, and control emissions of nitrogen oxides (NO_X), sulphur oxides (SO_X) and particulate matter (PM) from ships operating in certain waters in the vicinity of the Commonwealth of Puerto Rico and the United States Virgin Islands, as described below, in accordance with regulations 13, 14, and Appendix III to MARPOL Annex VI.

A lengthier Technical Support Document can be retrieved electronically from the following website: http://www.epa.gov/otaq/oceanvessels.htm.

1.1 Country Submitting this ECA Proposal

This ECA proposal is submitted by the United States. The Commonwealth of Puerto Rico and the U.S. Virgin Islands are unincorporated territories of the United States. These islands are subject to U.S. jurisdiction and sovereignty and their residents are U.S. citizens. Consequently, the U.S. Government has a fundamental interest and responsibility in protecting public health and the environment in Puerto Rico and the U.S. Virgin Islands.

The United States is a Party to MARPOL Annex VI, having deposited its instrument of ratification with the IMO on 8 October 2008.

1.2 Criteria for Designation of an Emission Control Area

Pursuant to MARPOL Annex VI, an ECA may be considered for adoption if supported by a demonstrated need to prevent, reduce, and control air pollution from ships. Section 3 of Appendix III to MARPOL Annex VI sets out the following eight criteria for designation of an ECA:

3.1.1 a clear delineation of the proposed area of application, along with a reference chart on which the area is marked;

3.1.2 the type or types of emission(s) that is or are being proposed for control (i.e. NO_X or SO_X and particulate matter or all three types of emissions);

3.1.3 a description of the human populations and environmental areas at risk from the impacts of ship emissions;

3.1.4 an assessment that emissions from ships operating in the proposed area of application are contributing to ambient concentrations of air pollution or to adverse environmental impacts. Such assessment shall include a description of the impacts of the relevant emissions on human health and the environment, such as adverse impacts to terrestrial and aquatic ecosystems, areas of natural productivity, critical habitats, water quality, human health, and areas of cultural and scientific significance, if applicable. The sources of relevant data including methodologies used shall be identified;

3.1.5 relevant information pertaining to the meteorological conditions in the proposed area of application to the human populations and environmental areas at risk, in particular prevailing wind patterns, or to topographical, geological, oceanographic, morphological, or other conditions that contribute to ambient concentrations of air pollution or adverse environmental impacts;

3.1.6 the nature of the ship traffic in the proposed Emission Control Area, including the patterns and density of such traffic;

3.1.7 a description of the control measures taken by the proposing Party or Parties addressing land-based sources of NO_X, SO_X and particulate matter emissions affecting the human populations and environmental areas at risk that are in place and operating concurrent with the consideration of measures to be adopted in relation to provisions of regulations 13 and 14 of Annex VI; and

3.1.8 the relative costs of reducing emissions from ships when compared with land-based controls, and the economic impacts on shipping engaged in international trade.

The balance of this Information Document for MEPC 61/7/3 addresses each of the above eight criteria in turn. It is respectfully submitted that the information contained in MEPC 61/7/3 and this Information Document fulfils all of the above criteria.

2 Description of Area Proposed for ECA Designation

Criterion 3.1.1 The proposal shall include a clear delineation of the proposed area of application, along with a reference chart on which the area is marked.

The area proposed for ECA designation is illustrated in Figure 2-1. This area is located in the Caribbean Sea and consists of waters surrounding the islands of the Commonwealth of Puerto Rico and the U.S. Virgin Islands. In addition, the draft regulatory text prepared for this proposal includes the full set of coordinates delineating the proposed area.

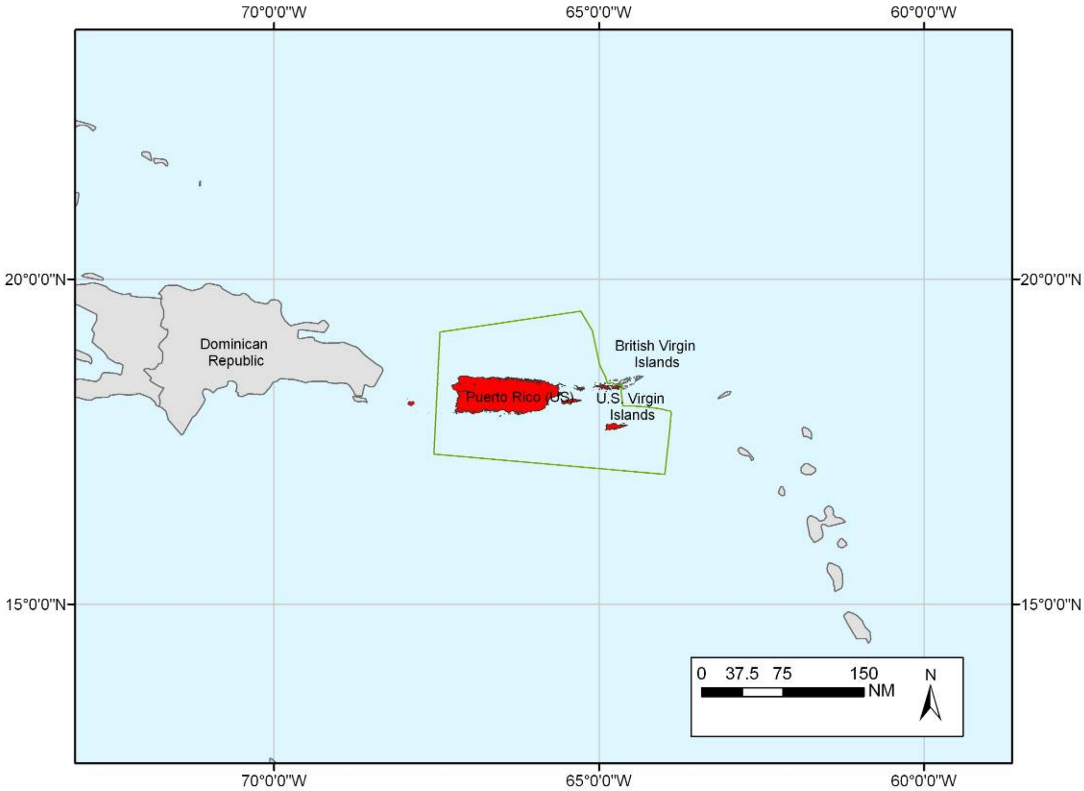

Figure 2-1: Area Proposed for ECA Designation

Overall, the area of the proposed ECA reflects the geographic nature of the included islands, which are generally arranged on a west-east axis. The proposed ECA would not extend into marine areas subject to the sovereignty, sovereign rights, or jurisdiction of any State other than the United States.

The western edge of the proposed area would generally run north-south to the east of the Mona Passage, 12 or more nautical miles from the west coast of the main island. This boundary excludes the Puerto Rican islands of Mona and Monito, which are nature preserves that lie approximately midway between the main island of Puerto Rico and the Dominican Republic. The choice of this boundary attempts to strike a balance between emission reduction benefits for the population and environment of Puerto Rico and the safety of ships operating in the Mona Passage. As proposed, this boundary should have minimal impacts on ships operating in the area.

The eastern edge of the proposed area would generally run north-south, but also extend eastward through the area between the U.S. Virgin Islands and the British Virgin Islands as well as eastward toward the area between Saint Croix and Anguilla and Saint Kitts. To the east, the proposed ECA is bounded such that it does not extend into marine areas subject to the sovereignty, sovereign rights, or jurisdiction of any State other than the United States.

The northern edge of the proposed area would extend about 50 nm from the territorial sea baselines of Puerto Rico and the U.S. Virgin Islands.

The southern edge of the proposed area would extend about 40 nm from the territorial sea baselines of Puerto Rico and the U.S. Virgin Islands.

The size and shape of the ECA were determined using the information presented in this Information Document. Specifically, back trajectory modelling was used to evaluate the probability that offshore ship emissions impact selected onshore sites in Puerto Rico and the Virgin Islands (see section 5.3.1). Then, to construct an emission control area that would be equally protective, on average as the recently designated North American ECA, the boundaries of the proposed ECA were drawn to reflect similar spatial probabilities as the North American.

The above information fulfils criteria 3.1.1 of MARPOL Annex VI, Appendix III.

3 Types of Emissions Proposed for Control

Criterion 3.1.2 *The proposal shall include the type or types of emission(s) that is or are being proposed for control (i.e. NO_X or SO_X and particulate matter or all three types of emissions).*

The U.S. Government proposes designation of an ECA for the Commonwealth of Puerto Rico and the U.S. Virgin Islands to reduce emissions of NO_X, SO_X and particulate matter (PM). This section describes each of these pollutants and provides a summary of their health and environmental impacts. Additional information can be found in the Technical Support Document prepared for this proposal.

The information in this section, as expanded on in the Technical Support Document fulfils criteria 3.1.2 of MARPOL Annex VI, Appendix III.

3.1 NO_X, SO_X and PM Emissions

Ships operating in the proposed ECA emit NO_X, SO_X and PM as a direct result of the high sulphur fuel used in these engines and due to internal combustion engine processes. In addition to the direct emissions of these pollutants, NO_X and SO_X are precursors to fine particulate matter, and NO_X is a precursor to ground level ozone. Although SO_X and PM are regulated under regulation 14 and NO_X is regulated under regulation 13, they are discussed as a group in this section because their impacts are interrelated.

3.2 Particulate Matter

Particulate matter is a generic term for a broad class of chemically and physically diverse substances. It can be principally characterized as discrete particles that exist in the condensed (liquid or solid) phase spanning several orders of magnitude in size. PM_{10} refers to particles less than or equal to 10 micrometres (μm) in aerodynamic diameter. $PM_{2.5}$ refers to fine particles, less than or equal to 2.5 μm in aerodynamic diameter. Inhalable (or "thoracic") coarse particles refer to those particles greater than 2.5 μm but less than or equal to 10 μm in aerodynamic diameter. Ultrafine PM refers to particles less than 100 nanometres (0.1 μm) in aerodynamic diameter.

Ambient fine particulate matter is composed of primary $PM_{2.5}$ (directly emitted particles) and secondary $PM_{2.5}$ (particles created through chemical and physical interactions of precursor pollutants). NO_X and SO_X can directly lead to the formation of secondary $PM_{2.5}$. The majority of the PM associated with ships, both that which is directly emitted and that which is secondarily formed from ships' emissions of NO_X and SO_X, is in the fine particle size fraction.

It is highly beneficial, from a public health perspective, to control PM emissions due to its impacts on the respiratory and cardiovascular systems. The World Health Organization (WHO) has set air quality guidelines (AQG) for $PM_{2.5}$ (WHO, 2006). The annual mean $PM_{2.5}$ guideline established by WHO is 10 μg/m^3 and the 24-hour mean $PM_{2.5}$ guideline is 25 μg/m^3. Although these guidelines have been established, it is important to understand that scientists have not identified any ambient threshold for PM below which no health effects are observed. It is also important to regulate PM from an environmental welfare perspective. PM can cause visibility impairment, ecological effects, and materials damage and soiling. Sections 5.4 and 5.5 of this document contain more information on the health and environmental impacts of PM.

3.3 Ozone

Ground-level ozone pollution, also known as smog, is formed by the reaction of volatile organic compounds (VOCs) and NO_X in the atmosphere in the presence of sunlight. These pollutants, often referred to as ozone precursors, are emitted by many types of pollution sources such as on-road vehicles and non-road engines (including ships), power plants, chemical plants, refineries, makers of consumer and commercial products, industrial facilities, and smaller area sources. The U.S. Government has already imposed restrictions on ozone precursors and other emissions from a wide range of anthropogenic sources, including land-based industrial and transportation sources as well as consumer and commercial products.

The science of ozone formation, transport, and accumulation is complex. Ground-level ozone is produced and destroyed in a cyclical set of chemical reactions, many of which are sensitive to temperature and sunlight. When ambient temperatures and sunlight levels remain high for several days and the air is relatively stagnant, ozone and its precursors can build up and result in more ozone than typically would occur on a single high-temperature day. The areas in the proposed ECA have high temperatures and sunlight and there is a possibility for stagnant conditions, especially in areas with terrain. In addition, ozone can be transported hundreds of kilometres downwind of precursor emissions, resulting in elevated ozone levels even in areas with low local VOC or NO_X emissions.

It is highly beneficial, from a public health perspective, to regulate ozone due to its effects on the respiratory and cardiovascular systems. Exposure to ozone can cause decreases in lung function and breathing discomfort, leading to restricted activity days for those with respiratory problems. Ozone can also aggravate asthma, leading to more asthma attacks. Ozone exposure may also contribute to premature death, especially in people with heart and lung disease. The WHO has also set air quality guidelines (AQG) for ozone. The 8-hour mean ozone guideline established by WHO is 50 ppb, or approximately 100 μg/m^3. It is also important to control ozone from an environmental health perspective. Some environmental effects associated with the presence of ozone in the ambient air are visible leaf injury and decreased plant growth. Sections 5.4 and 5.5 of this document contain more information on the health and environmental impacts of ozone.

3.4 Sulphur Oxides and Nitrogen Oxides

Sulphur dioxide (SO_2), a member of the sulphur oxide (SO_X) family of gases, is formed from burning fuels containing sulphur (e.g., coal or oil derived), extracting gasoline from oil, or extracting metals from ore. Nitrogen dioxide (NO_2) is a member of the NO_X family of gases. Most NO_2 is formed in the air through the oxidation of nitric oxide (NO) emitted when fuel is burned at a high temperature. SO_2 and NO_2 can dissolve in water vapour and further oxidize to form sulphuric and nitric acid which react with ammonia to form sulphates and nitrates, both of which are important components of ambient PM. As mentioned previously, NO_X is also a precursor of ozone.

Exposure to NO_2 and/or SO_2 can cause respiratory problems. The WHO has set air quality guidelines (AQG) for SO_2 and NO_2. The WHO's annual mean NO_2 guideline is 40 $\mu g/m^3$ and the 1-hour mean NO_2 guideline is 200 $\mu g/m^3$. There are two SO_2 guidelines established by the WHO, the 24-hour mean SO_2 guideline is 20 $\mu g/m^3$ and the 10-minute mean SO_2 guideline is 500 $\mu g/m^3$. It is also important to control NO_X and SO_X from an environmental health perspective. Environmental effects associated with the presence of NO_X and SO_X in the ambient air are acidification of terrestrial and aquatic ecosystems, eutrophication of aquatic systems and nitrogen loading in terrestrial ecosystems. Sections 5.4 and 5.5 of this document contain more information on the health and environmental impacts of NO_X and SO_X.

4 Description of Population and Environmental Areas at Risk

Criterion 3.1.3 The proposal shall include a description of the human populations and environmental areas at risk from the impacts of ship emissions.

The proposed Emission Control Area includes the Commonwealth of Puerto Rico and the U.S. Virgin Islands. These islands are unincorporated territories of the United States. They are situated where the Western Atlantic Ocean meets the Caribbean Sea, among the chain of islands called the Antilles of the West Indies. This section briefly describes the geography, population, and economy of each of these U.S. territories.

4.1 The Commonwealth of Puerto Rico

The Commonwealth of Puerto Rico is an archipelago of the easternmost islands of the Greater Antilles. Puerto Rico consists of the main island of Puerto Rico and several smaller islands including Vieques, Culebra, Mona and Monito, Desecheo, Caja de Muertos, and La Isleta de San Juan.

Puerto Rico is geographically distinctive, containing a wide variety of land forms and ecosystems. The main island of Puerto Rico measures about 180 km east-west and 65 km north-south, with a total land area of 9,000 sq km. Puerto Rico is comprised of coastal plains bisected east to west by a chain of mountains (USGS, 1999). The main mountain range is La Cordillera Central (highest elevation 1,339 metres at Cerro de Punta). This central mountain range affects weather patterns, in part by lifting the moist air masses and increasing rainfall, especially on the eastern side on the main island.

Puerto Rico also contains a great deal of natural diversity. Ecosystems range from bioluminescent bays and tropical mangrove swamps to dazzling coral reefs. Puerto Rico has two areas classified by UNESCO as World Biosphere Reserves: Luquillo and Guanica. The Luquillo Mountains in the northeast of Puerto Rico contain the only protected tropical rainforest in the United States forest system, El Yunque. The Guanica Reserve, located in the southwest of the island, consists of several mangrove cays and a subtropical dry forest (UNESCO, 2008). Furthermore, Mona and Monito Island, 70 km off the west coast of the main island, has been denoted as the Galapagos of the Caribbean. It contains sensitive ecosystems and several endangered species (Mac *et al.*, 2008).

Due to the geography of the islands, the population of Puerto Rico is densely clustered near the coasts into highly urbanized communities. Rural areas account for only two per cent of the total population in Puerto Rico. Figure 4-1 illustrates the high population density along the coast. This map shows the co-location of commercial ports with the most densely populated regions. As a consequence of the their proximity to ports and the coastline, inhabitants of the main island of Puerto Rico, as well as Vieques and Culebra, are clearly affected by ship emissions.

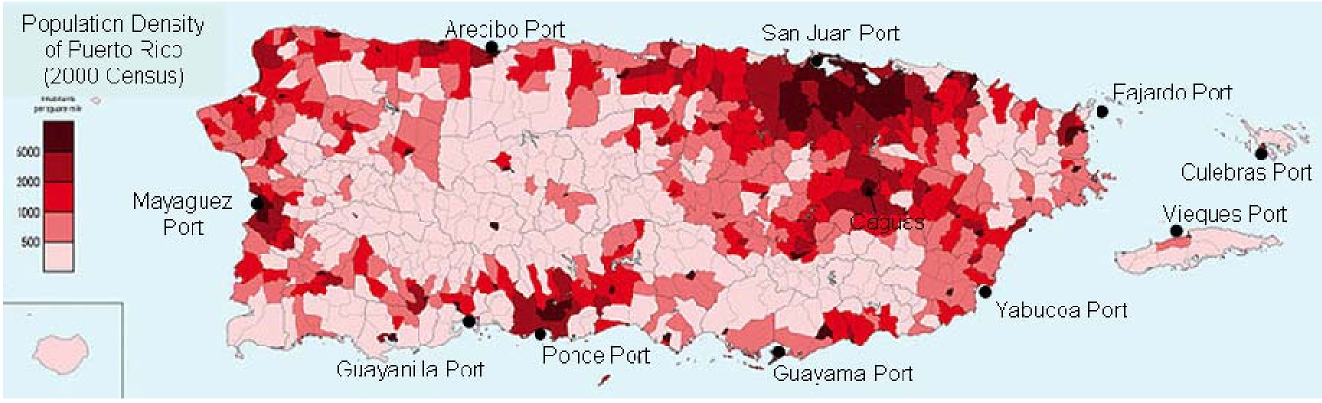

Figure 4-1: Port locations and population density of Puerto Rico

The U.S. Census Bureau estimates the total population of Puerto Rico at approximately 4.0 million people for 2009 (U.S. Census Bureau, 2010a). If Puerto Rico were a U.S. state, it would rank 27th in population size, after Kentucky and before Oregon. On the other hand, Puerto Rico ranks behind all 50 states except Delaware and Rhode Island in land area, at 9,000 square kilometres. This gives Puerto Rico an average population density of about 440 people per square kilometre, second highest in the United States after New Jersey (CIA, 2010a). Only around 20 countries in the world have a population density higher than Puerto Rico (Population Reference Bureau, 2009).

