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# CHAIN REACTION: THE INDIRECT EFFECTS OF CLIMATE CHANGE ON MARITIME ACTIVITY

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CHAIN REACTION:  
THE INDIRECT EFFECTS OF CLIMATE CHANGE  
ON MARITIME ACTIVITY

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A Thesis  
Presented to  
the Graduate School of  
Clemson University

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In Partial Fulfillment  
of the Requirements for the Degree  
Master of City and Regional Planning

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by  
John Stuart Ridout  
May 2008

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Accepted by:  
Dr. Anne Dunning, Committee Chair  
Prof. Stephen Sperry  
Dr. Charles Rice

## **Abstract**

Global climate change has the potential to alter the environment as well as the ways humans interact with it. Specifically, scientists can quickly imagine the effects of global warming in the ocean environment, but a secondary impact will be how humans adapt to this changed world. Ice clearance will lead to navigable Arctic waterways and more potential polar shipping routes. Increased shipping routes will alter or increase global shipping activity. Existing port activity will increase to meet new economic demands, but much of that activity will be concentrated outside Arctic waters. The changes will also affect the ecosystems of these ports. Consequently, changes to shipping patterns have far-reaching effects beyond the ports themselves.

This project has synthesized material and knowledge from four large and highly researched topics: climate change, current and future Arctic conditions, transoceanic shipping, and marine transportation affects the environment. The objectives of this study were to identify the future shipping volumes to 2045 when polar ice melt will enable seasonal shipping traffic. The study provided a 2045 projection of the future shipping volumes along with an integrated analysis of potential ecological threats of future shipping volumes extrapolated from current maritime impacts. A critical link exists between the impacts of climate change, future shipping volumes, and the environment. The findings conclude that shipping size and volume will increase significantly. The threats to the local ecosystem will increase and large-scale shifts in port preference will have the most challenging obstacles to overcome.

## **Dedication**

For Greg, Mom, Dad, and Amy.

Thanks for putting up with me... for brief moments of time that feel like an eternity.

## **Acknowledgements**

I want to thank Dr. Anne Dunning, my advisor, mentor, and friend for her patience that makes my visions achievable. In addition, I want to thank my committee members, Prof. Stephen Sperry and Dr. Charles Rice for their support and insight that made this research possible. Lastly, I must thank the fish and coral that I stared at for “inspiration”.

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## **Chapter 1: Introduction**

Global climate change has the potential to alter the environment as well as the ways humans interact with this environment. Specifically, scientists can quickly imagine the effects of global warming in the ocean environment, but a secondary impact will be how humans adapt to this changed world. Ice clearance will lead to navigable Arctic waterways and more potential polar shipping routes. Increased shipping routes will alter or increase global shipping activity. For instance, in a 2007 magazine article J. Roach estimates Asian-European and Asian-American shipping routes could be up to 33 percent faster with potential Arctic routes than with traditional Suez or Panama Canal routes. As a result, existing ports either might experience a boon of activity or might no longer be as competitive or attractive in global shipping. For instance, if there is an efficient route from China over the North Pole to the east coast of North America, west coast ports might see a decline in shipping and port activity, while east coast ports will bear additional burdens of increased traffic. Existing port activity will increase to meet new economic demands, but much of that activity will be concentrated outside arctic waters. The changes will also affect the ecosystems of these ports. Consequently, changes to shipping patterns have far-reaching effects beyond the surface level of ports themselves.

This review synthesizes material and knowledge from four large and highly researched topics: climate change, current and future Arctic conditions, transoceanic shipping, and marine transportation affects the environment. In addition, it projects the potential growth in maritime traffic for the United States. A critical link exists between the impacts of climate change, particularly future shipping volumes and the environment.

This study examines the connection between waterborne transport and the aquatic environment. Moreover, the research will take an original approach to a subset of the field of environmental impact by focusing on one specific human action, itself the result of climate change.

The gap in the current literature is how climate change, maritime shipping, and the marine ecosystem will interact in the future. Currently, there is the general understanding of how human activity is influencing the global climate; there is the knowledge of how marine shipping can affect the marine ecosystem, and there are predictions into the future activity of marine freight. However, there has not been a comprehensive study into how climate change, ecology, and transportation will interact into the future. As a result, the questions remain are as followed:

- 1) How will shipping volumes change in the future?
- 2) How will an Arctic route redistribute shipping volumes?
- 3) How will marine ships change in the future?
- 4) How will future marine transportation affect the future condition of marine ecosystems?

To answer these research questions this paper identified the following projection and issues in order to answer how future conditions in maritime transportation will affect marine environments:

- Project future growth in shipping
- Project trans-Arctic scenarios
- Identify current trends in maritime practices and ecological impacts
- Synthesize current impacts to determine possible future conditions

As a result, the study provides a 2045 projection of the future shipping volumes along with an integrated analysis of potential ecological threats of future shipping volumes based on current maritime impacts. This report is divided into 12 separate chapters. Chapters two through five discuss the current conditions of the impacts of both climate change, change in sea ice, and the affects of maritime shipping on the environment. Chapter six and seven address the current gap in climate change and human activity when applied to marine environments. Chapter eight identifies the recent trends and conditions of the maritime industry. Chapters nine through eleven address the future conditions of maritime shipping, projected volumes and redistribution of containerized cargo as the result of a trans-Arctic route. Finally, Chapter twelve provides the conclusion that links the issues of climate change, human activity and the environment into a continuous cycle of action and reaction.

## **Chapter 2: Climate Change**

Climate change is a controversial topic with significant political debate. Often, academic, political, and entertainment venues are blurred. For example, Al Gore, a notable politician, shares the Nobel Prize with the Intergovernmental Panel on Climate Change, an organization that bases climate assessment on peer-reviewed and published scientific/technical literature. As a result, the public receives a blurred vision of climate change inevitably linked to politics. Asserting a climate change position causes economic and social division. If an individual accepts or refutes climate change, then secondary debates ensue. Often these secondary political, economic, or popular solutions to climate change hinder the actual understanding of the process. As an obvious example, accepting the likelihood of climate change does not necessitate buying a hybrid vehicle. The tendency to subscribe political divisions to each side extends to the academic proponents and critics; however, this group is less politically motivated than political, economical, and entertainment research. They have less to gain from choosing a side, and less desire for a single uniform position.

### **Historical Tradition**

Climate change, often referred to as global warming, is an older topic than many realize. Human civilization has recorded the weather to ensure crop growth since the earliest of time, and the birth of modern recognition of climate changes dates back to the early 1700s in Europe. Early climate change was thought to explain why European culture was able to climb to its self-perceived pinnacle of civilization; consequently, this early form of climatology established an understanding that the environment was not

infinitely stable and that changes in temperature and precipitation could have significant influence on human development (J. Fleming, 1998 p.11). On the other side of the ocean, Colonial America desired to understand why the climate was substantially different than that of Europe. The warmer summers and much colder winters were difficult for many colonists. European elitists used the harsher climate as an example that the new world was a semi-wasteland (p.21). Early Americans, including Benjamin Franklin, attempted to fend off European notions that the climate was unbearable. At this time, Americans believed in a general trend that the land was warming, claiming that the reduction of the vast woodlands would in some cases prevent snow and frost (p.25).

Further scientific studies of climate change continued, and in the late 19<sup>th</sup> century, molecular studies of the atmosphere began to propose that carbon dioxide concentrations were increasing and contributed to a warming trend. This period also produced the concept of the “greenhouse effect,” although the author of the term is debatable. Early predictions proposed the possibilities and likely scenarios if the carbon dioxide or carbonic acid levels increased. The most accurate example, articulated by Svante Arrhenius in 1896, claimed that the Arctic regions would increase eight to nine degrees Celsius if carbon concentrations increased (J. Fleming, 1998 p.75). The concept of climate change and the potential for the Arctic to undergo significant temperature change has been noted in scholarly research for well over a century. The difference between historical research 100 years ago and modern understanding has to do with an advancement of technology and better equipment. Regardless of the methods or time period of climate change research, the fundamental underlying principle is that human activity is capable to cause changes in the climate of an area.