Not only is Puerto Rico densely populated, but the population is heavily distributed among groups that are especially sensitive to air pollution, particularly children and the elderly. Over 1.5 million, or 38 per cent of the population, is under 18 or over the age of 65. About 45 per cent of the population was classified at or below the poverty threshold in 2008 (U.S. Census Bureau, 2010b). This is well above the national average in the United States, 13 per cent. The poverty rate for children in Puerto Rico is even higher: 56 per cent. Moreover, much of this population lacks adequate access to medical services. Approximately 32 per cent of the population, or 1.27 million Puerto Ricans, are considered medically underserved (HRSA, 2010).

San Juan, Puerto Rico's largest city, has a population of about 420,000 within the municipio[1] boundaries and 2.6 million throughout the metropolitan area (U.S. Census Bureau, 2010c). The area has a population density of about 950 people per square kilometre, making it 170th in population density among urban areas worldwide (City Mayor Statistics, 2010). Located on the North shore of Puerto Rico, San Juan is built along one of the biggest natural harbours in the Caribbean Sea. The Port of San Juan is the centre for goods movement on the island, moving approximately 11 million metric tonnes of product on nearly 3,800 vessel trips in 2008. Based on tonnage, San Juan ranks 49th out of the top 150 commercial ports in the United States (USACE, 2010). San Juan is also a major destination for cruise ship passengers. In 2008 an estimated 1.4 million passengers on

[1] A municipio is the primary legal subdivision of Puerto Rico.

over 500 port calls visited the Port of San Juan, making it one of the top cruise destinations in the Caribbean (PRPA, 2009).

The city of Ponce, located on the southwest side of the main island, is also the home to a major port. Ponce is Puerto Rico's second largest municipio with 180,000 inhabitants (U.S. Census Bureau, 2010a). The port complex, which will be renamed Port of the Americas, is undergoing large-scale redevelopment in order to relieve the congestion in San Juan. The port currently ranks 83 out of the top 150 commercial ports in the United States. When completed, Port of the Americas will be capable of handling up to 1.5 million twenty-foot containers and 600,000 tons of general cargo each year. As of 2008, 3.8 million metric tons of goods moved through the port in Ponce (USACE, 2008).

Mayaguez, an industrial and port city on the west coast of the island, is home to approximately 90,000 people. The port in Mayaguez moved approximately 350,000 tons of cargo in 2008, much of which was fuel shipments (USACE, 2008).

Similarly, the port city of Arecibo, just downwind (west) of San Juan, is home to a port primarily used for importing fuel. In 2008, fuel shipments alone totalled 53,000 tons (USACE, 2008). Arecibo contains 100,000 residents (U.S. Census Bureau, 2010a). The city's terrain consists of hills surrounding the city, forming a natural bowl.

The inland city of Caguas in eastern Puerto Rico is another major commercial centre. It is situated in a valley surrounded by mountains, where air pollutants tend to accumulate rather than disperse. Other major cities include Guayama, Yabucoa and Fajardo. Population and density figures for all of the main coastal and inland municipio are listed in Table 4-1.

Table 4-1: Annual Estimates of the Resident Population and population density for Municipios of Puerto Rico (U.S. Census Bureau: 2010a).

MUNICIPIO	POPULATION (2009)	POP. DENSITY (PEOPLE/KM^2)
Arecibo	102,770	315
San Juan	420,326	3,394
Fajardo	42,365	548
Yabucoa	48,615	339
Guayama	45,372	270
Ponce	178,346	600
Guayanilla	23,752	217
Mayaguez	92,156	458
Caguas	143,274	944
Culebras	2,156	72
Vieques	9,311	71

Beginning in the 1950s, U.S. tax and other policies encouraged economic development in Puerto Rico. As a result, the economy of the territory has moved from agricultural (sugar production) to industrial, with manufacturing currently accounting for about 45 per cent of GDP and agriculture only about 1 per cent. Puerto Rico has very strong economic links with the continental United States. Because of its lack of natural resources, the territory obtains the raw materials as well as chemicals, machinery and equipment, clothing, food, fish, and petroleum from outside the island, mainly from the continental United States (55 per cent), Ireland (24 per cent) and Japan (5 per cent). Finished goods include chemicals, electronics, apparel, canned tuna, rum, beverage concentrates, and medical equipment, and are mainly destined for the continental United States (90 per cent) (GDB, 2008).

As a group, the major ports of Puerto Rico (referred to as the customs district of Puerto Rico), ranks in the top 25 ports in the United States in terms of foreign trade and value (MARAD, 2010). In addition to ships entering Puerto Rican ports, there is a substantial amount of ship activity around the island from vessels on their way to or from the Panama Canal and other countries in the Americas. These ship operations are described in section 7.

Finally, tourism is an important component of Puerto Rico's economy. According to the UN World Tourism Organization, Puerto Rico had about 4 million international tourist arrivals in 2007, ranking it 50th in the world (UN WTO, 2009). About one third of the tourists are cruise ships passengers.

In sum, Puerto Rico's economy is highly dependent on marine transportation. This dependency, in combination with the physical and human geography of the territory, place its population and environment at an elevated risk from ship-related air pollution.

4.2 United States Virgin Islands

The U.S. Virgin Islands are the westernmost islands of the Lesser Antilles, located between Puerto Rico (about 90 miles west) and the British Virgin Islands, and near the Anegada passage, a deep (2,300 metre) channel that connects the Atlantic Ocean with the Caribbean Sea. The U.S. Virgin Islands are comprised of three main islands, Saint Thomas, Saint John, and Saint Croix, as well as several dozen smaller islands. The entire island chain measures about 45 km east-west by about 11 km north-south.

This area is geologically active, being near the boundary of the Caribbean and North American plates. The U.S. Virgin Islands are volcanic in origin and mostly hilly to rugged and mountainous with little level land, although jungle-like regions may be found on the elevated plateaus. These islands are known for their white sand beaches and coral reefs. More than half of the island of St. John is managed by the U.S. National Park Service, since the Virgin Islands National Park was expanded in 1962. That action increased the Park's size by adding over 5,000 acres of submerged lands to protect and preserve coral gardens and seascapes. Several other natural areas have been officially designated for preservation and conservation, including the Virgin Islands Coral Reef Monument, whose reefs are sheltered by mangrove forests and sea grass beds (Mac *et al.*, 1998). UNESCO has designated over two-thirds of the island of St. Johns as a World Biosphere Reserve. (UNESCO, 2008).

Like Puerto Rico, geographic constraints result in the citizens of the U.S. Virgin Islands being located in densely populated coastal areas. Figure 4-2 illustrates the major cities of the three main U.S. Virgin Islands and their population densities. Also, like Puerto Rico, this map shows that all inhabitants of the U.S. Virgin Islands live in close proximity to commercial ports or the coasts and are clearly affected by ship emissions.

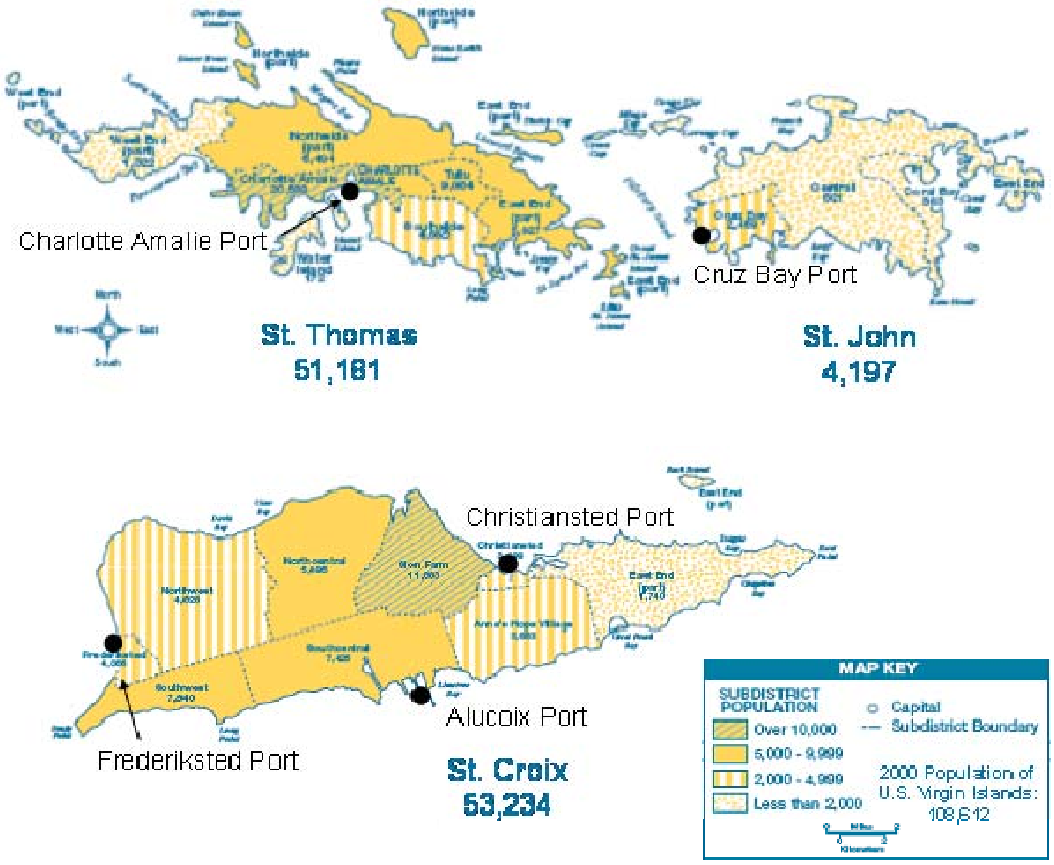

Figure 4-2: Port locations and population density of the U.S. Virgin Islands

The total population of the U.S. Virgin Islands is about 109,000 people. The population density of the islands is about 360 people per square kilometre. Only 34 countries in the world have a population density higher than the U.S. Virgin Islands. This population is spread between St. Thomas (51,000 people; 630 people per square kilometre) and St. Croix (60,000 people; 280 people per square kilometre). An additional 4,000 people live in St. John; the rest of the islands have small or no populations (U.S. Census Bureau, 2003).

St. Thomas is the site of the U.S. Virgin Islands' capital and largest city, Charlotte Amalie. Approximately 19,000 people live in the capital (U.S. Census Bureau, 2003). Charlotte Amalie, as is typical of St. Thomas and St. John islands, is characterized by steep topography that tends to contain air pollution.

Charlotte Amalie is also the location of the largest port in the U.S. Virgin Islands, St. Thomas Port. In 2005, St. Thomas alone saw over two million cruise passengers and over 800 cruise ship calls. In addition to cruise ships, smaller ferries and other passenger vessels frequent the port and the small islands across from Charlotte Amalie (Hassel Island and Water Island). St. Thomas is also a major transhipment port for cargo destined elsewhere in the Caribbean. In total, Virgin Island ports handled over one million tons of cargo in 2005 (VIPA, 2009).

St. Croix is the largest and most populous of the U.S. Virgin Islands and contains the Ports of Frederiksted, Alucoix, and Christiansted. The most heavily populated areas of St. Croix are located downwind of Christiansted Port.

The main industry in the U.S. Virgin Islands is tourism, which accounts for about 80 per cent of GNP. Like Puerto Rico, the economy of the U.S. Virgin Islands is dependent on outside sources of raw materials and other manufacturing inputs. Finished goods including textiles, electronics, rum, and pharmaceuticals, are mainly destined for the continental United States and Puerto Rico (CIA, 2010b).

Finally, St. Croix is the location of one of the world's largest petroleum refineries, Hovensa. A joint venture between Hess Corporation and Petroleos de Venezuela, this refinery supplies heating oil and gasoline to the U.S. Gulf and East coasts. With a capacity of about 500,000 barrels per day, Hovensa is one of the 10 largest refineries in the world and the largest private employer in the U.S. Virgin Islands. This refinery is subject to the United States domestic environmental regulations (U.S. EIA, 2009).

In sum, the economy of the U.S. Virgin Islands is highly dependent on marine transportation. This dependency, in combination with the physical and human geography of the territory, place its population and environment at an elevated risk from ship-related pollution.

4.3 Other Affected Islands

In addition to the U.S. territories that will be directly covered by the proposed ECA, other island states in the Caribbean can also be expected to see benefits of ECA designation for these territories. Due to the direction of the trade winds and the proximity of these U.S. territories to other island states, ship compliance with the emission limits and fuel sulphur controls while operating in the proposed ECA will reduce NO_X, SO_X, and particulate matter emissions and thus the amount of those emissions transported across sea and land. This can be expected to yield measurable air quality benefits to other islands located in close proximity to, or downwind of, the proposed ECA, including the U.K. Virgin Islands, the Dominican Republic, and even islands as far away as Haiti and Jamaica.

4.4 Summary

The description of Puerto Rico and the U.S. Virgin Islands contained in this section shows they are highly populated islands that receive considerable ship traffic, both in terms of trade (imports of raw materials and oil) and exports (manufactured goods, petroleum products) and tourism. Commercial and tourism ports are located throughout these islands. In addition, as described in section 7, Puerto Rico and the U.S. Virgin Islands are located in areas of high ship traffic density, as ships voyaging from Europe, Africa and Asia travelling through the Panama Canal and to other countries in the Caribbean and Americas operate in passages to the east and west of these islands. The combination of people and sensitive ecosystems being located in close proximity to ports and areas of ship activity with the high levels of ship activity in this area mean that emissions from ships are contributing to ambient concentrations of air pollution and to adverse environmental impacts in Puerto Rico and the U.S. Virgin Islands. The information presented in this section, as expanded on in the Technical Support Document, fulfils criteria 3.1.3 of MARPOL Annex VI, Appendix III.

5 Contribution of Ships to Air Pollution and Other Environmental Problems

Criterion 3.1.4 The proposal shall include an assessment that emissions from ships operating in the proposed area of application are contributing to ambient concentrations of air pollution or to adverse environmental impacts. Such assessment shall include a description of the impacts of the relevant emissions on human health and the environment, such as adverse impacts to terrestrial and aquatic ecosystems, areas of natural productivity, critical habitats, water quality, human health, and areas of cultural and scientific significance, if applicable. The sources of relevant data including methodologies used shall be identified.

5.1 Synopsis of the Assessment

Emissions from ships clearly contribute to ambient concentrations of air pollution and adverse human health and environmental impacts in the Commonwealth of Puerto Rico and the U.S. Virgin Islands. This section contains an assessment of this contribution and a description of these impacts. The sources of relevant data including methodologies used are contained in the Technical Support Document prepared for this proposal.

This assessment begins in section 5.2 with a presentation of the estimated air emission inventories for Puerto Rico and the U.S. Virgin Islands for each of the pollutants to be controlled by the proposed ECA: NO_X, SO_X and PM. Then in section 5.3 we discuss the likelihood of offshore ship emissions impacting onshore locations. When considered in combination with the geography and population densities of Puerto Rico and the U.S. Virgin Islands, described in section 4, the result is that millions of people are being exposed to ship emissions. We also discuss available ambient air quality monitoring data for Puerto Rico and the U.S. Virgin Islands. Section 5.4 describes the human health impacts of ships' emissions on populations living in the affected area, and section 5.5 describes the adverse impacts of ship emissions to ecosystems.

The data presented in section 5.2 show that the contribution of ships to air emission inventories in Puerto Rico and the U.S. Virgin Islands is substantial. This is unsurprising given that these are islands and they depend on marine transportation for many aspects of economic activity and the requirements of daily life. In addition, due to its natural beauty, this area is a popular destination for tourism. The sources of these ship emissions are primarily ships that call on ports in Puerto Rico and the U.S. Virgin Islands. Other ships en route to or from the Panama Canal or other destinations in the Americas but that do not stop in Puerto Rico or the U.S. Virgin Islands may also contribute to emissions, to the extent that they operate in the area. We estimate that in 2020, absent any control, ships operating within the proposed ECA will contribute 38,000 tonnes of NO_X, 30,000 tonnes of SO_X, and 3,600 tonnes of PM to Puerto Rico's and the U.S. Virgin Islands' emission inventories, accounting for 38 per cent, 37 per cent, and 27 per cent of the total area inventory of manmade NO_X, SO_X and PM, respectively. Application of the ECA controls in this area would reduce these emissions substantially.

In section 5.3, we show how these ship emissions contribute to ambient air quality. Back trajectory modelling shows that in addition to ships operating in port areas and along the coasts of Puerto Rico and the U.S. Virgin Islands, ship emissions from as far as 200 nm offshore affect air quality onshore. There is substantial ship traffic in and around Puerto Rico and the U.S. Virgin Islands and this ship activity is in close proximity to heavily populated areas collectively containing almost four million inhabitants.[2]

The human health and environmental impacts of ship emissions are serious. According to scientific studies, both ambient $PM_{2.5}$ and ozone are associated with a broad array of adverse impacts to human health, which are summarized in section 5.4. Emissions from ships also adversely impact sensitive environmental areas across Puerto Rico and the U.S. Virgin Islands. As described in section 5.5, these impacts widely affect terrestrial and aquatic ecosystems, including areas of natural productivity, critical habitats and areas of cultural and scientific significance.

For all of the reasons set out in this section, ECA designation is appropriate for the islands of Puerto Rico and the U.S. Virgin Islands. To determine the boundaries of the proposed ECA, we use the back trajectory modelling to evaluate the probability that offshore ship emissions impact selected onshore sites in Puerto Rico and the Virgin Islands (see section 5.3.1). Then, to construct an emission control area that would be equally protective, on average as the recently designated North American ECA the boundaries of the proposed ECA were drawn to reflect similar spatial probabilities as the North American ECA.

5.2 Ship Emissions Inventories

Ships operating in the area proposed for ECA designation contribute to air pollution that is harmful to human health and the environment. This section presents the results of inventory modelling for the proposed ECA for 2020 and briefly describes the key modelling assumptions used to estimate these inventories. This inventory modelling uses well-known and accepted methods and assumptions. Emission inventories are estimated for two different scenarios: 1) continuation of current NO_X, SO_X and PM emissions performance (baseline scenario), and 2) adoption of the proposed ECA requirements (control scenario). The Technical Support Document prepared for this proposal contains more details about the inventory modelling methodology and results.

5.2.1 Contribution of Ships to Emissions Inventories

Table 5-1 summarizes emissions inventories from ships operating in the proposed ECA for NO_X, SO_X and PM, as well as the contribution of ship emissions to total emissions inventories from anthropogenic sources in 2020, under the baseline and control scenarios. These data indicate that ships are an important contributor to total NO_X, SO_X and PM emissions. The estimates reported in Table 5-1 include all man-made emissions from Puerto Rico and the U.S. Virgin Islands, as well as all shipping within the proposed ECA. The emissions estimates from land-based mobile source sectors account for reductions from controls in place as well as expected growth. Stationary source emissions are estimated to remain unchanged from current levels. For more details on how land-based source inventories were developed, please see the Technical Support Document.

2 Ship activity patterns are described in Section 7.

Table 5-1: Emissions Inventory Contribution of Ships in 2020 [a, b]

SOURCE CATEGORY	METRIC TONNES PER YEAR			
	2020 Current Performance	2020 ECA		
	Total	Total	Tonnes Reduced	Per cent Reduction
SO_X				
Commercial marine	29,600	1,100	28,500	96%
Marine % of all man-made sources	36%	2%		
$PM_{2.5}$ [c]				
Commercial marine	3,500	500	3,000	86%
Marine % of all man-made sources	26%	5%		
NO_X [d]				
Commercial marine	37,000	27,000	10,000	27%
Marine % of all man-made sources	37%	30%		

Notes:

[a] The ship inventories include emissions within the proposed ECA. See Figure 7-3 for the spatial illustration of the area and the shipping lanes within.