### *Current Status of Climate Change*

Current research and literature on global climate change is much more refined and includes specific topics resulting in many microcosms of knowledge, from carbon dioxide tracking to environmental specific effects of seawater change. Furthermore, there is considerable political and mainstream disagreement about climate change. As evidence accumulates, so does scientific consensus. Now, the more difficult question is how human activity contributes to climate change. Other complications in the understanding of climate change are the numerous differences in model predictions.

### *Climate Change Models*

Since the 1970s there has been an increase in the complexity of climate change models. The models have been increasing the number of variables to include inputs ranging from volcanic activity, photosynthesis, precipitation, cloud cover, carbon dioxide, and other emissions from human sources. Like all modeling, the inputs dictate the eventual result. Because many of these models create predictions of both climate change and other natural processes one hundred years into the future, small differences can have a long-range impact on the prediction. In some cases, the models themselves have to be readjusted to fit current data. For example, the Arctic sea ice models project different starting levels for ice regression: some are below the current observed levels and some are above.

Climate change models also incorporate different inputs and different reliance on historical climate data. Most projections from the Intergovernmental Panel on Climate Change show a significant increase in projected future temperatures (IPCC, 2007). Some of the more conservative estimates of temperature increases project a positive change of

two to three degrees Celsius for the year 2100 (IPCC, 2007). The more drastic models project an increase of temperature of four to five degrees Celsius for the same year (IPCC, 2007). Regardless of the model, the predictions depend on the projected increase of carbon dioxide.

One-hundred year carbon dioxide forecasts and to a lesser extent, sulfur dioxide determine climate change models. While sulfur dioxide models show a slight increase before declining over the next 100 years, carbon dioxide is projected to increase in its atmospheric concentration. Carbon dioxide is expected to increase from current levels of 370 parts per million to a range of 500 to 900 parts per million over the course of the next 100 years (IPCC, 2007). An increase in carbon dioxide is probable since carbon dioxide has risen from 290 parts per million to 370 parts per million in the last century. The predictions with the lowest increase in temperature change also have the lowest forecasts of carbon dioxide. The carbon dioxide models with the greatest increase in concentration have the greatest increase in temperature change but do not necessarily have the greatest concentrations of sulfur dioxide.

In addition to future models determining the possible effects of climate change, considerable research has investigated the historical patterns of the global climate. Most of the historical temperature data are indirect proxies retrieved from tree rings, ice cores, sediments, and coral records (Mann, 1999, p. 759). The last 1,000 years, if not longer, of global climate data are available for interpretation. The historical data support that the climate is in constant variation with warming and cooling periods. Most identifiable changes within the last millennium include the medieval warm period, the 15<sup>th</sup> century Little Ice Age, and the recent “hockey stick effect” in the 20<sup>th</sup> century. Mann (1999)

proposes the “hockey stick effect,” an anomaly in the recorded temperature data that refers to the drastic warming trend in the 20<sup>th</sup> century. The “hockey stick” of the 20<sup>th</sup> century breaks the pattern of cooling and shows a one degree Celsius increase over the course of 100 years and is by far the greatest change in 1000 years of data. In the last 1000 years, a general cooling trend began with the Little Ice Age. The temperatures from mid 1400s through the end of the 19<sup>th</sup> century were generally cooler than other periods. This cooling effect from 1400s through 1900 should not be confused with the counterpart of global warming. Global cooling appeared as an alternative theory in the 1970s.