[b] For this analysis, the commercial marine vessel emissions inventory does not include ships powered by "Category 1" or "Category 2" (i.e. <30 L/cyl) engines. These smaller engines installed on U.S.-flag vessels are already subject to strict national standards affecting NOX, PM, and fuel sulphur content. Engines above 130 kW but less than 30 L/cyl on foreign-flag vessels are covered by Annex VI; however, the Annex VI reductions for these vessels have not been included in the analysis.

[c] The PM2.5 inventories include directly-emitted PM2.5 only.

[d] In 2020, only a portion of ships in the fleet will have been built since 2016, when ECA 'Tier III' NOX limits must be met. Annual fleet wide NOX reductions will increase for several years after 2020 as ships built since 2016 continue to come into service.

As seen in Table 5-1, commercial marine vessels are a significant contributor to baseline (uncontrolled) emission inventories. Ships currently contribute about 36 per cent of SO_X, 26 per cent of $PM_{2.5}$ and 37 per cent of NO_X emissions from all man-made sources.

The estimated emission reductions for 2020 associated with the ECA designation are expected to be substantial at approximately 3,000 tonnes of $PM_{2.5}$, 10,000 tonnes of NO_X, and 28,500 tonnes of SOx reduced. This amounts to a reduction of 86 per cent and 96 per cent of annual emissions for $PM_{2.5}$, and SO_X, respectively. These inventory reductions mean that the contribution of ships to total emissions in the area are expected to decrease from 36 per cent to 2 per cent for SO_X and from 26 per cent to 5 per cent for PM. ECA controls would reduce the 2020 NO_X inventory by about 27 per cent. Since the ECA NO_X limits apply to new vessels only and begin in 2016, larger reductions are expected in future years as ships implement the Annex VI Tier III NO_X emission limits. These are substantial emission inventory reductions, which would clearly have an impact on ambient levels of ozone and PM.

The emission impacts could even be greater if the growth rates were increased to account for the opening in 2014 of the expanded Panama Canal in 2014, and if the inventories reflected the impacts of smaller (below 130 kW) engines installed on foreign vessels. Both of these impacts are discussed in section 5.2.2.

5.2.2 Emissions Inventory Modelling and Inputs for 2020 Current Performance (Baseline) Scenario

This section describes three key features of the modelling used to estimate the baseline emissions inventory for the proposed ECA. These are the choice of 2020 as the year of analysis; the types of engine emissions included in the inventory, and how the inventory for 2020 was constructed.

The modelling presented here estimates the expected effect of shipping emissions in 2020. The year 2020 was chosen because it allows the use of detailed emission inventories that were created for other emission sources (e.g., land-based stationary and mobile sources) as part of wider scale air pollution modelling efforts. This allows us to compare the ship emission inventories to total anthropogenic emission inventories for Puerto Rico and the Virgin Islands. The choice of 2020 is also consistent with the fuel cost analysis.

The use of 2020 has two implications for the inventory analysis. First, with regard to the impacts of the ECA fuel sulphur requirements, the choice of 2020 slightly over-estimates the immediate benefits of the programme in 2015. However, since the fuel controls apply to all vessels beginning in 2015 (there is no phase-in), the estimated impacts of the fuel requirement in 2020 are expected to be similar to the impacts in 2015, with the difference due to growth in the marine transportation sector. Therefore, the use of 2020 as the analytic year will still provide a representative scenario for the impact of the 0.1 per cent fuel sulphur requirement on human health and the environment. Second, with regard to the NO_X impacts, the use of 2020 includes only five years of turnover to the Tier III standards. Because of the long service lives of engines on ocean-going vessels, this mean that the fleet will not be fully turned over for some time and therefore the full benefits of the ECA NO_X controls are not reflected in the analysis. In conclusion, the choice of 2020 as the analytic year provides a balance between modelling too early of a year where the Tier III NO_X standards may not yet apply and modelling too late of a year where there may be more uncertainty associated with projecting emissions into the future. It should be noted that, although the 0.5% global fuel sulphur standard goes into effect in 2020, we did not include the global standard in the 2020 analysis. This approach provides an estimate of benefits in the early (pre-2020) years of the programme.

The ship emissions inventories presented in Table 5-1 are for U.S.- and foreign-flagged commercial marine vessels with "Category 3" propulsion engines. Category 3 marine diesel engines are those engines with per cylinder displacement at or above 30 litres. The inventories include emissions from both propulsion and auxiliary engines installed on these vessels. The ship inventories do not include emissions from smaller vessels with Category 1 and 2 propulsion engines. It is appropriate to exclude smaller U.S.-flag vessels from this analysis because they are already subject to stringent national standards. However, the exclusion of emissions from smaller foreign-flag vessels means the inventories presented in Table 5-1 are underestimated. These smaller vessels will also be covered by the ECA engine standards and fuel sulphur limits.

The 2020 ship emission inventories are a combination of two inventory estimates: in-port and underway (or inter-port). Detailed port emissions inventories were developed for seven ports in Puerto Rico and five ports in the U.S. Virgin Islands. These ports are the principal ports based on total freight tonnage. These port inventories were constructed based on port call data combined with ship characteristics and activity estimates. Underway emissions are estimated using the Ship Traffic, Energy, and Environmental Model (STEEM). STEEM includes a waterway network of shipping lanes based on 20 years of observed ship locations obtained from two global ship reporting databases: the International Comprehensive Ocean-Atmospheric Data Set (ICOADS), and the Automated Mutual-Assistance Vessel Rescue (AMVER) system. The ship movement information in STEEM was primarily obtained from the United States Army Corp of Engineers (USACE) entrance and clearance data, combined with ship attributes data from Lloyd's Maritime Intelligence Unit. A more complete description of the shipping traffic is provided in section 7.

The in-port and underway emission inventories were developed for a base year of 2002, the most recent year for which input data was available. Inventories for 2020 were then projected using derived growth rates and emission factors. The growth rates are based on the expected demand for marine bunker fuels associated with the flow of commodities into and out of the United States (US EPA, 2009b). Fuel consumption by trade route and commodity type were developed using an econometric model for commodity projections, along with ship and voyage characteristics. The growth rate for the proposed ECA is a composite growth rate for the United States. This growth rate does not account for the opening of the expanded Panama Canal in 2014. As a result, it is possible that the growth rate used in this analysis underestimates ship activity in 2020. The emissions factors for the projected 2020 inventories include the MARPOL Annex VI Tier I and Tier II NO_X standards. For the reasons noted above, they do not include the 2020 global fuel sulphur cap.

5.2.3 Emissions Inventory Modelling and Inputs for 2020 Development for 2020 ECA Performance (Control) Scenario

To estimate the impacts of the ECA controls in the proposed area, NO_X, SO_X, and PM emissions were adjusted to account for the emission reductions associated with the ECA engine standards and fuel sulphur limits. Since the engine standards apply to new engines only beginning in 2016, the NO_X adjustment accounts for the portion of the fleet subject to the ECA emission limits in 2020. SO_X and PM emissions were adjusted as a function of fuel sulphur content, assuming the in-use fuel sulphur content meets the ECA limit of 0.1 per cent.

The 2020 inventory estimates assume that ship activity patterns in the uncontrolled and controlled scenarios are the same, and that ships do not revise their routing to avoid the ECA. This is a reasonable assumption for ships that enter ports in Puerto Rico and the U.S. Virgin Islands. For other vessels, the extent to which ships would reroute to circumvent the ECA boundary is dependent on the unique characteristics of the specific voyage: the amount of time that would otherwise be spent in the proposed ECA, the next destination, and the impacts of rerouting on operating costs as compared to fuel costs saved.

5.3 Ships' Contribution to Ambient Air Quality

The significant contribution by ships to $PM_{2.5}$, NO_X and SO_X emission inventories in Puerto Rico and the U.S. Virgin Islands means that these ships also have a significant contribution to ambient levels of ozone, $PM_{2.5}$, NO_X and SO_X.

5.3.1 Ship Emissions and Ambient Air Quality

The inventory estimates presented above show there are substantial ship emissions in the proposed ECA area around Puerto Rico and the U.S. Virgin Islands. As presented in Table 5-1, by 2020 ships are projected to be responsible for 37 per cent, 36 per cent, and 26 per cent of the total man-made NO_X, SO_X and direct $PM_{2.5}$ emissions in the proposed ECA.[3] In addition to ships large contribution of directly emitted pollutants, NO_X and SO_X also contribute to secondary PM formation and NO_X is a precursor to ground level ozone. Due to the regional meteorology and the relatively small size of the islands, emissions from ships will impact people and ecosystems throughout Puerto Rico and the U.S. Virgin Islands.

Meteorological modelling was performed to evaluate the probability that offshore ship emissions, including emissions both inside and outside the area of the proposed ECA, affect onshore sites in Puerto Rico and the U.S. Virgin Islands (STI, 2009). This analysis looks at the likelihood of an offshore parcel of air reaching Puerto Rico and the Virgin Islands. Offshore emissions in these areas could also affect neighbouring countries but these effects were not modelled. To conduct this evaluation, a back trajectory analysis was completed, which uses interpolated meteorological fields to track a parcel of air backward in time from a specified location. The HYSPLIT model was used to model these back trajectories. HYSPLIT was developed by the NOAA ARL (Air Resources Laboratory, 2008) and uses archived three-dimensional meteorological fields to compute simple air parcel trajectories. Back trajectories from seven locations in Puerto Rico and the Virgin Islands were calculated and that data was aggregated to evaluate the probability that emissions from offshore have an impact on selected onshore sites.

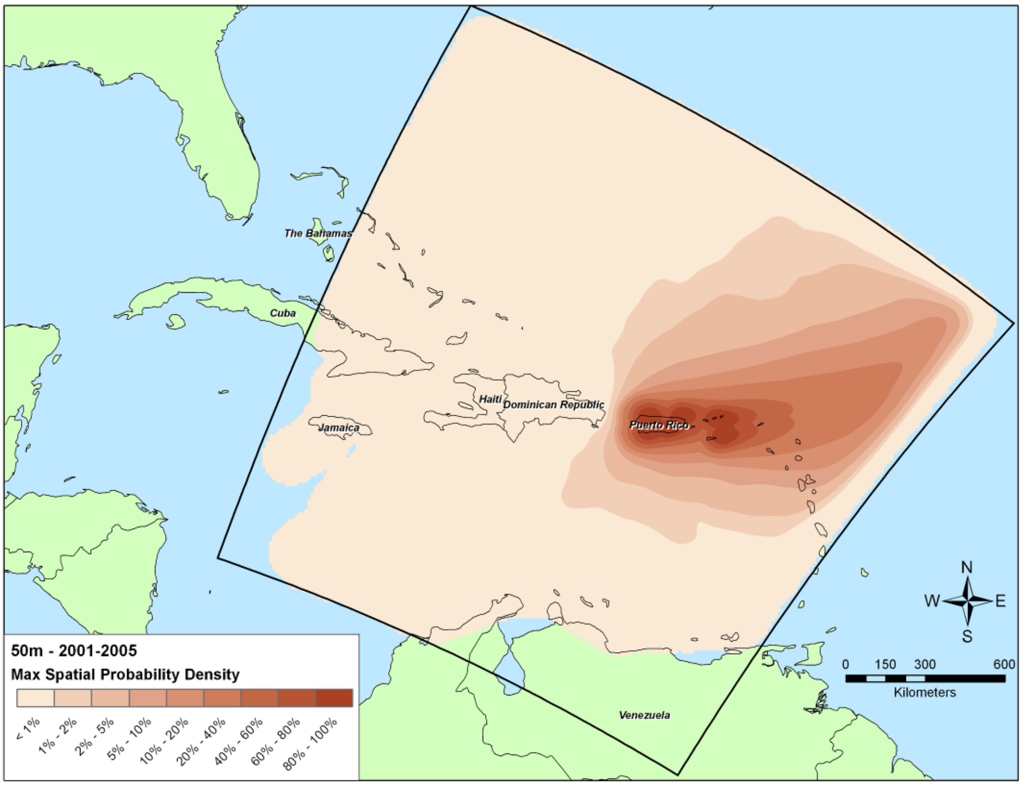

Figure 5-1: Probability that Emissions from Offshore have an Impact on Selected Onshore Sites

[3] Secondary or indirect PM is not included in the inventory. This is because indirect PM is formed in the atmosphere.

Figure 5-1 displays the probability that trajectories originating in a given location offshore would impact any of the onshore receptor sites. The highest probability values (>80%) are clustered within about 75 km of each receptor site. The region with probability values exceeding 20% extends over 200 km east of the Virgin Islands and has a lateral extent (north-south) of greater than 100 km from each monitoring site. Section 6, and specifically Figure 6-2, further illustrate that winds in Puerto Rico and the U.S. Virgin Islands are predominantly from the East but can also range from north-easterly to south-easterly. Analyses indicate that very limited transport occurs from areas west of Puerto Rico. However, dominant easterly flows may transport ship emissions from shipping lanes north and northeast of Puerto Rico and the Virgin Islands to populated areas. Therefore, emissions from ships are contributing to onshore ambient air concentrations of ozone, $PM_{2.5}$, NO_X and SO_X, and haze. The following sections will explain how the islands' populations and ecosystems are being impacted due to their exposure to these air pollutants.

5.3.2 Air Monitoring Data in Puerto Rico and the United States Virgin Islands

Ship emissions are impacting PM, ozone, NO_X, and SO_X levels in Puerto Rico and the U.S. Virgin Islands. This section discusses monitoring data available for Puerto Rico and the U.S. Virgin Islands. The monitoring data includes the significant impact from ship emissions and illustrates that reducing ship emissions would provide benefits through improving air quality, public health and the environment.

In their air-monitoring network, the Puerto Rico Environmental Quality Board (PREQB) operates six continuous $PM_{2.5}$ monitors year-round. The six monitors represent six regions that include all of the main island of Puerto Rico along with Vieques and Culebras. The monitoring sites are located at Caguas, Barceloneta, Vistas del Morro in Cataño, Police Office in Cataño, Magas Arriba in Guayanilla, and Jobos in Guayama. Using air monitoring data from 2006-2008, the San Juan Metropolitan Statistical Area recorded annual average $PM_{2.5}$ levels as high as 7.8 $\mu g/m^3$. Figure 5-2 presents the annual $PM_{2.5}$ design values, using 2006 through 2008 data, for the six monitoring sites. These design values are calculated using the 3-year average of the respective annual averages and are by metropolitan statistical area.[4] It is important to note that scientists have not identified any ambient threshold for particulate matter below which no damage to health is observed. More detail on the public health impacts of PM is contained in section 5.4.

[4] The design value calculation described here is different than the method used by the WHO to calculate the air quality guidelines which are described in Section 3.1.1.

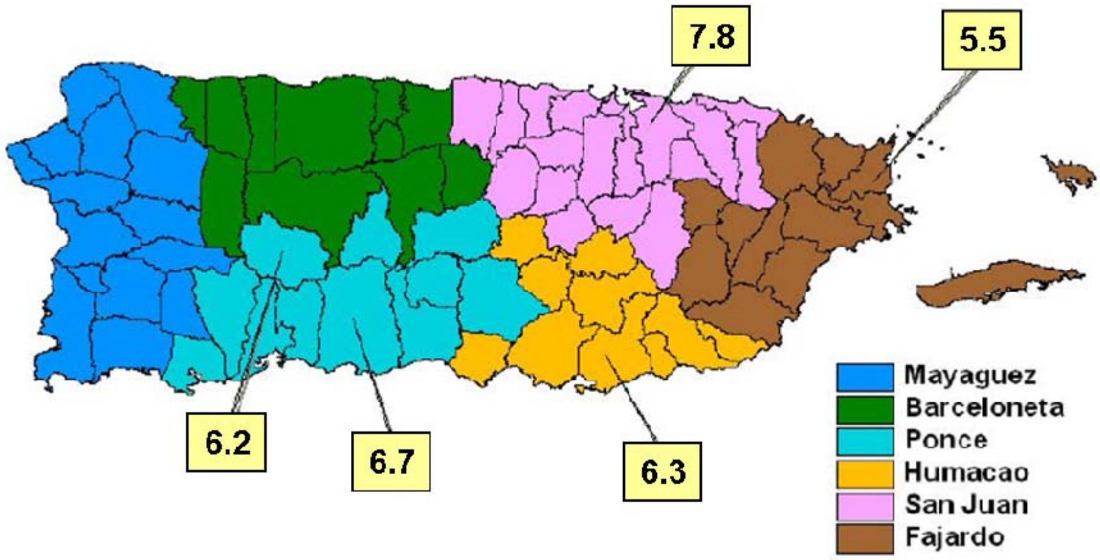

Figure 5-2: Annual Average $PM_{2.5}$ Design Values (2006-2008) for Puerto Rico [$\mu g/m^3$]

Monitoring data are also collected for PM_{10} which includes all particles less than or equal to 10 micrometres in aerodynamic diameter. Guaynabo County, just west of San Juan, was recently re-designated from nonattainment to attainment for PM_{10} (Federal Register, 2010). A nonattainment area is an area that does not meet the national ambient air quality standard (NAAQS) for the pollutant. Although Guaynabo is no longer a nonattainment area, with continuing population and economic growth there will need to be additional efforts to continue to ensure ongoing attainment with the PM_{10} air quality standards. Concurrently to re-designating Guaynabo, the U.S. government accepted their Limited Maintenance Plan. Guaynabo's limited maintenance plan includes contingency provisions that can be promptly put into place to correct any violation of the NAAQS which may occur after re-designation of an area to attainment. The emission reductions from this proposed ECA will help Guaynabo to reduce the likelihood of a violation and the need for the contingency provisions. The ECA designation will also support implementation of certain contingency measures. For example, one contingency measure that would be put into force in the case of a violation would require no visible emissions from ships in San Juan Bay. This contingency measure will be easier to achieve through an ECA because visible emissions are particulate matter and this proposed ECA would reduce ship emissions of particulate matter. In sum, the reductions in ship emissions being proposed in this ECA will help ensure maintenance with the PM standards both in Guaynabo and the rest of Puerto Rico and the U.S. Virgin Islands and provide healthful air quality for the region.

The PREQB operates two ozone sites in the air-monitoring network. One ozone air-monitoring site is deployed at Cataño and the other site is deployed at Juncos municipalities. Both ozone samplers are operated year-round. Ozone design values are calculated by taking the 3-year average of the annual 4th highest daily maximum 8-hour average concentration.[5] Figure 5-3 presents the ozone design values for the two monitoring sites.

[5] The design value calculation described here is different than the method used by the WHO to calculate the air quality guidelines which are described in Section 3.1.2.

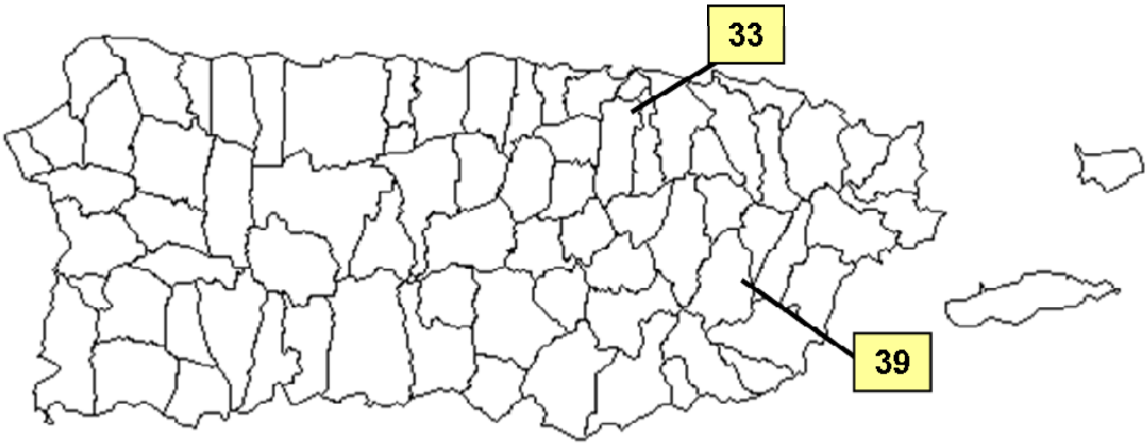

Figure 5-3: 8-hour Ozone Design Values (2006-2008) for Puerto Rico [ppb]

Air quality data is also collected on the U.S. Virgin Islands. The Division of Environmental Protection (DEP), an operating unit of the Department of Planning and Natural Resources, collects PM_{10} and $PM_{2.5}$ data on the U.S. Virgin Islands at St. Croix and St. Thomas. Ozone samples are collected on the island of St. John by the Virgin Islands National Parks. Sulphur dioxide monitoring is conducted on St. Croix. Ambient levels of ozone and PM monitored in the U.S. Virgin Islands have increased slightly in recent years but remain below the NAAQS. The U.S. government recently finished reviewing the NAAQS for SO_2 and a final rule was released on 3 June 2010. The island of St. Croix was listed as one of the locations where monitored SO_2 data (from 2007-2009) was above the SO_2 standard. The monitored SO_2 concentration in St. Croix was 79 ppb and the standard is 75 ppb (U.S. EPA, 2010). Although stationary sources are the major contributor to ambient SO_2 levels, any reductions in SO_2 emissions due to this proposed ECA would be helpful to the Virgin Islands as they work to maintain the standard.

In summary, there are substantial ship emissions in the proposed ECA areas around Puerto Rico and the U.S. Virgin Islands. These emissions from ships contribute to $PM_{2.5}$ and ozone concentrations in Puerto Rico and the U.S. Virgin Islands as well as contributing to concentrations of NO_X and SO_X. As such, it is highly beneficial, from a public and environmental health perspective, to control ship emissions of $PM_{2.5}$, NO_X and SO_X. More detail on the public and environmental health impacts of PM, ozone, NO_X and SO_X is contained in sections 5.4 and 5.5.

5.4 Impacts of Ship Emissions on Human Health

Ships that operate in the proposed ECA generate emissions that increase on-land concentrations of harmful air pollutants such as $PM_{2.5}$, ozone, NO_X and SO_X. Human exposure to these pollutants results in serious health impacts. For more information on the health effects associated with $PM_{2.5}$, ozone, sulphur oxides and nitrogen oxides, see the Technical Support Document prepared for this proposal.

5.4.1 PM Health Effects

Scientific studies show ambient PM (whether emitted directly or formed in the atmosphere) is associated with a series of adverse human health effects. These health effects are discussed in detail in the United States Environmental Protection Agency's (EPA's) Integrated Science Assessment for Particulate Matter (ISA) (U.S. EPA, 2009a). Further discussion of health effects associated with PM can also be found in the Technical

Support Document for the March 2009 Proposal to Designate an Emission Control Area for Nitrogen Oxides, Sulphur Oxides and Particulate Matter (U.S. EPA, 2009b).

The ISA concludes that health effects associated with short-term exposures (hours to days) to ambient $PM_{2.5}$ include cardiovascular effects, such as altered vasomotor function and hospital admissions and emergency department visits for ischemic heart disease and congestive heart failure, and respiratory effects, such as exacerbation of asthma symptoms in children and hospital admissions and emergency department visits for chronic obstructive pulmonary disease (COPD) and respiratory infections. The ISA notes that long-term exposure to $PM_{2.5}$ (months to years) is associated with the development/progression of cardiovascular disease, premature mortality, and respiratory effects, including reduced lung function growth, increased respiratory symptoms, and asthma development. The ISA concludes that the currently available scientific evidence from epidemiologic, controlled human exposure and toxicological studies supports a causal association between short-term and long-term exposures to $PM_{2.5}$ and cardiovascular effects and mortality. Furthermore, the ISA concludes that the collective evidence supports likely causal associations between short-term and long-term $PM_{2.5}$ exposures and respiratory effects. The ISA also concludes that the scientific evidence is suggestive of a causal association for reproductive and developmental effects and cancer, mutagenicity, and genotoxicity and long-term exposure to $PM_{2.5}$.

In addition to the general PM health effects mentioned above, exposure to diesel particulate matter has also been associated with adverse health effects. Marine diesel engines emit diesel exhaust, a complex mixture which includes gaseous compounds and diesel particulate matter (DPM). The DPM present in diesel exhaust consists of fine particles (< 2.5 μm), including a subgroup with a large number of ultrafine particles (< 0.1 μm). These ultrafine particles have a large surface area which makes them an excellent medium for adsorbing organics and their small size makes them highly respirable. Many of the organic compounds present on the particles and in the gases are individually known to have mutagenic and carcinogenic properties. In the United States EPA's 2002 Diesel Health Assessment Document, exposure to diesel exhaust was classified as likely to be carcinogenic to humans by inhalation from environmental exposures, in accordance with the revised draft 1996/1999 U.S. EPA cancer guidelines (U.S. EPA, 2002a). A number of other agencies (National Institute for Occupational Safety and Health, the International Agency for Research on Cancer, the World Health Organization, California EPA, and the U.S. Department of Health and Human Services) have made similar classifications.

Non-cancer health effects of acute and chronic exposure to diesel exhaust emissions are also of concern. Adverse pulmonary effects are well-quantified (Ishinishi *et al.*, 1988), (Heinrich *et al.*, 1995), (Mauderly *et al.*, 1987), (Nikula *et al.*, 1995). In addition to pulmonary effects, acute exposure to diesel exhaust has been associated with irritation of the eye, nose, and throat, respiratory symptoms (cough and phlegm), and neurophysiological symptoms such as headache, light-headedness, nausea, vomiting, and numbness or tingling of the extremities (U.S. EPA, 2002a).

5.4.2 Ozone Health Effects

The human health and welfare effects of ozone are well documented and are assessed in the U.S. EPA's 2006 ozone Air Quality Criteria Document (U.S. EPA, 2006a) and Staff Paper (U.S. EPA, 2007a). People who are more susceptible to effects associated with exposure to ozone can include children, the elderly, and individuals with asthma. Those with greater exposures to ozone, for instance due to time spent outdoors (e.g., children and outdoor workers), are also of particular concern. Ozone can irritate the respiratory system, causing coughing, throat irritation, and breathing discomfort. Ozone can reduce lung function and cause pulmonary inflammation in healthy individuals. Ozone can also aggravate asthma, leading to more asthma attacks that require medical attention and/or the use of additional medication. Thus, ambient ozone may cause both healthy and asthmatic individuals to limit their outdoor activities. In addition, there is suggestive evidence of a contribution of ozone to cardiovascular-related morbidity and highly suggestive evidence that short-term ozone exposure directly or indirectly contributes to non-accidental and cardiopulmonary-related mortality. Short-term exposure to ambient ozone is likely to contribute to premature deaths (NRC, 2008). Animal toxicological evidence indicates that with repeated exposure, ozone can inflame and damage the lining of the lungs, which may lead to permanent changes in lung tissue and irreversible reductions in lung function. The respiratory effects observed in controlled human exposure studies and animal studies are coherent with the evidence from epidemiologic studies, supporting a causal relationship between acute ambient ozone exposures and increased respiratory-related emergency room visits and hospitalizations in the warm season. In addition, there is suggestive evidence of a contribution of ozone to cardiovascular-related morbidity and non-accidental and cardiopulmonary mortality.

5.4.3 SO_2 Health Effects

Information on the health effects of SO_2 can be found in the U.S. EPA's ISA for Sulphur Oxides (US EPA, 2008a). SO_2 has long been known to cause adverse respiratory health effects, particularly among individuals with asthma. Other potentially sensitive groups include children and the elderly. During periods of elevated ventilation, asthmatics may experience symptomatic bronchoconstriction within minutes of exposure. Following an extensive evaluation of health evidence from epidemiologic and laboratory studies, the EPA has concluded that there is a causal relationship between respiratory health effects and short-term exposure to SO_2. Separately, based on an evaluation of the epidemiologic evidence of associations between short-term exposure to SO_2 and mortality, the EPA has concluded that the overall evidence is suggestive of a causal relationship between short-term exposure to SO_2 and mortality.

5.4.4 NO_2 Health Effects

Information on the health effects of NO_2 can be found in the U.S. EPA's ISA for Nitrogen Oxides (US EPA, 2008b). The EPA has concluded that the findings of epidemiologic, controlled human exposure, and animal toxicological studies provide evidence that is sufficient to infer a likely causal relationship between respiratory effects and short-term NO_2 exposure. The ISA concludes that the strongest evidence for such a relationship comes from epidemiologic studies of respiratory effects including symptoms, emergency department visits, and hospital admissions. The ISA also draws two broad conclusions regarding airway responsiveness following NO_2 exposure. First, the ISA concludes that NO_2 exposure may enhance the sensitivity to allergen-induced decrements in lung function and increase the allergen-induced airway inflammatory response following 30-minute exposures of asthmatics to NO_2 concentrations as low as 0.26 ppm. In addition, small but significant increases in non-specific airway hyper-responsiveness were reported following 1-hour exposures of asthmatics to 0.1 ppm NO_2. Second, exposure to NO_2 has been found to enhance the inherent responsiveness of the airway to subsequent nonspecific challenges in controlled human exposure studies of asthmatic subjects. Enhanced airway responsiveness could have important clinical implications for asthmatics since transient increases in airway responsiveness following NO_2 exposure have the potential to increase symptoms and worsen asthma control. Together, the epidemiologic and experimental data sets form a plausible, consistent, and coherent description of a relationship between NO_2 exposures and an array of adverse health effects that range from the onset of respiratory symptoms to hospital admission.

5.4.5 Puerto Rico Asthma Rates

Emissions of NO_X, SO_X and PM from ships contribute to ambient concentrations of NO_X ozone, SO_X and PM. As explained above and in Chapter 2 of the Technical Support Document prepared for this proposal, there are well-established links between ambient concentrations of NO_X ozone, SO_X and PM and asthma. Two studies by the Puerto Rico Department of Health in collaboration with the Puerto Rico Asthma Coalition found a higher asthma mortality rate in Puerto Rico than for the continental United States for the period since 1980 (Bartolomei-Diaz, 2006, Puerto Rico Department of Health, 2008). For the period 1980 to 1998, these researchers found that the asthma mortality rate for Puerto Rico was 2.5 times higher than in the continental U.S. While the Puerto Rican asthma mortality rate experienced a decreasing and then a stable pattern from 2000-2004, it remains about two times higher than that in the continental U.S. for that same time period. The more recent of the two studies also looked at the lifetime asthma prevalence in Puerto Rico, defined as those individuals who at some time in their life have been diagnosed with asthma. This study found the lifetime asthma prevalence rate over the period 2000-2007 to be 1.5 times higher in Puerto Rico than in the continental U.S. The reductions in NO_X, SO_X and PM emissions as a result of this proposed ECA would aid in reducing the prevalence of and mortality from asthma in Puerto Rico. In addition to helping reduce asthma rates, lowering ships emissions of NO_X, SO_X and PM would also have a positive impact on the many other serious health problems detailed in this section and in the Technical Support Document.

5.5 Impacts of Ship Emissions on Ecosystems

In addition to their health impacts, emissions of NO_X, SO_X, and PM from ships are also of concern in Puerto Rico and the U.S. Virgin Islands because they cause harm to ecosystems. These islands are comprised of many highly sensitive ecosystems including wetlands, estuaries, and extensive coral reefs that are already vulnerable and threatened.

Deposition of nitrogen and sulphur compounds cause acidification in both terrestrial and aquatic ecosystems, including the acidification of coastal ocean waters, by altering surface seawater chemistry (Doney, 2007). They also contribute to the problem of excess nutrient enrichment which can lead to eutrophication that promotes increased growth of certain phytoplankton and other marine plants, which may lead to a shift in ecosystems. Emissions from ships can contribute to adverse effects from a variety of pollutants on wetlands, estuaries, coral reefs and other natural protected areas[6] in Puerto Rico and the U.S. Virgin Islands.

Modelling conducted by the U.S. Government in support of the North American ECA shows that if ships maintain their current emissions performance, in 2020 they would be responsible for a significant amount of sulphur and nitrogen deposition along the entire United States coastline (including the East, West and Gulf coasts)-between 10-25% of total deposition of these compounds. Although we are unable to model this relationship for Puerto Rico and the U.S. Virgin Islands, we expect that Puerto Rico and the U.S. Virgin Islands similarly receive ship-related deposition, with contributions of ship-related deposition to total deposition of sulphur and nitrogen compounds being similar to those seen along the United States coastline. Given current technical/modelling limitations, we believe this is a conservative assumption due to the relative contribution of on-land deposition sources in Puerto Rico and the U.S. Virgin Islands versus on-land sources in the United States (the United States has a larger population, more on-road vehicle miles travelled, and more

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6 Defined by the International Union for Conservation of Nature as a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.

stationary and point NO_X and SO_X sources). At current emissions performance, by 2020, ships would have an even larger impact on terrestrial and aquatic ecosystems, including areas of natural productivity and critical habitats throughout these islands. Given the fragile ecosystems found throughout this area, and described in more detail below, reducing ship emissions that contribute to sulphur and nitrogen deposition in both Puerto Rico and the U.S. Virgin Islands is urgent. Adopting the proposed ECA for Puerto Rico and the U.S. Virgin Islands will significantly reduce the annual total sulphur and nitrogen deposition occurring in these sensitive ecosystems and will contribute to the recovery of sensitive ecosystems.

Section 5.5.1, below, describes the protected areas in Puerto Rico and the U.S. Virgin Islands. Section 5.5.2 discusses acid deposition and its impacts on coral reefs in Puerto Rico and the U.S. Virgin Islands. We describe the problems of nutrient enrichment and eutrophication and how that affects the San Juan Bay estuary in section 5.5.3. Finally, we describe the impacts of ship emissions on visibility and ozone in sections 5.5.4 and 5.5.5 respectively.

5.5.1 Protected areas in Puerto Rico and the U.S. Virgin Islands

There are a significant number of natural protected areas in Puerto Rico and the U.S. Virgin Islands. Figure 5-4 and Figure 5-5 depict estuarine wetland, marine wetlands, and natural protected areas in the Unites Stated Puerto Rico and the U.S. Virgin Islands. According to Puerto Rico's Department of Natural Resources, 8.24 % of all land in Puerto Rico is protected. Total estuary protected wet land is 31.80%; 51.49% of coral reefs and 49.24% of sea grasses are protected.

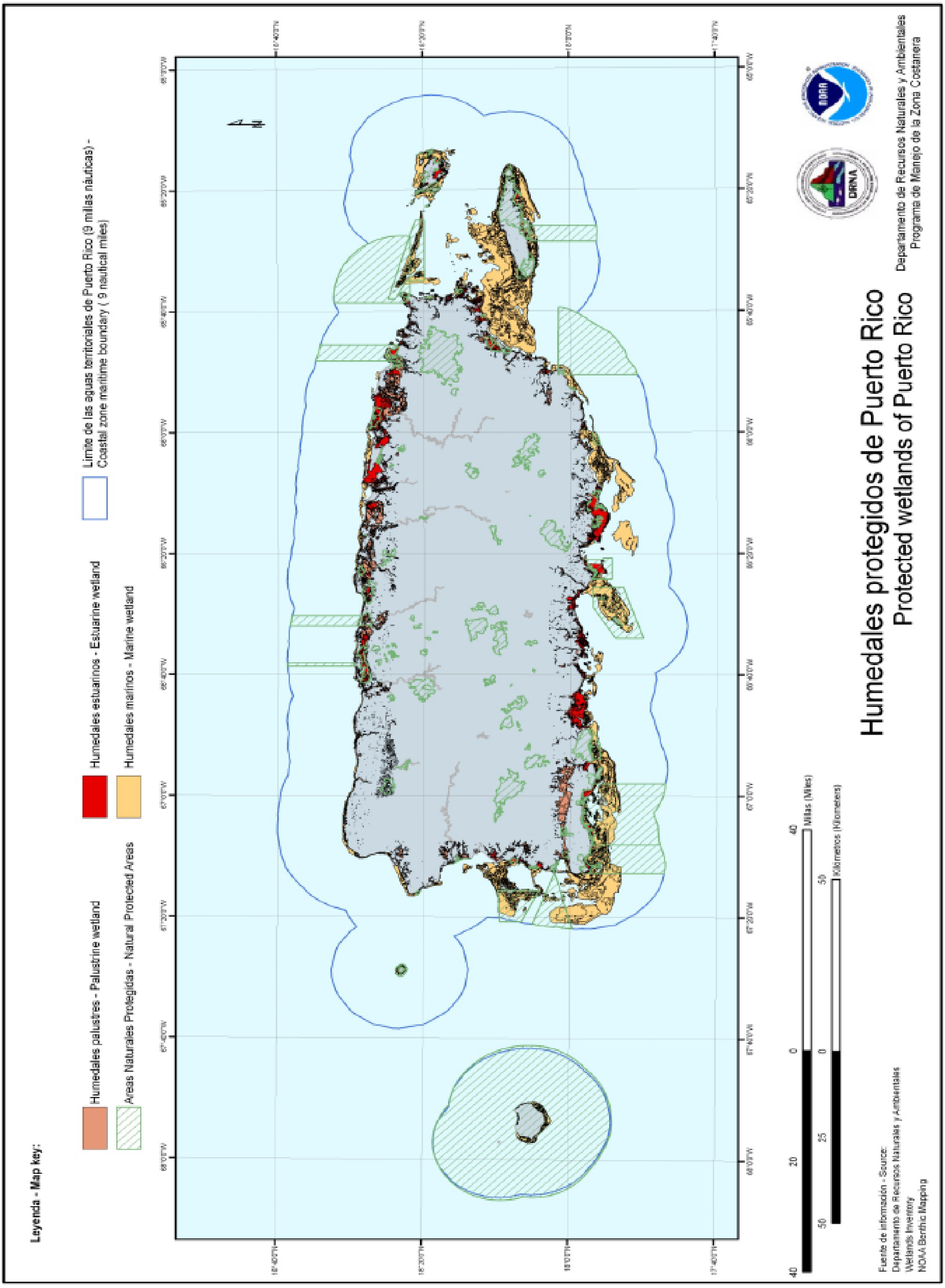

Figure 5-4: Estuary Wetlands, Marine Wetlands, and Natural Protected Areas of Puerto Rico