### **Global Cooling**

The basic foundations for global cooling theories shared similar origins with global warming research. Both proposed that human activity created changes in the climate. However, the basic human atmospheric input is different. Instead of an increasing temperature due to carbon dioxide, global cooling researchers observed a decreasing temperature due to an increase in aerosols (S. Rasool and S. Schneider, 1971, 138). Global cooling does not refute the warming effects of carbon dioxide, but rather it supports that the increased aerosols would overwhelm warming and cause a greater cooling effect. According to this theory, long-term use of aerosol will create a greater net cooling that would negate the increased carbon dioxide warming and cause the potential for a human triggered ice age (138). The global cooling proposed during the 1970s coincided with a brief cooling trend for about a decade. However, the overall trend of the 20<sup>th</sup> century was a warming trend (Mann, 1999, 759). While the outcome for global cooling is different from the outcome for global warming, the basic principles are the



same. Both propose that human activity and production of specific gases impact on the overall climate.

Ultimately there is a great potential that a general warming trend is being experienced. While some unresolved questions and political debates remain over the causes and future impacts of a warmer environment, the supporting evidence suggests a strong likelihood that the environment is changing. Climate change is attracting those who identify new opportunities from a potential event. For example, governments are scrambling to lay claims to previously inaccessible areas in the Arctic to seize their resource deposits (Peter Tyson, 2007). The potential resources and financial gains resulting from global climate change, draws the attention of governments, international business, and particularly some maritime freight companies.

### **Criticism of Climate Change**

Researchers, politicians, and the public do not agree or embrace a uniform consensus of climate change, leading to the proposal of several alternative positions including the global cooling theory in the 1970s, critical analysis of various climate change methodologies like that of Mann's "hockey stick", and finally denialists of climate change in general. Most of the objections or alternative theories reject or replace certain aspects and inputs of many global warming and climate change models and theories. Global cooling, the first alternative theory to global warming, is a climate change theory and is similar to both historical theories on climate change and modern theories of climate change.

Global cooling evolved side by side with global warming theories in the 1960s and 1970s, as a brief cooling anomaly was observed in the late 1960s and early 1970s

(Lanzante, J.R., T.C. Peterson, F.J. Wentz, and K.Y. Vinnikovn, 2007, 53). Surprisingly, global cooling received significant public press and would contribute to the denialist arguments. Many skeptics of climate change cite a general cooling trend since 1940, if the more extreme warm years are removed from the data set (National Assessment of the Potential Impact of Climate Change (NACC): Climate Change Impacts on the United States, 2000). Although the denialists and skeptics cite that there is a cooling trend, this cooling trend is not a supporting argument for a stable climate theory. This cooling argument is more of a contrasting argument to a warming theory or evidence, not a position on actual climate change.

In addition, there are multiple versions of the skeptic climate change argument, including a denial of any form of climate change, a denial of human induced climate change and finally the inability to stop the global economy which is dependent on the consumption of carbon emitting fuels (S. Fred Singer, 2007). Often, these arguments appeal to an overall ignorance or inability to measure the most accurate conditions and then dismiss the finding or conclusion.

Other arguments, such as the inability to reduce carbon dioxide due to economic pressures or processes normally do not contest the topic of climate change. As a result, the arguments asserting that economic practices could not be changed if human produced carbon dioxide is a contributing factor to climate change is an *ignoratio elenchus* argument or an irreverent topic because it does not address the validity of climate change. While many skeptic arguments point out methodological problems of some models, many suffer from logical fallacies. Denial of climate change due to the lack of evidence or lack of human causation suffers from the appeal to ignorance fallacy. While denialist

arguments are often logically unsound, there are global cooling arguments that, at one point, were logically sound and supported by early data.