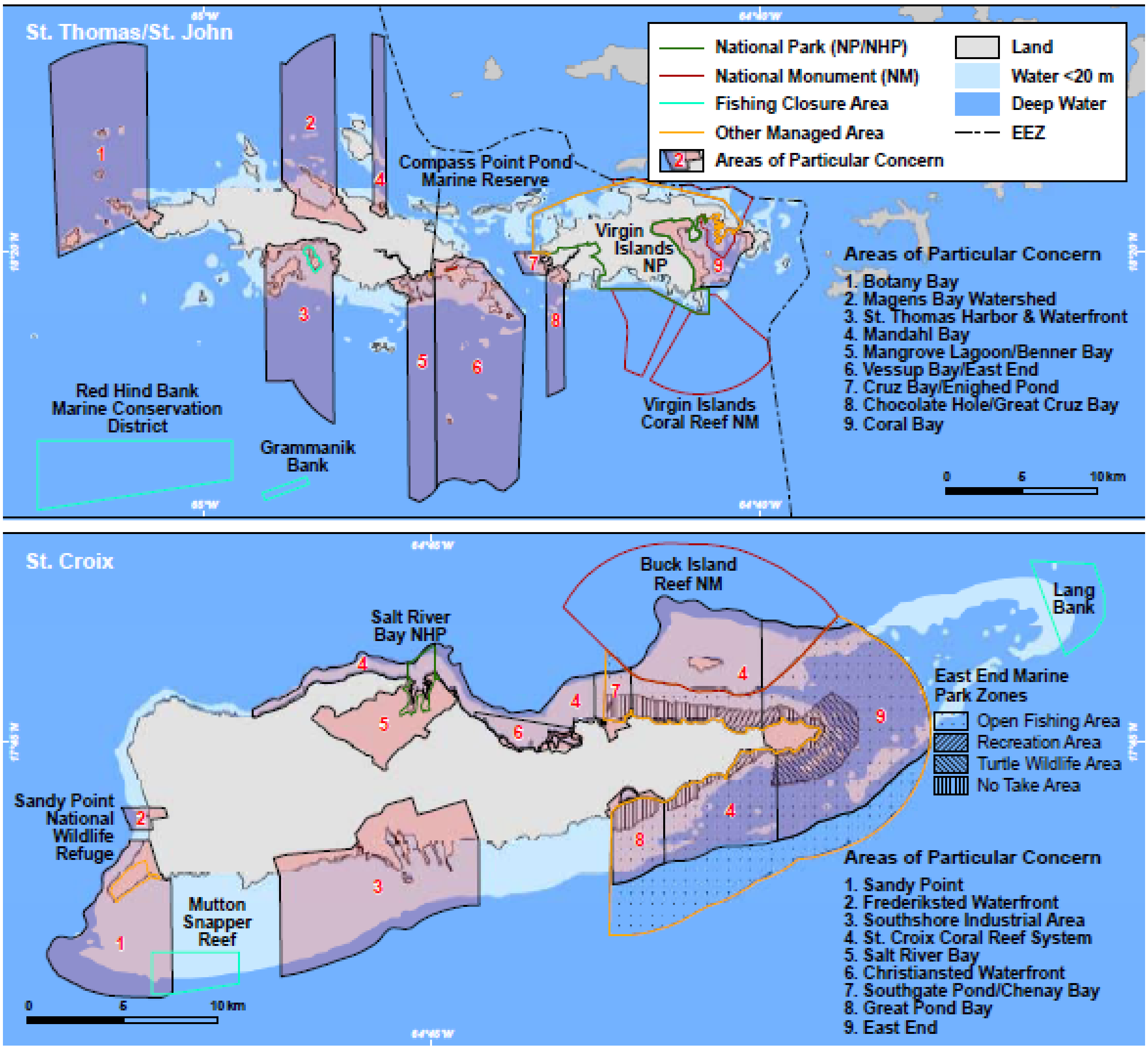

Figure 5-5: Map of U.S. Virgin Islands Showing Managed Protected Areas [a]

Notes:

[a] Developed by the United States National Oceanic and Atmospheric Administration's (NOAA's) Centre for Coastal Monitoring and Assessment, Biogeography Team (CCMA-BT) based on visual interpretation of aerial photography and hyper-spectral imagers. For more information, see: http://biogeo.nos.noaa.gov.

5.5.2 Ecological Impacts of Acid Deposition in Puerto Rico and the U.S. Virgin Islands

Deposition of nitrogen and sulphur causes acidification, which alters biogeochemistry and affects animal and plant life in terrestrial and aquatic ecosystems. Major effects can include a decline in some forest tree species, and a loss of biodiversity of fishes, zooplankton, and macro invertebrates.

In Puerto Rico and the U.S. Virgin Islands, we are mainly concerned with impacts of nitrogen and sulphur deposition on inland forest areas, natural preserves and national parks, mangrove and sea grass areas, estuaries and coral reef ecosystems. The United States is concerned that across Puerto Rico and the U.S. Virgin Islands, sensitive ecosystems are being impacted by deposition resulting from NO_X and SO_X emissions from stationary sources, area sources, and mobile sources, including ships' emissions. While the

United States is taking steps to address these concerns under the Land Based Sources Protocol of the Cartagena Convention (see section 8), additional control of ships is needed.

Acidification of ocean and coastal waters impacts marine organisms that form calcium carbonate ($CaCO_3$) shells such as corals, sea urchins and certain types of plankton by reducing the amount of $CaCO_3$ that is dissolved in sea water. This impedes the growth of any organism that incorporates dissolved $CaCO_3$ to form a shell or a skeleton. These organisms provide critical food sources and habitats that when disrupted could lead to the demise of entire coral reef ecosystems.

5.5.2.1 Acid Wet Deposition in Puerto Rico and the U.S. Virgin Islands

Ambient air quality monitoring data collected from Puerto Rico and the U.S. Virgin Islands between 2002 and 2007 indicate that wet deposition[7] levels of both sulphate and nitrate compounds are significant and elevated, especially for sulphate.[8] In general, wet deposition of nitrates (NO_3) and sulphates (SO_4) is higher in Puerto Rico than in the U.S. Virgin Islands, as can be seen in Table 5-2. The sulphate wet deposition levels recorded in Puerto Rico range from 19 kg/ha per year to 33 kg/ha from 2003 – 2007 and are comparable to areas of the United States which exhibit high levels of sulphate deposition. The nitrate deposition data for Puerto Rico, while not quite as elevated as for sulphates, are comparable to many areas along the U.S. Gulf Coast and South-eastern Atlantic coastal areas. These data indicate that Puerto Rico and the U.S. Virgin Islands are currently exposed to large amounts of nitrogen and sulphur deposition. The major contribution by ships to NO_X and SO_X emission inventories in Puerto Rico and the U.S. Virgin Islands means that ships are the source of a significant portion of nitrogen and sulphur deposition.

Table 5-2: Acid Wet Deposition in Puerto Rico and U.S. Virgin Islands (2002-2007)

	PUERTO RICO		U.S. VIRGIN ISLANDS	
Year	NO_3 (kg/ha)	SO_4 (kg/ha)	NO_3 (kg/ha)	SO_4 (kg/ha)
2007	7	19	3	9
2006	9	31	3	9
2005	X	X	3	10
2004	11	33	2	7
2003	10	28	3	8
2002	X	X	3	8

5.5.2.2 Acidification of Coral reefs

Coral reef ecosystems in Puerto Rico and the U.S. Virgin Islands comprise diverse habitats, including coral reefs, sea grass beds, and mangroves, that host abundant and diverse marine organisms (Rohmann, 2005). These biologically rich ecosystems play an important role in the socio-economic activities of coastal areas. For example, the reef habitats support the valuable fishing and tourism industries. However, the reef habitats are negatively impacted by these industries, including emissions from ships including cruise ships.

[7] Deposition processes can occur in two modes: dry and wet. Precipitation determines the amount and extent of wet deposition of pollutants into ecosystems. Wet deposition occurs when gases (such as NO_X and SO_X) or particles (such as nitrates and sulphates) are 'washed' out of the air by rain, snow, fog, or some other form of precipitation.

[8] The National Atmospheric Deposition Program (NADP)/National Trends Network operated by the University of Illinois (http://nadp.sws.uiuc.edu) serves as the repository for annual data for wet deposition for the entire United States. including Puerto Rico and the U.S. Virgin Islands.

Complex reef ecosystems in Puerto Rico and the U.S. Virgin Islands with significant amount of live coral have experienced steep declines in overall population and in coral species (Waddell and Clarke, 2008). As a result, the percentage of mean live hard coral cover[9] today is no greater than 10%.[10] Increases in CO_2, NO_X and SO_X emissions likely contribute to ocean acidification which results in less available calcium carbonate for shell deposition and growth of marine organisms. If this trend continues it may prevent future coral reef growth altogether and result in the permanent alteration of these important ecosystems.

Coral Reefs in Puerto Rico

Along with the main island of Puerto Rico, there are two uninhabited small islands off the east coast (Culebra and Vieques), and three uninhabited islands (Mona, Monito, Desecheo) off the west coast. Most coral reefs occur on the east, south and west coasts of the main island, with fringing reefs being the most common type. The western two-thirds of the north coast consists of mainly hard ground and reef rock with low to very low coral cover and some small, sparse, low coral colonies. Coral reefs cover approximately 3,370 km^2 within three nautical miles of the coasts. The main islands of Puerto Rico, including Culebra and Vieques, are almost completely encircled by reefs, although coral reef abundance is highly variable, depending on the local conditions. Figure 5-6 shows the distribution of coral reefs in Puerto Rico as developed by NOAA.

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9 Coral cover is a measure of the proportion of reef surface covered by live stony coral instead of sponges, algae, or other organisms.

10 NOAA's Healthy Reefs for Healthy People program defines coral cover levels of 10% or lower as 'red flags' and recognizes a target level of 30% and above for reefs in the Mesoamerican Reef Region (http://healthyreefs.org/healthy-reef-indicators/coral-cover.html).

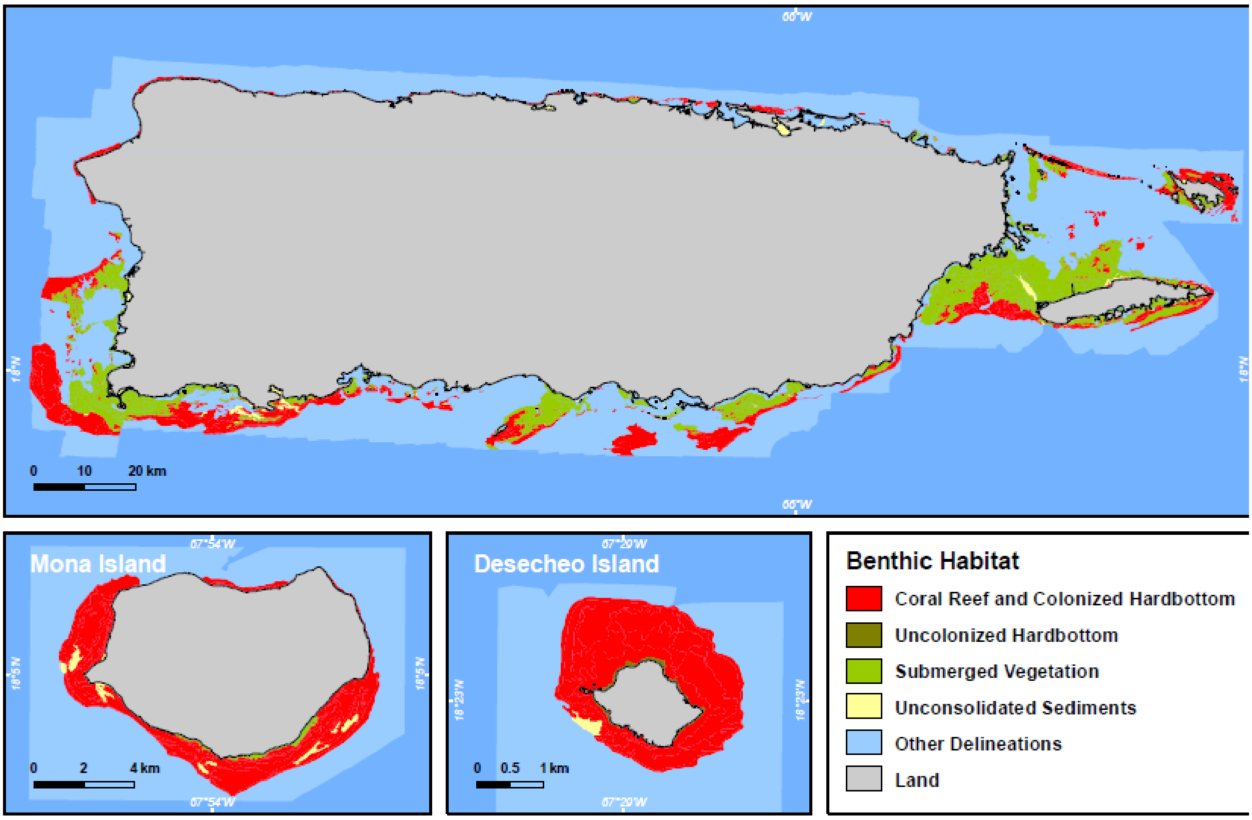

Figure 5-6: Distribution and Extent of Coral Reef Ecosystems in Puerto Rico [a]

Notes:

[a] Map developed by NOAA's Centre for Coastal Monitoring and Assessment, Biogeography Team (CCMA-BT) based on visual interpretation of aerial photography and hyper-spectral imagers. For more information, see: http://biogeo.nos.noaa.gov.

The Puerto Rico Coral Reef Ecosystem Monitoring Program monitors 12 reefs from six Marine Preserve Areas (MPAs), and is sponsored by NOAA and has been administered by Puerto Rico's Department of Natural and Environmental Resources (DNER) since 1999 (Garcia, 2008). The MPAs include reef sites at Isla Desecheo, Rincon, Mayaguez, Guanica, Isla Caja de Muerto, and Ponce. Data from the programme show that the benthic community at some of the reef systems are experiencing decline – including decline in live coral cover as well as a general trend of decline in the abundance of fish populations (statistically significant in seven of the 12 reef stations surveyed).

The declines in the health of key reef-building corals have become a concern to the U.S. Government. In 2004, NOAA received a petition to protect Elkhorn (Acropora palmata), Staghorn (A. cervicornis) and fused Staghorn (A. prolifera) corals under the Endangered Species Act (ESA) of 1973, as amended. NOAA found that petition had merit and convened a Biological Review Team (BRT) to review the status of these species. Based on the results of the status review, in 2006 NOAA's National Marine Fisheries Service issued a final rule listing Elkhorn and Staghorn corals as threatened throughout their known range.

Coral Reefs in the U.S. Virgin Islands

In the U.S. Virgin Islands, coral reefs occur around all the major islands of St. Croix, St. John, and St. Thomas, as well as the offshore bays, as depicted in Figure 5-7. Fringing reefs, deep reefs (wall and shelf-edge), patch reefs, and spur and groove formations are present, although only St. Croix has barrier reefs. Bank reefs and scattered patch reefs with high coral diversity occur deeper offshore. The U.S. Departments of Interior, and Commerce, and the Virgin Islands Government have jurisdiction over submerged lands with coral reefs within the U.S. Virgin Islands. In 2001, NOAA completed maps of U.S. Virgin Islands coral reefs and associated ecosystems to a depth of 20 m. Of the 485 km^2, 61% consisted of coral reefs and hard-bottom habitats[11], 33% were sea grass beds (labelled as submerged vegetation), and the rest was sand or rock.

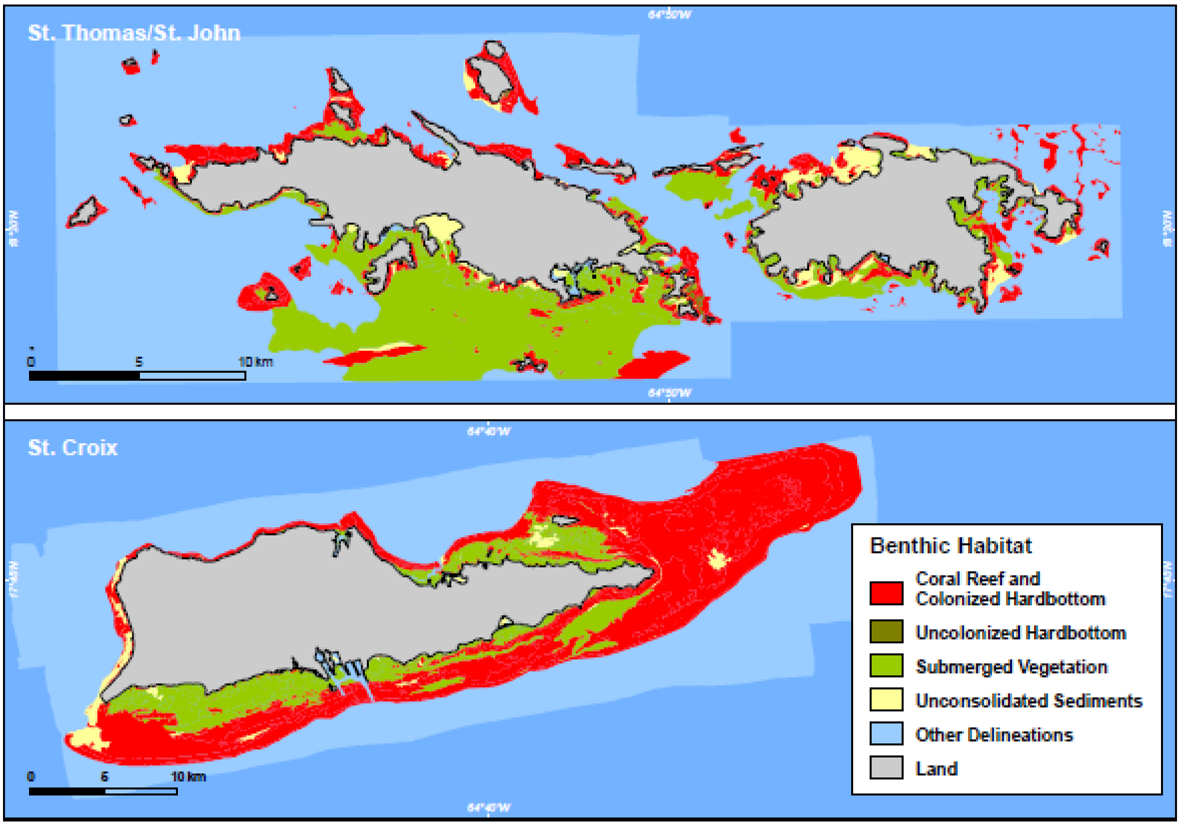

Figure 5-7: Benthic Habitat Maps[a] – Distribution and Extent of Coral Reef Ecosystems in U.S. Virgin Islands (Rothenberger, 2008)

Notes:

a Near shore benthic habitat maps were developed by NOAA's Centre for Coastal Monitoring and Assessment, Biogeography Team (CCMA-BT) based on visual interpretation of aerial photography and hyper-spectral imagers. For more information, see: http://biogeo.nos.noaa.gov.

Coral reefs in the U.S. Virgin Islands have changed dramatically in the last three decades. Insights into these changes come from long-term monitoring of sites ranging in depth from sea level to 40 m. Live coral cover has declined; coral diseases have become more numerous and prevalent; macroalgal cover has increased; fish of some species are smaller, less numerous or only rarely seen; and the long spined black sea urchins *Diadema antillarum* are less abundant. Coral cover has declined on most if not all reefs in the

[11] Sonar technology was used to generate the benthic habitat maps in Figures 5-6 and 5-7 and does not distinguish whether or not coral reefs exist on hard-bottom substrate; nor does it distinguish live coral from denuded skeleton. Hard-bottom substrate does not necessarily have corals on it nor does a reef necessarily exist where hard-bottom substrate exists. Hard-bottom is the only substrate where coral reefs might exist (but don't necessarily exist).