### *Changing Conditions of the Arctic*

The Arctic is undergoing significant change, linked to observations and the evidence of global climate change. Many climate change and polar climate change arguments appear vicious cycle; however, it is the natural process that continually reacts in a continuous process, not the argument. The beginning premise asserts that the overall climate is warming and that the Arctic is experiencing the most dramatic increase in temperature (Huntington & Weller, 2005, 3). As a result, the Arctic warming leads to a greater melting process of Arctic sea ice and permafrost (Rigor et al. 2000). The melting sea ice therefore contributes to the evidence that there is a general warming trend. The association between climate change and ice melt it is a circular process. The decrease of sea ice leads to a decrease in the reflective ability of the North Pole to reflect solar radiation. An increase in the absorption of solar radiation in the Polar Regions combined with an increase in the concentration of carbon dioxide, a greenhouse gas, will contribute to an overall warming trend (Huntington and Weller, 2005, 4). The process is a sequence, with multiple variables. The arguments, however is not circular but is aligned with other theories of energy cycles.

The recorded data supports that the Arctic, together with the Antarctic Peninsula, experienced the greatest regional warming on Earth in recent decades, largely due to various feedback processes (Huntington and Weller, 2005, 4). The Antarctic is a different type of polar environment than the Arctic. Comparatively, the Arctic is mostly an ice-covered water body, and the Antarctic is an ice-covered land mass. Because the

Arctic is mostly a frozen sea, the altitude is much lower than the Antarctic, which has an altitude of more than 9,000 feet in some points. These different conditions lead to different polar patterns. Antarctica has experienced stabilization and a slight increase in the polar ice. However, the coastal regions of Antarctica have experienced ice melt in specific locations.

In the Arctic, the annual temperatures increased two to three degrees Celsius since 1950 (Huntington and Weller, 2005, 4). The winter months have experience a more dramatic increase of four degrees Celsius making the overall winter season shorter (3). Furthermore, the trend of warming has accelerated in the past decade, and future projections suggest a continuation of increased warming and the winter months receiving the greatest increase of temperature (3). Because a significant economic interest surrounds the likelihood of a vastly different polar region, the expectation is that there will be major impacts on the environment (13).

As global climate change affects the Arctic regions, the slightest differences in temperature affect the condition of the Arctic Ocean. The result is a changing physical environment, specifically the environment supporting marine shipping. The most important change for marine shipping is the status and condition of Arctic sea ice. Because it only takes a few degrees to change the threshold of whether or not ice freezes or remains frozen, the sea ice will reflect changes in Arctic temperatures rapidly. Eventually, if the temperatures increase enough, then the ice will melt sufficiently, to accommodate shipping routes may develop in the lower polar region.

### **Chapter 3: Arctic Thawing**

The extent of the sea ice is the most important factor affecting the possibility of Arctic shipping routes. Without the retreat of sea ice, there are few available options of transporting large volumes of goods across the Arctic regions. Sea ice is a primary indicator of climate change (John E Walsh et al. 2005, 186). The decrease of the sea ice is closely related to the average and projected global surface temperature. (184)

The major measurement of sea ice is extent of surface. While ice thickness is important, there is less consistent data (John E. Walsh et al. 2005, 189). Compared to ice thickness, the extent of sea ice is easier to determine from satellite data (National Snow and Ice Data Center, 2007). Sea ice extent is a dimension of the ocean area in the presence of ice. A sea ice concentration of 15 percent is the minimum which sea ice extent is noted (National Snow and Ice Data Center, 2007).

#### **Ice Melting**

The Arctic sea ice is melting. In the last 40 years, a continuing pattern of declining sea ice coverage has been recorded in the Arctic Ocean and the peripheral seas. Since 2002, the possibility of a navigable shipping route increased significantly. The extent of the sea ice during the summer months has been ten percent less than the 1979-2000 mean ice recession (Richter-Menge et al. 2006, 16). Arctic ice reached a record low level in July 2007 with the single greatest period of ice loss in recorded data (National Snow and Ice Data Center, 2007). In 2007, sea ice extended about 18 percent below the pre-1980 average. The 2007 record is not an anomaly within the sea ice minimum data. The years 1990, 1995, 2002, 2005, and 2007 set record lows for the summer ice coverage

(Richter-Menge et al. 2006, 16.). While these were record lows, the years 2003, 2004, and 2006 recorded sea ice levels less than the 1995 levels. (16) Recent records indicated that the melt season increased by about 5.3 days per decade (Harald Loeng et al. 2005, 457). On a whole, sea ice is beginning to melt earlier and freeze later in the year, and this pattern is likely to continue into the future.

Arctic ice coverage reaches its maximum extent between the end of February and early March. During March and April, the Arctic sea ice begins to melt until it reaches the maximum retreat by the end of August and into September. Various models simulate the ice recession up to the year 2100, and most models show a significant decline in the extent of sea ice in both March and September (Harald Loeng et al. 2005, 457). In March, ice coverage is expected to decline to a total extent of about of 12.5 million square kilometers from 14 million square kilometers in the year 2100. This reduction is roughly a 12 to 22 percent decline in the maximum sea ice coverage (471-472). The decline in winter ice means that there will be less ice to melt before in the spring for Arctic shipping routes can become feasible.

### **2000 to 2100 Sea Ice Projections**

In September, sea ice extents ranged from five to seven million square kilometers in the first few years of the 20<sup>th</sup> century (Harald Loeng et al. 2005, 471-472, Gordon McBean et al, 2005). From the record low sea ice extent, September lows are expected to continue to have less sea ice. The average of the Arctic Climate Impact Assessment designated models show a decrease in sea ice from seven million square kilometers to about two to three million square kilometers (ACIA, 2005, 193). The most extreme model forecast a complete loss of sea ice around 2050 (ACIA, 2005, 193). The overall

percent change in the extent of the sea ice ranged from 12 to 46 percent (ACIA, 2005, 193).

**Table 1: ACIA Projected Ice Melt**

Source: Walsh, J. (2005) Cryosphere and Hydrology. C. Symon (Ed.) *Arctic Climate Impact Assessment* (pp.184-236) Canada: Cambridge University Press

| Year 2100                    | Conservative  | Moderate      | Model Maximum |
|------------------------------|---------------|---------------|---------------|
| Temp. Increase (Celsius)     | 1-3           | 2-4           | 4-5           |
| Carbon Dioxide               | 400ppm        | 600ppm        | 900ppm        |
| March Ice (km <sup>2</sup> ) | 12-14 million | 10-12 million | 5 million     |
| Sept. Ice (km <sup>2</sup> ) | 5-7 million   | 2.5 million   | 0             |
| Ice Change (%)               | 0-12          | 12-46         | 46+           |

A more conservative average is an overall reduction in sea ice of 20 percent by 2050 (Serreze et al. 2002). Models of sea ice levels suggest that navigable waterways through certain corridors of the Arctic Ocean are very likely by the middle of the 21<sup>st</sup> century, if not earlier (Arne Instanes, 2005, 910).

Complete melting of sea ice in the Arctic is not needed for trans-Arctic shipping; however, shipping requires a sufficient and stable channel during a specific season. The exact passages that would be ice-free long enough for shipping remains more challenging to predict. A stable route is difficult to determine because of the wide variation of sea-ice location. Sea ice varies in the maximum and minimum coverage of sea ice, which exacerbates the challenges of planning a trans-Arctic route (Gorden McBean et al.).

## **Chapter 4: Global Shipping**

As human society progresses into the 21<sup>st</sup> century, the worldwide economy is globalizing. Two main reasons for this economic phenomenon include the availability of low-cost communication and of low-cost and relatively high-speed transoceanic shipping. Low-cost, high-efficiency shipping has made it cheaper to produce goods in countries with low labor costs and ship via containers to post-industrial countries than to produce the good within the post-industrial country itself. Because of maritime shipping's success, the heavy demand of transoceanic shipping has increased while shipping companies scramble to produce larger and faster ships to meet market demand.