U.S. Virgin Islands for which there are quantitative data. In the 1970s and 1980s coral cover on some reefs was over 40% and even higher in some shallow Elkhorn coral zones (Gladfelter *et al.* 1977, Gladfelter 1982, Rogers *et al.* 1983, Edmunds 2002). By the 1990s, many long-term monitoring sites had coral cover of about 25% or less, and macroalgal cover, although variable, often reached much higher values than in the past. Coral cover continued to decline or remain stable until the major 2005 bleaching /disease event.[12] Now coral cover is less than 12% on many reefs, including five long term study sites in St. John and St. Croix covering over 10 ha of reefs that formerly had high coral cover and diversity.

5.5.3 Ecological Impacts of Nitrogen Enrichment in Puerto Rico and the U.S. Virgin Islands

In addition to the role nitrogen deposition plays in acidification, it also causes ecosystem nutrient enrichment which can lead to eutrophication that alters biogeochemical cycles and harms animal and plant life and alters biodiversity of terrestrial ecosystems. Nitrogen deposition can contribute to eutrophication of estuaries and coastal waters which result in toxic algal blooms and fish kills. Ecosystems may be impacted by nitrogen deposition rates as low as 2 kg N/ha/yr (US EPA, 2008c). The significant contribution by ships to emission inventories in Puerto Rico and the U.S. Virgin Islands means that these ships also have a significant contribution to nitrogen deposition levels which can contribute to eutrophication.

The San Juan Bay Estuary, located on the north-eastern side of Puerto Rico, is semi-enclosed by the surrounding mainland, mangroves, and wetlands and is linked to the Atlantic Ocean by a series of interconnected bays, channels, and lagoons. The limited flushing capacity and low tidal range of this estuarine system makes the San Juan Bay Estuary susceptible to the impacts of deposition including the retention of toxic pollutants (US EPA, 2007b). Figure 5-8 shows the extent of the San Juan Bay Estuary. The Estuary has served as a centre of commerce and shipping in the Caribbean and is currently a centre for commercial and recreational fisheries and recreational activities for this highly urbanized area.

[12] Coral bleaching is associated with a variety of stresses including increased sea surface temperatures. This causes the coral to expel symbiotic micro-algae living in their tissues – algae that provide corals with food. Losing their algae leaves coral tissues devoid of color, and thus appearing to be bleached. Prolonged coral bleaching (over a week) can lead to coral death and the subsequent loss of coral reef habitats for a range of marine life. August 2005 saw the beginning of a record-breaking coral bleaching event throughout the Caribbean region. The U.S. Virgin Islands were hit particularly hard: up to 95 per cent of the corals bleached, and some areas saw 40 per cent of the coral area killed.

Figure 5-8: Extent of San Juan Bay Estuary Program Study Area [a]

Notes:

[a] U.S EPA National Estuary Program Coastal Condition Report 2006.Chapter 7: Puerto Rico: San Juan Bay Estuary Partnership coastal Condition. June 2007. pp 385-400.

In 2002, the U.S. EPA conducted a comprehensive biological and chemical assessment of sediment throughout the San Juan Bay Estuary (US EPA, 2002b). In addition, the U.S. EPA conducted independent fish tissue contaminants surveys in the San Jose Lagoon, a coastal lagoon within the San Juan Bay Estuary System. Based on data collected during these efforts, the overall condition of the estuary is rated as poor. Figure 5-9 shows the per cent of estuarine area rated good, fair, and poor. The most common and widespread impairment to the estuary's waters is nutrient enrichment, which is caused by excess nitrogen and can lead to eutrophication. The significant contribution by ships to emission inventories in Puerto Rico and the U.S. Virgin Islands means that these ships also have a significant contribution to nitrogen deposition levels and nutrient enrichment, which can contribute to eutrophication.

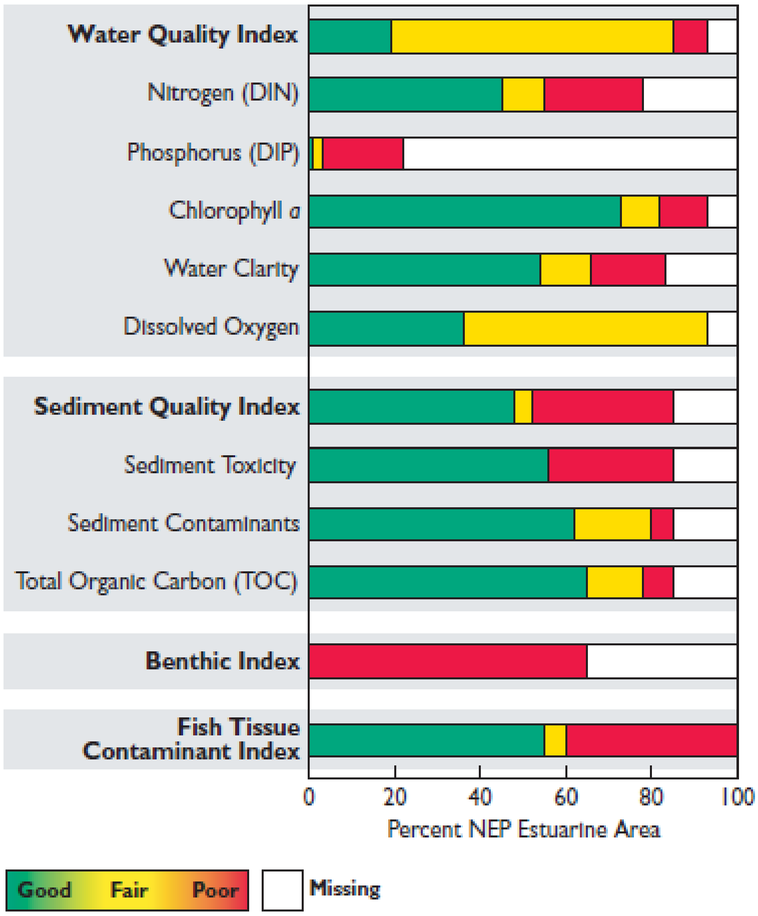

Figure 5-9: Percentage of San Juan Bay Estuary area achieving each ranking for all indices and component indicators [a]

Notes:

[a] U.S. EPA National Estuary Program Coastal Condition Report 2006. Chapter 7: Puerto Rico: San Juan Bay Estuary Partnership Coastal Condition. June 2007, pp 385-400.

5.5.4 Visibility in Puerto Rico and the U.S. Virgin Islands

Good visibility increases the quality of life where individuals live and work, and where they engage in recreational activities. Airborne particles degrade visibility by scattering and absorbing light. Ship emissions of primary NO_X, SO_X and $PM_{2.5}$ (which contribute to the formation of secondary $PM_{2.5}$) contribute to poor visibility in Puerto Rico and the U.S. Virgin Islands.

The U.S. Government places special emphasis on protecting visibility in national parks and wilderness areas. Section 169 of the Clean Air Act requires the U.S. Government to address existing visibility impairment and future visibility impairment in the 156 national parks and wilderness areas which are categorized as Mandatory Class I Federal areas. Virgin Islands National Park is a Mandatory Class I Federal area. The national park covers over 5,900 hectares, approximately 60% of the island of Saint John in the U.S. Virgin Islands, plus a few isolated sites on the neighbouring island of St. Thomas.

Studies done for the continental U.S. have shown that ship emissions contribute to sulphate particles, which degrade visibility in Mandatory Class I Federal areas. For instance, one study concluded that shipping and port emissions from the Pacific Coast showed significant contributions to atmospheric sulphate concentrations over large areas of the western U.S. and that reducing those emissions is important in controlling haze at Mandatory Class I Federal areas (Xu *et al*., 2006).

The emissions reductions associated with this proposed ECA would improve visibility in Puerto Rico and the U.S. Virgin Islands as a whole, as well as in sensitive areas such as the Virgin Islands National Park.

5.5.5 Ecological Impacts of Ozone in Puerto Rico and the U.S. Virgin Islands

Elevated ozone levels contribute to environmental effects, with impacts to plants and ecosystems being of most concern. Ozone can produce both acute and chronic injury in sensitive species depending on the concentration level and the duration of the exposure. Ozone effects also tend to accumulate over the growing season of the plant, so that even low concentrations experienced for a longer duration have the potential to create chronic stress on vegetation. Ozone damage to plants includes visible injury to leaves and impaired photosynthesis, both of which can lead to reduced plant growth and reproduction, resulting in reduced crop yields, forestry production, and use of sensitive ornamentals in landscaping. In addition, the impairment of photosynthesis, the process by which the plant makes carbohydrates (its source of energy and food), can lead to a subsequent reduction in root growth and carbohydrate storage below ground, resulting in other, more subtle plant and ecosystems impacts.

These latter impacts include increased susceptibility of plants to insect attack, disease, harsh weather, interspecies competition and overall decreased plant vigour. The adverse effects of ozone on forest and other natural vegetation can potentially lead to species shifts and loss from the affected ecosystems, resulting in a loss or reduction in associated ecosystem goods and services. Lastly, visible ozone injury to leaves can result in a loss of aesthetic value in areas of special scenic significance like national parks and wilderness areas. The emissions reductions associated with this proposed ECA would improve ozone in Puerto Rico and the U.S. Virgin Islands. The final 2006 Ozone Air Quality Criteria Document presents more detailed information on ozone effects on vegetation and ecosystems.

5.6 Benefits

As described in section 5.3 and section 6, ships subject to the proposed ECA generate emissions that result in elevated on-land concentrations of harmful air pollutants such as $PM_{2.5}$ and ozone, as well as NO_X and SO_X. Human exposure to these pollutants, as described in section 5.4, results in serious health impacts, such as lung cancer, premature mortality, aggravation of respiratory and cardiovascular disease, aggravated asthma, acute respiratory symptoms, chronic bronchitis, decreased lung function, and increased risk of myocardial infarction.[13] These pollutants also result in serious impacts on ecosystems, visibility, and materials damage and soiling. The human health and environmental effects from these pollutants are substantial, and ocean-going vessels are significant contributors to these pollutants through their emissions. Pollutants emitted in ports and along

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[13] The causal association between health and environmental effects and exposure to PM and SO_x is also documented in the IMO Note by the Secretariat, "Input from the four subgroups and individual experts to the final report of the Informal Cross Government/Industry Scientific Group of Experts," BLG 12/INF.10, 28 December 2007, pp. 122-131.

highly-populated coastal areas subject to significant marine traffic contribute to poor air quality in the areas in which they occur and also in inland areas due to emissions transport associated with prevailing meteorological conditions.

The NO_X, SO_X and PM reductions associated with compliance with the ECA engine requirements and fuel sulphur limits would reduce the burden of ill-health for humans and detrimental effects on the environment that occur as a result of exposure to ship emissions. These benefits would accrue not only to areas located within the boundary of the proposed ECA but also to areas that are downwind, which would also see reduced ship emissions. In addition, the proposed ECA would aid Puerto Rico and the U.S. Virgin Islands achieve or maintain compliance with local and federal air quality standards.

These health and environmental benefits are expected to be substantial. An article published by the American Chemical Society journal *Environmental Science & Technology* linked PM-related emissions from diesel-powered ocean-going vessels to annual cardiopulmonary and lung cancer deaths. The study estimated that the number of people dying from heart and lung disease globally as a result of under-regulated shipping emissions totalled 60,000 in 2002, and that the death toll was estimated to grow by 40 per cent by 2012 due to continued large increase in global shipping traffic (Corbett *et al.*, 2007).

In addition, the analysis for the recently adopted North American Emission Control Area demonstrated that controlling ship-related emissions will improve human health in the form of avoided premature deaths and other serious human health effects, as well as other important public health and environmental effects (U.S. EPA, 2009b). Improving ship emissions to ECA standards in the North American ECA is estimated to avoid between 3,700 and 8,300 premature deaths in 2020.[14] Improving ship emissions to ECA standards will also result in the avoidance of 3,500 cases of chronic bronchitis, 5,600 hospital admissions and emergency room visits, 9,300 cases of acute bronchitis, and 3,400,000 days of restricted physical activity. While the benefits to Puerto Rico and the U.S. Virgin Islands are not expected to be this large, both because the area and affected populations are significantly smaller, the reduction in ship-related NO_X, SO_X and PM emissions will substantially reduce the health and environmental risks posed by exposure to poor air quality in these areas.

Both the analysis of the North American ECA and the Corbett study share a common approach to estimating human health benefits. They first estimate the air quality changes associated with emission reductions using a photochemical grid model (such as the Community Multiscale Air Quality Model) and then apply health effect and economic valuation coefficients (derived from peer-reviewed epidemiological and economic studies) to estimate the benefits of an incremental change in air quality. The strength of this approach is that it can provide a refined estimate of the health benefits of a given reduction in pollutant emissions. However, this approach is limited by regional data availability. For the analysis of the proposed ECA, these tools were not available for the Caribbean region to estimate improvements in ambient air quality, and the associated health and environmental benefits, related to emission reductions from ocean-going vessels. However, the ship-related

14 Note that the health impact estimates discussed here are taken directly from the North American ECA document (MEPC 59/6/5). However, between the submission of that document to IMO in April 2009, and the publication of the related final U.S. regulations to control emissions from ocean-going vessels in April 2010, the U.S. EPA updated its assumption about the presence of a health-related threshold in the PM-related concentration-response functions (at 10 $\mu g/m^3$) below which there are no associations between exposure to $PM_{2.5}$ and health impacts. Based on a thorough review of the body of scientific literature, EPA revised its health impact estimation approach to assume that such a threshold does not exist and that a no-threshold model that calculates incremental health impacts down to the lowest modelled $PM_{2.5}$ air quality levels was appropriate. This updated assumption increased U.S. estimates of PM-related premature mortality related to the ECA by approximately 60 to 70 per cent in 2020.

reduction in emissions of the magnitude expected from the proposed ECA will contribute to improvements in air quality over land and will result in health and environmental benefits that, if quantified, have the potential to be substantial.

5.7 Summary

The material presented in this section 5 demonstrates that emissions from ships operating in the proposed ECA are contributing to adverse impacts on human health and the environment. The sources of relevant data and methodologies used have been identified. Where the reader seeks additional details beyond what is described here, the Technical Support Document is available for reference. Thus, this proposal for an ECA fulfils each portion of Criterion 3.1.4 of MARPOL Annex VI, Appendix III.

6 Role of Meteorological Conditions in Influencing Air Pollution

Criterion 3.1.5 *The proposal shall include relevant information pertaining to the meteorological conditions in the proposed area of application to the human populations and environmental areas at risk, in particular prevailing wind patterns, or to topographical, geological, oceanographic, morphological, or other conditions that contribute to ambient concentrations of air pollution or adverse environmental impacts.*

The Commonwealth of Puerto Rico and the U.S. Virgin Islands are located in an area of considerable shipping activity. In addition to those ships that enter local ports, ships voyaging from Europe, Africa and Asia through the Panama Canal, and to and from other countries in the Caribbean and Americas operate in passages to the east and west of these islands. This section outlines the role of meteorology in influencing how emissions from ships affect ambient air concentrations over Puerto Rico and the U.S. Virgin Islands.

Once air pollution has been emitted into the atmosphere, the processes that determine pollutant concentrations in space and time (i.e. advection, diffusion/dilution, deposition, and chemical transformation) are largely determined by meteorology. Day-to-day and hourly variations in air pollutant concentrations are often dependent on weather features that range in size from the synoptic scale (1,000 km) to the local scale (1-100 km). The relative importance of the different meteorological scales depends on the pollutant's atmospheric lifetime. Pollutants that are highly reactive (e.g., nitric oxide, some volatile organic compounds) will not travel far and thus it is only necessary to consider local scale phenomena in determining their fate. Other pollutants (e.g., black carbon, ozone, sulphur dioxide, and particulate sulphates and nitrates) have been demonstrated to persist for longer times (5-10 days) before being significantly dispersed, deposited, or converted to other species (Clarke *et al.*, 2001; Karamchandani *et al.*, 2006). While meteorological phenomena of all sizes affect the eventual impacts of ship emissions, the longer range regional transport of pollutants from shipping is largely dictated by large scale meteorological patterns.

Prevailing wind patterns have an important role in the eventual fate of emissions from ships. While there can be exceptions on individual days and at individual locations, the portion of the Caribbean Sea included in the proposed ECA is within the easterly trade winds. In Puerto Rico, wind speeds are generally in the range of 5 to 15 knots (nautical miles per hour) during the day and less than 5 knots at night. Due to the smaller land masses, wind speeds for the U.S. Virgin Islands are slightly higher. Figure 6-1 presents a wind barb diagram, which represents typical wind conditions in and around Puerto Rico and the U.S. Virgin Islands (NOAA, 2009a). The barbs point in the direction that the wind is coming from, while the tips denote wind speed. In the snapshot of wind speed shown in Figure 6-1, the wind is moving from east to west.

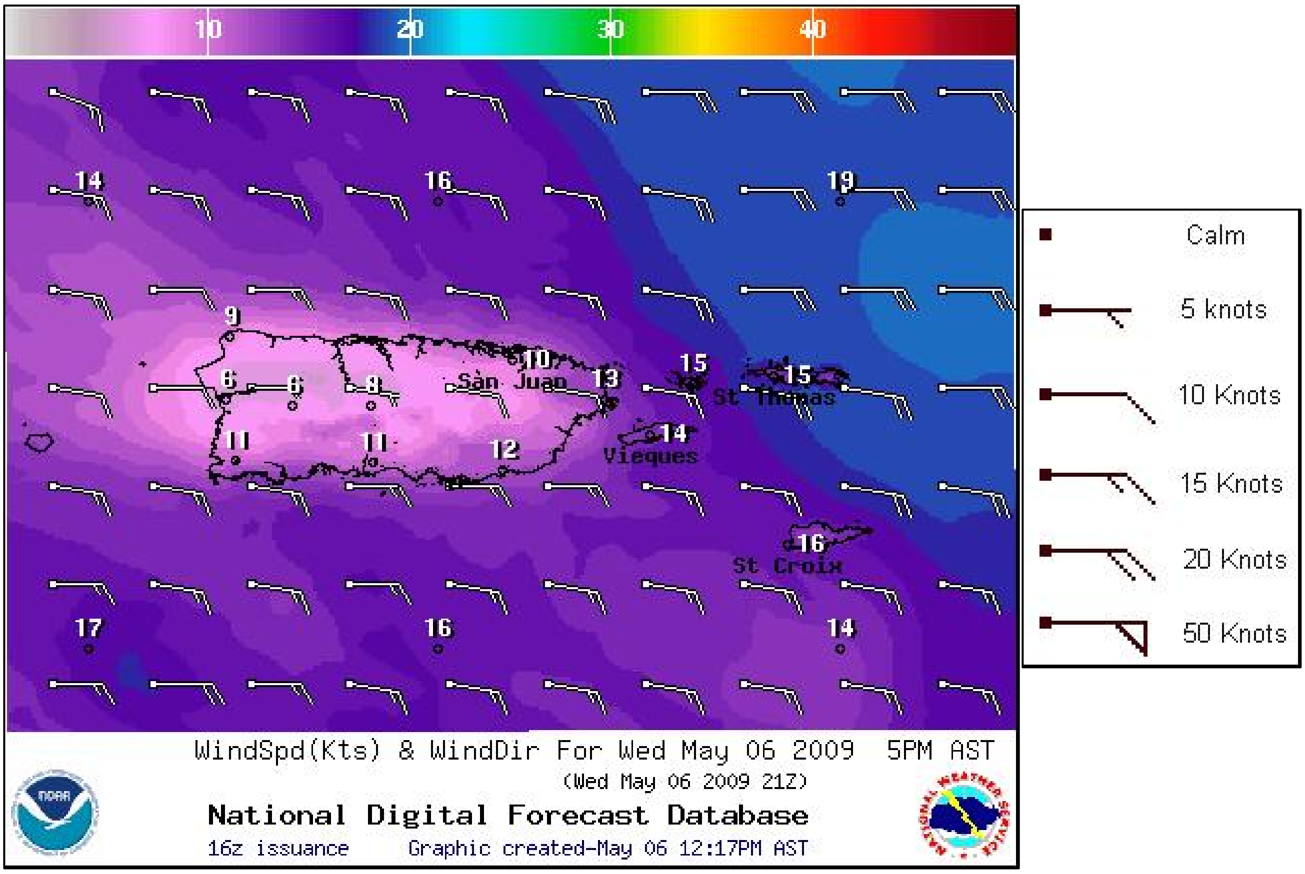

Figure 6-1: Wind Barbs Showing Typical Wind Conditions for Puerto Rico and the U.S. Virgin Islands

In addition to the general observations about wind patterns described above, we can use wind rose diagrams to describe how meteorology affects the transport of air pollutants closer to shore. A wind rose is a graphic tool used by meteorologists to give a succinct view of how wind speed and direction are typically distributed at a particular location. Figure 6-2 presents wind rose diagrams for six different locations within the proposed ECA (NOAA, 2009b). These wind rose diagrams show a distribution of wind speed and direction over the period from 1973 to 2004. The length of the bars represents the frequency that wind has been recorded from that direction. Distribution of wind speed is denoted by colour. Note that Figure 6-2 presents wind rose diagrams for March only. Due to the consistent nature of the trade winds, similar results are seen in other months. Although the trade winds are fairly consistent, some fluctuation in wind direction is observed in Puerto Rico and the U.S. Virgin Islands. Typical winds range from north easterly to south easterly, with infrequent movement of air masses from the west. The one exception is Mayaguez, on the western coast of Puerto Rico, which experiences a much higher frequency of westerly winds. This is primarily due to the effect of the central mountains on air flow around the island.

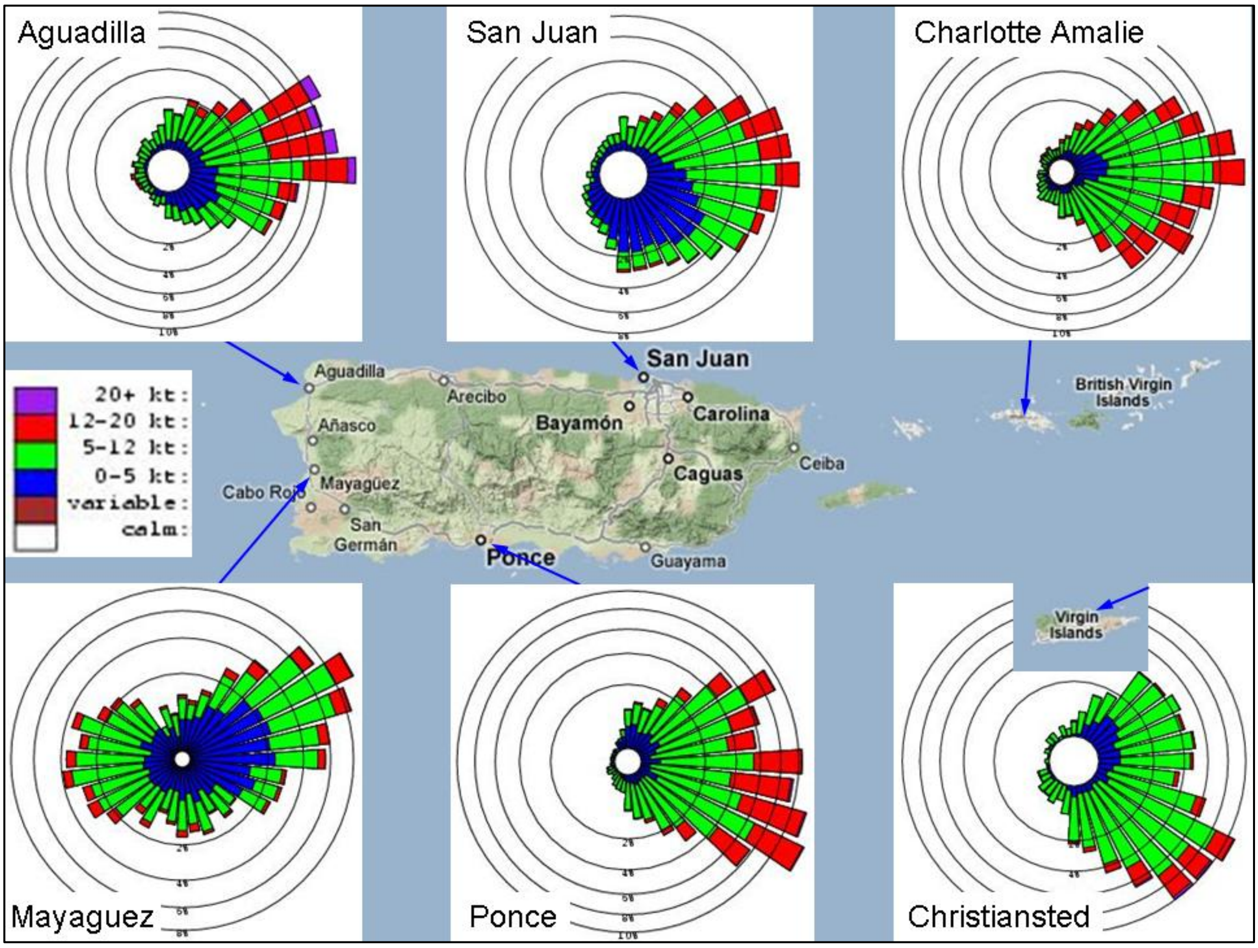

Figure 6-2: March Wind Rose Distributions of Wind Speed and Direction; 1973-2004

In addition to prevailing winds, atmospheric stability also affects land-based impacts from ship plumes. The stability of the atmosphere into which emissions are injected can determine how much vertical dilution can occur along the transport path. Prospero and Carlson (1972) used field study data to identify a sharp temperature inversion at around 1,500 metres over the western equatorial North Atlantic. When ship emissions are injected into this relatively shallow boundary layer, concentrated plumes can be maintained for long distances. This marine inversion limits the vertical dilution of ship emissions until they make landfall.

The last key meteorological element that is particularly relevant to any consideration of shipping emissions on human health and ecosystems is deposition. Deposition processes can occur in two modes: dry and wet. Precipitation determines the amount and extent of wet deposition of pollutants into ecosystems. Wet deposition occurs when gases or particles are 'washed' out of the air by rain, snow, fog, or some other form of precipitation. The amount of precipitation over the Caribbean Sea varies by location and season depending upon synoptic meteorological patterns. Most of the rainfall that occurs in Puerto Rico and the U.S. Virgin Islands is associated with easterly waves. Easterly waves are an elongated area of relatively low air pressure, oriented north to south, which move from east to west across the tropics causing areas of cloudiness and thunderstorms. In between these easterly waves, the meteorology is generally characterized by high pressure systems. These conditions inhibit the removal of particulates from the atmosphere via deposition until they reach shore. It is well-established that Puerto Rico and the U.S. Virgin Islands can receive significant deposition of fine particulate Saharan dust during the late Spring through early fall (Schlatter, 1995; Goudie and Middleton, 2001) in between easterly waves. These particles are transported within the stable Saharan layer (1.5 km above the surface) and can settle to the surface in locations far downwind from their origin. Similarly, it is believed that a large fraction of emissions from ocean-going vessels are also transported on-shore in these locations, prior to removal by dilution, deposition, or chemical transformation.

The proximity of the populations of Puerto Rico and the U.S. Virgin Islands to the coast and the nearness of shipping activity lead to the conclusion that populations on these islands would be adversely impacted by air pollution originating from ships. As shown in section 7, there is shipping activity on all sides of Puerto Rico and the U.S. Virgin Islands. Therefore, regardless of which way the wind blows, there is a high potential for ship emissions to affect air pollution over land.

In summary, meteorological conditions in Puerto Rico and the U.S. Virgin Islands ensure that a significant portion of at-sea emissions are transported to the area, and emissions that occur in port or coastal areas remain in the area, where they contribute to harmful human health and ecological impacts. Thus, this proposal for an ECA fulfils Criterion 3.1.5 of MARPOL Annex VI, Appendix III.

7 Shipping Traffic in the Proposed Area

Criterion 3.1.6 *The proposal shall include the nature of the ship traffic in the proposed Emission Control Area, including the patterns and density of such traffic.*

7.1 Ship Traffic Patterns

To understand the nature of shipping traffic occurring around the Commonwealth of Puerto Rico and the U.S. Virgin Islands, we first evaluated vessel activity. This was done using a spatial allocation approach based on using a composite of two datasets, the International Comprehensive Ocean-Atmosphere data set (ICOADS), which is the world's largest data set for global marine surface observations, and the Automated Mutual-assistance Vessel Rescue System data set (AMVER), which is a voluntary global ship reporting system. Individual ship positions from the merged ICOADS & AMVER dataset for 2000-2002 are shown in Figure 7-1 (Wang *et al.*, 2007). In this figure, Puerto Rico and the U.S. Virgin Islands are highlighted in red.

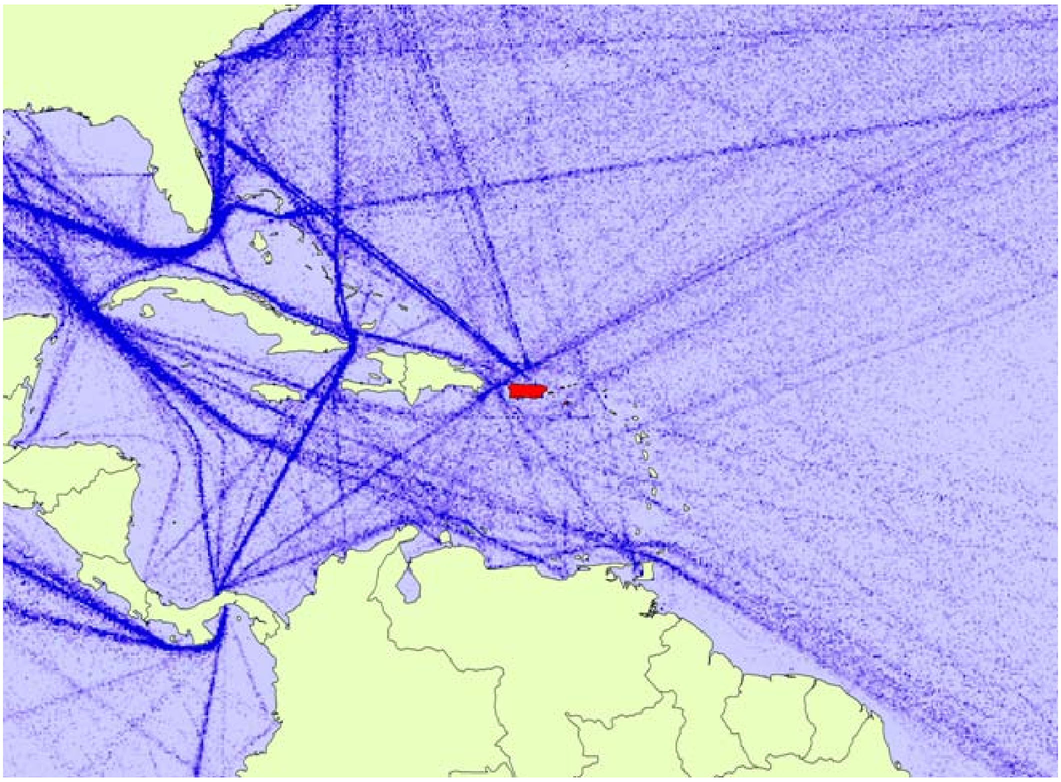

Figure 7-1: ICOADS and AMVER Ship Position Data for 2000-2002

The map in Figure 7-1 shows that ship traffic is present all around Puerto Rico and the U.S. Virgin Islands, with a particularly dense line of activity passing between Puerto Rico and the Dominican Republic. There is also heavy ship traffic between Jacksonville, Florida and Puerto Rico, and between Houston, Texas and Puerto Rico, as well as traffic to and from the Panama Canal.

To provide additional clarity, this positional data is used to estimate ship traffic patterns, density, activity and emissions in the area surrounding Puerto Rico and the U.S. Virgin Islands. This is done by aggregating the data using the Ship Traffic, Energy, and Environment Model (STEEM). In STEEM the spatial distribution of ship reporting frequencies is assumed to represent the distribution of ship traffic intensity, and emissions are proportional to intensity of activity. The model then creates shipping lanes, which are a statistical representation of the pathways commonly used by ships (Wang *et al.*, 2007). All ships in the positional database are located on a lane, and each lane's width is a product of ship traffic intensity and navigational constraints. These data are used to produce emission estimates.

Traffic density and patterns can be observed from STEEM output. A higher level of emissions indicates higher anticipated ship traffic in an area. CO_2 emissions, which are directly proportional to engine power and fuel consumption, are shown in Figure 7-2. These estimates are for 2002; the estimates would be expected to be higher for 2020 due to growth in ship activity generally and due to the opening of the expanded Panama Canal in 2014. These CO_2 emission traces also illustrate the statistically most likely paths for ships to take as they travel between ports. The shipping patterns illustrated in Figure 7-2 provide the foundation for the underway emissions inventory described in section 5.

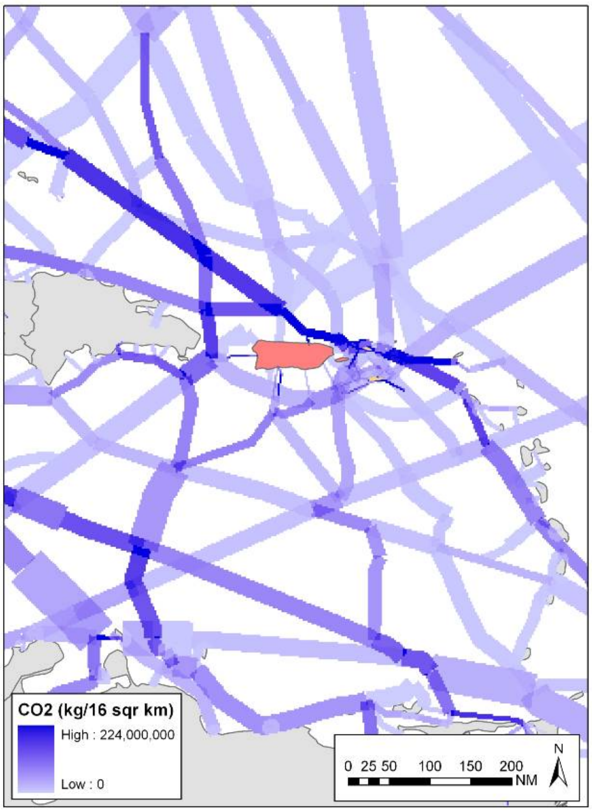

Figure 7-2: STEEM estimates of shipping lanes and carbon dioxide emissions around Puerto Rico and the U.S. Virgin Islands, 2000-2

Figure 7-2 emphasizes the high degree of ship activity around Puerto Rico and the U.S. Virgin Islands, both from ships that enter Puerto Rican ports and those that travel around the islands on their way to or from the Panama Canal and the Americas. It also illustrates the heavy traffic to the islands to the East of Puerto Rico and the U.S. Virgin Islands.

7.2 Summary

The nature, patterns, and density of the shipping traffic in the proposed ECA have been described and portrayed in Figures 7-1 and 7-2. Thus, this proposal for an ECA fulfils Criterion 3.1.6 of MARPOL Annex VI, Appendix III.

8 Control of Land-based Sources

Criterion 3.1.7 *The proposal shall include a description of the control measures taken by the proposing Party or Parties addressing land-based sources of NO_X, SO_X, and particulate matter emissions affecting the human populations and environmental areas at risk that are in place and operating concurrent with the consideration of measures to be adopted in relation to provisions of regulations 13 and 14 of Annex VI.*

8.1 Applicable Laws

The Commonwealth of Puerto Rico and the U.S. Virgin Islands are unincorporated territories of the United States, thus they are subject to U.S. jurisdiction and sovereignty. Since 1992, federal departments, agencies, and officials have been directed to treat Puerto Rico administratively as if it were a state. Thus the federal air pollution control programmes in place across the continental U.S., which are some of the most stringent in the world, are also in force in Puerto Rico and the U.S. Virgin Islands.

In addition to the federal control programmes, each territory also enforces local air pollution control regulations. Federally-approved territorial emission standards for NO_X, SO_X and PM covering a variety of source categories have been in place since the 1980's in both Puerto Rico and the U.S. Virgin Islands. Additional pollution control programmes are under development through the Cartagena Convention's Land Based Sources of Marine Pollution Protocol, ratified by the United States in 2009, whose programmatic framework is provided by the Caribbean Environment Programme. Under this protocol, the U.S. will prevent, reduce and control pollution from land-based sources, including air emission sources that contribute to atmospheric deposition of pollutants of concern.

8.2 Description of Land-based Sources

The economies of these island territories include capital-intensive industries such as petrochemicals, pharmaceuticals, technology, electronics, textiles, and processed foods. An estimated 45 per cent and 19 per cent of the Gross Domestic Products (GDP) of Puerto Rico and the U.S. Virgin Islands, respectively, come from the manufacturing sector (U.S. CIA World Fact Book, 2009). By comparison, the GDP by sector for the continental United States is very similar to the U.S. Virgin Islands, while the GDP for Puerto Rico has a stronger emphasis on industry. In reviewing these data, shown in Table 8-1, one may see that these island territories are bustling centres of commerce, engaged in producing useful goods and environmental wastes just as the continental U.S. is. Thus, the need for controls is similarly strong.

Table 8-1: Per cent of Gross Domestic Product by Sector

	INDUSTRY	SERVICES INCLUDING TOURISM	AGRICULTURE
Puerto Rico	45	54	1
U.S. Virgin	19	80	1
U.S. Mainland	22	77	1

8.3 Controls in Place

Both the federal and territorial governments have already imposed stringent restrictions on emissions of NO_X, SO_X, PM and other air pollutants from a wide range of land-based industrial (stationary) and transportation (mobile) sources as well as consumer and commercial products. The most significant air pollution sources have applied advanced emission control technology where feasible, reducing emissions by as much as 99 per cent in many cases. Further reductions are expected as older facilities are updated, the vehicle fleets experience turnover, and new sources comply with even stricter requirements.

The federal and territorial governments have applied a wide range of programmatic approaches to achieve significant reductions in air pollution. Regulatory regimes typically mandate emissions reductions either through pollution prevention such as the use of cleaner fuels or raw materials and improved practices or by requiring after-treatment or other air cleaning technologies.

Significant emission reductions of $NO_{X,}$ SO_X and PM in Puerto Rico and the U.S. Virgin Islands have been achieved via performance standards for new combustion sources and other industrial processes. As the electric utilities, petroleum refineries and cement manufacturing plants operating on Puerto Rico and the U.S. Virgin Islands have come into compliance with sector-specific standards, the annual rate of NO_X, SO_X, and PM emissions from this group of sources have decreased by about 20 per cent,[15] 80 per cent, and 70 per cent[16], respectively, compared to a decade earlier. In terms of mobile sources, since 2004, NO_X, SO_X and PM emissions from highway and non-road heavy duty engines and equipment in Puerto Rico and the U.S. Virgin Islands have been decreasing as a result of federal performance and emission standards that are fully phased in as of 2010 for highway trucks and will be fully phased in by 2015 for non-road vehicles. In addition, federal standards for marine diesel engines with per cylinder displacement less than 30 litres began to apply in 2004. The federal marine diesel engine standards reflect more stringent NO_X controls for vessels manufactured through 2015; in 2016, the federal NO_X limits are similar in stringency to the MARPOL Annex VI limits. The federal programme also includes PM, hydrocarbon, and carbon monoxide limits. Finally, to allow the use of high efficiency after-treatment technology, diesel fuel for use in highway vehicles in these territories was reduced to less than 0.0015 per cent (15 parts per million by weight) sulphur beginning in 2006. Diesel fuel for use in non-road engines and equipment will be reduced to this level beginning in 2010, and diesel fuel for marine use will be required to meet this limit by 2014.

The territorial governments continue to plan for growth as they manage their air pollution inventories. For example, as part of a new programme to maintain air quality in the San Juan area, described in more detail in section 5.3, many emissions sources located near ports must comply with regulations governing cargo handling as well as other land-side port activities to offset growth in ship activity.

As land-based sources of emissions are increasingly controlled, the relative contribution of ship emissions to public health and environmental impacts is increasing. The gains that have been made by extensive domestic regulations to control emissions from land-based sources could be eroded by expected growth in shipping activity, without action to reduce ship emissions.

8.4 Summary

As described above, extensive control measures have been adopted in Puerto Rico and the U.S. Virgin Islands, to reduce air pollution from land-based sources. Thus, this proposal for an ECA fulfils Criterion 3.1.7 of MARPOL Annex VI, Appendix III.

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15 Major permitted sources NO_X emission trends 2004 to 2008, as verified by USVI DPNR.

16 Major permitted source SO_X and PM emission rates verified by PREQB, calculated before and after federally enforceable fuel sulphur content standard effective in 2007.

9 Relative Costs of Reducing Emissions from Ships

Criterion 3.1.8 The proposal shall include the relative costs of reducing emissions from ships when compared with land-based controls, and the economic impacts on shipping engaged in international trade.

This section describes our estimates of the cost of operating in the proposed ECA. These costs are then compared to those associated with land-based controls. In addition, this section discusses the anticipated economic impact of the proposed ECA.

9.1 Summary of Total Costs

The total costs associated with improving ship emissions from current performance to ECA standards in 2020 include the differential costs of using lower sulphur fuel, and the use of urea on vessels equipped with selective catalytic reduction systems (SCR) to meet Tier III NO_X standards. This analysis draws on detailed cost and fuel production studies performed in support of the North American ECA proposal (MEPC 59/6/5) for estimates of per-unit costs (RTI, 2008; Ensys and RTI, 2009). Total costs for the proposed ECA are developed using these per-unit costs. Table 9-1 presents the total costs estimated for this proposed ECA, including the costs associated with the use of using lower sulphur fuel instead of residual fuel, and the operational costs associated with the use of urea in after-treatment systems used on Tier III engines (in 2006 U.S. dollars). The total estimated additional costs associated with the proposed ECA are approximately $70 million in 2020.

Table 9-1: 2020 Total Incremental Cost of the Proposed ECA ($millions)

OPERATIONAL COSTS ASSOCIATED WITH THE ECA		
Residual Fuel Usage	Baseline (Without the ECA)	$169
	With the ECA	$0
Distillate Fuel Usage	Baseline (Without the ECA)	$19
	With the ECA	$252
Total Additional Fuel Costs Associated with the ECA		$64
Total Urea Costs Associated with the ECA		$6.0
Total Additional Operational Costs Associated with the ECA		$70

9.2 Operational Costs

Operational costs refer to those that are incurred whenever the vessel is operating. This analysis considers operating costs associated with both the low sulphur fuel requirement and the Tier III NO_X standards that would go into place in the proposed ECA for new vessels beginning in 2016.

With respect to the low sulphur fuel requirement, we assume that all vessels in 2020 will comply with the standards by switching to low sulphur distillate fuel when operating in the proposed ECA. As an alternative, an exhaust gas cleaning unit may be used. It is expected that this alternative equivalent technology would only be used in the case where the operator determines that it would result in a cost savings relative to the use of distillate fuel. To the extent that operators choose an alternative technology, the costs may be overstated in this analysis.

Total fuel costs are derived using estimated fuel consumption values and per-tonne incremental cost projections of using lower sulphur fuel. The fuel consumption estimates are those developed in the inventory analysis and presented in Chapter 1 of the Technical Support Document prepared for this proposal. The per-tonne fuel cost projections were developed using the WORLD model, in support of the North American ECA proposal (U.S. EPA, 2009). These estimates are based on fuel price projections estimated by the U.S. Energy Information Administration (EIA) in 2008. We believe the use of these fuel cost estimates is appropriate for three reasons. First, use of these fuel cost estimates allows for a comparable analysis between the two programmes. Second, the WORLD modelling was performed recently, which is especially important given the uncertainty associated with making projections of cost impacts in 2020. Third, based on sensitivity modelling performed on fuel volumes, the impact of additional distillate demand as a result of this ECA would be small on the WORLD fuel cost estimates. As such, the price pressures as a result of this ECA would be negligible. This is especially true for this analysis, given that the volume of fuel consumed by ships operating in the proposed ECA is small (approximately 3.6 per cent) relative to the North American ECA.

There are two main cost components projected to increase as a result of compliance with the fuel requirements of the proposed ECA. The first component results from the shifting of operation on residual fuel to operation on higher cost distillate fuel; this is the dominant cost component. The second is a small cost associated with further desulphurizing distillate fuel to meet the 0.1 per cent fuel sulphur standard in the ECA. The methodology used to develop these per tonne fuel cost estimates is described in detail in the Technical Support Document developed for the North American ECA proposal. The estimated average increase in costs associated with switching from marine residual to distillate will be $145 per tonne.[17] This is the cost increase that will be borne by the shipping companies purchasing the fuel. Of this amount, $6 per tonne is the cost increase associated with distillate desulphurization. In other words, we estimate a cost increase of $6/tonne for distillate fuel used in an ECA. The remaining $140 is due to switching from residual fuel to distillate fuel. The cost differential is modelled based on costs to the refinery and assumes the market is in equilibrium.

For vessels built on or after January 1, 2016, we assume that the engines comply with the Tier III NO_X standards through the use of SCR. We recognize that other technologies may be used to meet the Tier III NO_X standards. For instance, development work has been performed with the goal of meeting these standards using exhaust gas recirculation and water injection strategies. If these technologies are used, then operating costs would be lower as urea would not be consumed in the vessel. As such, this analysis may overstate costs associated with the proposed ECA. At the same time we consider SCR technology because, at this time, it appears to be the most developed approach. Urea consumption for vessels equipped with SCR is expected to be 7.5 per cent of the fuel consumption. The urea operational costs are based on a price of $1.52 per gallon with a density of 1.09 g/cc. The cost per gallon was estimated for a 32.5 per cent urea solution delivered in bulk to the ship through research completed by ICF International for the U.S. Government, combined with historical urea price information (ICF International, 2008).

[17] Note that distillate fuel has higher energy content, on a per tonne basis, than residual fuel. As such, there is an offsetting cost savings, on a per tonne basis, for switching to distillate fuel. Based on a 5 per cent higher energy content for distillate, the net equivalent cost increase is estimated as $123 for each tonne of residual fuel that is being replaced by distillate fuel ($200/tonne for the high price case).

9.3 Vessel Costs

The cost analysis for the proposed ECA does not include equipment costs associated with vessel modifications to accommodate ECA fuel for new and existing vessels or associated with the Tier III NO_X limits for vessels built after 2016. This is reasonable for two reasons. First, as noted in section 9.5, approximately 55 per cent of commercial shipments to Puerto Rico and the U.S. Virgin Islands originate in the continental United States, and approximately 90 per cent of shipments from these areas are destined to the continental United States. Vessels that carry these goods will already be equipped to comply with the ECA requirements as they will operate in the North American ECA. Second, the ship positional data presented in section 7 suggests that most of the activity that occurs within the boundaries of the proposed ECA is ships that are entering ports in Puerto Rico or the U.S. Virgin Islands. There appears to be only limited activity from ships transiting the area and such transit activity that occurs is appears to be only at the outer boundary of the proposed ECA, where ships have a lesser impact on air quality[18] and where it would be possible to reroute to avoid the proposed ECA if a ship is not equipped with the fuel or engine equipment necessary to comply with the ECA requirements.

9.4 Costs in Comparison with Land-based Measures

To evaluate how cost-effective the proposed ECA will be in providing the expected emission reductions as compared to land-based measures, a ratio of engineering costs incurred per tonne of emissions is used to compare the proposed ECA to other control programmes.

As is shown in this section, the cost effectiveness of NO_X, SO_X and PM emissions reductions from the proposed ECA compare favourably to other land-based control programmes that have been implemented.

9.4.1 ECA Cost-Effectiveness

Section 5.1 of this document summarizes the inventory analyses from which the projections of pollutant reductions are drawn for the proposed ECA. Reducing ship emissions from today's performance to ECA standards will reduce local inventories of NO_X, SO_X and $PM_{2.5}$ in 2020 by approximately 10,000, 28,000 and 3,000 metric tonnes, respectively.

As described above, the costs of the proposed ECA in 2020 include the differential operating costs of using lower sulphur fuel, and the use of urea on vessels equipped with SCR systems to meet Tier III NO_X standards.

According to the methods used in support of regulatory development for other emissions sources in the U.S., the estimated cost-effectiveness of the proposed ECA in 2020 is $600 per tonne of NO_X removed, $1,100 per tonne of SO_X removed, and $11,000 per tonne of $PM_{2.5}$ removed. For the purposes of this analysis, half of the costs of fuel switching were allocated to PM and half were allocated to SO_X because the costs incurred to reduce SO_X emissions directly reduce emissions of PM as well. We use these cost-effectiveness estimates for comparison to land-based programmes.

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18 See Section 5 for a discussion of back trajectory analysis and the impacts of ship emissions on shore.

9.4.2 Land-based Control Programme Cost-Effectiveness

The cost of reducing air pollution from land-based sources has ranged greatly in the United States, including Puerto Rico and the U.S. Virgin Islands, depending on the pollutant, the type of control programme and the nature of the source. Programmes that are designed to capture the efficiency of designing and building new compliant sources tend to have better cost-effectiveness than programmes that principally rely on retrofitting existing sources. Given the wide range of sources and controls, the cost per tonne reduced also varies greatly. The cost of NO_X reductions has typically ranged from $200 to over $12,000 per tonne; the cost of PM reductions has typically ranged from $2,000 to over $50,000 per tonne; and the cost of SO_X reductions has typically ranged from $200 to $6,000 per tonne. The estimated cost effectiveness of the proposed ECA reported above is on the low side of each of these ranges.

Throughout these U.S. territories, the control measures that have been implemented on land-based sources have been well worthwhile when considering the benefits of the programmes. As an illustration, the lower sulphur fuel requirement adopted by the Commonwealth of Puerto Rico for its electric utility industry provided needed benefits of PM and SO_2 reductions at a cost of only $1,720 per ton of emissions reduced, if all costs are allocated to SO_2. The fuel with 0.5% sulphur (5,000 ppm) was found to be feasible by the utility, and provided valuable health and societal benefits. Additional cost comparisons are presented in the Technical Support Document prepared for this proposal.

9.5 Economic Impacts

An Economic Impact Analysis (EIA) provides information about the potential economic consequences of a regulatory action. The analysis is based on basic microeconomic theory to simulate how producers and consumers of products and services affected by the emission requirements can be expected to respond to an increase in production costs as a result of the new emission control programme for ships operating in the proposed ECA.

For islands like Puerto Rico and the U.S. Virgin Islands, there are no reasonable alternatives to transporting most goods to and from these areas by ship. As a result, demand for commercial shipping services is not expected to change as a result of the costs of complying with the proposed ECA. Because of this, increases in the cost of marine transportation services are expected to be passed on to consumers of these services through increases in freight rates. These costs, in turn, are expected to be passed on to the end consumers of the goods transported. While there may be some adjustment in demand in for marine transportation services the long run (i.e. an increase in the price of a good is expected to decrease demand for that good), such an adjustment would be minor given the lack of alternatives to marine transportation and given the small contribution of transportation to the total costs of goods (i.e. the price of goods transported by ship would not increase by very much as a result of compliance with the programme because shipping costs are only a small portion of the price of end goods).

Because freight rates are expected to be increased by the total amount of the costs of the ECA, we can evaluate the economic impacts of the proposed ECA by comparing the estimated increase in operating costs to total operating costs. Consistent with the cost analysis described above, equipment costs are not included in the economic impact analysis. It should be noted that as reported in the economic impact assessment performed for the North American ECA, equipment costs associated with compliance with the ECA fuel controls for existing vessels are relatively small, at less than $70,000 per vessel. These costs would increase the price of a new ship by 2 per cent or less.

We performed an economic analysis of the impacts of the ECA for four representative commercial vessel scenarios and three cruise ship scenarios.

The commercial ship scenarios are for three sizes of container vessels (two ships operating between Miami and Puerto Rico and one operating between Singapore and Puerto Rico) and one tanker vessel (operating between Venezuela and Puerto Rico). Each ship is assumed to operate at 80 per cent load, at a speed of 16 nm/h and with brake specific fuel consumption (BSFC) of 195 g/kW-h. The results of this analysis are reported in Table 9-2.

Table 9-2: Estimated Economic Impacts of PR/VI ECA for Various Ships (US$2006)

VESSEL TYPE	ROUTE	ENGINE POWER	PRE-ECA FUEL COST PER TRIP	POST-ECA FUEL COST PER TRIP	PRICE INCREASE PER TEU OR BARREL
Container (600 TEU)	Miami FL – San Juan, PR (930 nm; 100 nm in Proposed ECA)	5,000 kW	$14,900	$15,500	$1.00 (0.25%) $400 base cost
Container (1,400 TEU)	Miami FL – San Juan, PR (930 nm; 100 nm in Proposed ECA)	15,785 kW	$47,100	$49,000	$1.35 (0.34%) $400 base cost
Container (6,600 TEU)	Singapore – San Juan, PR (12,500 nm; 100 nm in Proposed ECA)	36,540 kW	$1,432,000	$1,434,000	$0.33 (0.04%) $800 base cost
Tanker (115,000 DWT; 780,000 bbl crude)	Venezuela – San Juan, PR (530 nm; 130 nm in Proposed ECA)	10,000 kW	$16,700	$18,200	$0.002/barrel (negligible %)

For these commercial vessels, the expected cost increase of shipping goods to or from Puerto Rico, as measured by the increase in costs per twenty-foot equivalent unit (TEU) or per barrel of fuel, is expected to be small, at significantly less than one per cent. We estimate that a container ship that operates part of the time in the ECA would see an increase in operating costs of US$1.00 to US$1.35 per TEU, depending on the size of the ship and the length of the route. This represents an increase of less than 1 per cent in the cost of shipping a 20-foot container. A container ship operating between Singapore and Puerto Rico is expected to see an increase in operating costs of about US$0.33 per TEU, or less than one per cent of the cost of shipping a 20-foot container. The price impacts on oil tanker services are also expected to be small, with an estimated price increase of less than US$0.002 per barrel.

Table 9-3: Estimated Economic Impacts of PR/VI ECA for Cruise Ships (US $2006)

VESSEL AND ROUTE TYPE	ROUTE	ENGINE POWER	PRE-ECA FUEL COST PER TRIP	POST-ECA FUEL COST PER TRIP	PRICE INCREASE PER PASSENGER PER DAY
Small Cruise Ship (32,000 GT and 800 passengers) Island Tour	San Juan, Puerto Rico; St. John U.S.V.I.; Basseterre, St. Kitts; Pointe-A-Pitre, Guadeloupe; Fort-de-France, Martinqiuqe; St. Georges, Grenada; Bridgetown, Barbados; St. John's, Antigua; Frederiksted, St. Croix U.S. V.I.; San Juan, Puerto Rico.	Main Engine: 22,000 kW, Auxiliary Engine: 4,100 kW	$123,000	$131,000	$1.30 ($10 per trip for the 8-day trip)
Medium Cruise Ship (80,000 GT and 2,000 passengers) Direct Trip to Puerto Rico	Fort Lauderdale, Florida; San Juan, Puerto Rico; Matthew Town, Bahamas, Fort Lauderdale, FL.	Main Engine: 53,000 kW, Auxiliary Engine: 1,500 kW	$298,000	$303,000	$0.60 ($3 per trip for the 5-day trip)
Large Cruise Ship (120,000 GT and 3,000 passengers) Long Tour of the Caribbean from the U.S. East Coast	New York, NY; Turk Islands; San Juan, Puerto Rico; St. Thomas, U.S.V.I.; Fort-de-France, Martinique; St. Georges, Grenada; Oranjestad, Aruba; Ocho Rios, Jamaica; Cozumel, Mexico; Key West, Florida; New York, New York.	Main Engine: 72,000 kW, Auxiliary Engine 2,000 kW	$987,000	$1,002,000	$0.40 ($6 per trip for the 14-day trip)

For similar sized cruise vessels, the expected cost increase of carrying passengers to or from Puerto Rico, as measured by the increase in costs per passenger per cruise, is expected to be small, at less than 1 per cent. We estimate that a cruise ship that operates part of the time in the ECA would see an increase in operating costs of US$0.40 to US$1.30 per passenger per night, depending on the size of the ship, the length of the route, and the number of passengers. This represents an increase of less than 1 per cent in the cost of a stateroom per night. A large cruise ship operating between New York and travelling throughout the Caribbean is expected to see an increase in operating costs of about US$6 per passenger per cruise. The price on a small cruise ship cruising from and returning to San Juan, Puerto Rico is expected to see an increase in operating costs of about US$10 per passenger per cruise. The price impacts on a medium-sized cruise ship operating on a nearly direct route between Fort Lauderdale, Florida and San Juan, Puerto Rico are also expected to be small, with an estimated price increase of less than US$3 per passenger per cruise. The estimated increase in costs per trip per passenger incurred as a result of this proposed ECA are substantially less than the average fuel surcharge currently incurred by passengers if the price of oil per barrel exceeds a certain threshold; this surcharge can range from US$5 to US$10 per passenger per day.

9.6 Summary

The material presented in this section shows that the proposed ECA is expected to be highly effective at achieving emissions reductions of NO_X, SO_X and PM for the given costs. Further, the relative costs of reducing emissions from ships and the economic impacts on the international shipping industry are expected to be reasonable. Thus, this proposal for an ECA fulfils Criterion 3.1.8 of Annex VI, Appendix III.

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