The large capacity, decreasing cost, and increasing speed of transoceanic shipping has led to an increase of transoceanic shipping and to the globalization of many consumer and industrial goods. Smaller objects with high value or time sensitivity might require air transport, but the expense of air transportation makes the movement of a vast quantity or heavy goods difficult. The most cost effective means of transport for large items, cheaper items, and non-time sensitive items is by ship. Most bulk cargo has a relative low cost value per ton that makes water transportation less costly (TRB, 2004, 16). The majority of all goods traded internationally are transported on the water. Thousands of containers are transported continuously across the oceans, and marine transportation is a part of a freight system that has been incorporated into the global production process (TRB, 2004, 16).

Unlike most transportation modes, commercial shipping is a unique mix of private companies relying on government or privatized harbors. This diverse system relies only on infrastructure in order for products to change modes. Unlike rail or truck, there is no



need for a designated railway or highways system to provide a right-of-way for transportation. The one exception is canals and a few altered waterways. For the most part, the support infrastructure at terminals increases efficiency or allows a normally inaccessible place to have a connection to marine transportation. Furthermore, marine transportation operates at a distanced from the general public. While air transportation relies on a terminal and runway for operation and serves a similar purpose as a port for marine traffic, air travel is closely connected to the public. Aircraft are common passenger vehicles and are often seen flying over urban centers. Therefore, the public shares a connection with aircraft that normally is not associated with marine freight transportation.

On the other hand, cargo ships operate far from most population centers and spend a large amount of time out at sea and away from spectators. A few coastal and port cities have a connection with marine transportation, but even these places do not have the same first-hand experience with container ships as many do with airlines. While marine transportation operates away from public attention, it has a close relationship with national and global economies (TRB 2004, 15). Marine transportation and freight in particular has kept pace with the demands of industry, government, and the public (TRB 2004, 16). As the global economy continues to change, transportation will have tremendous pressures to adapt and advance. For example, ships have expanded in size as increased demand for capacity has necessitated with the available technology. Maritime shipping evolves with the changes of human production.

### **Evolution of Marine Freight**

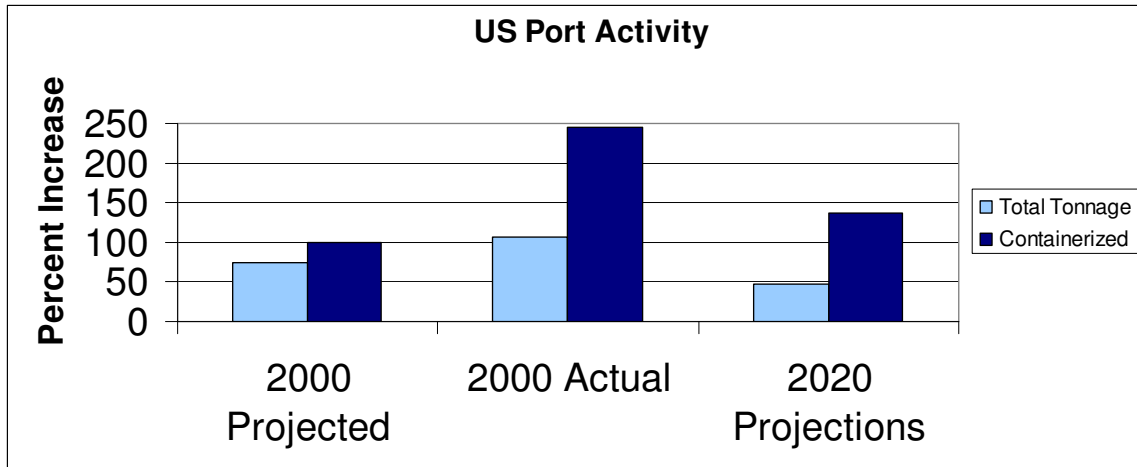
Shipping has been the basis for freight trade for over many thousands years. Early trade was based on small vessels making occasional, often seasonal journeys, to specific areas where there was shelter (Galil and Minchin, 2006, 71). In western society, these routes depend on the weather of the Mediterranean or Northern Atlantic and thus normally offered passage primarily in late spring through the summer. Modern shipping is now more of a year-round cycle in the movement of goods. Compared to historic time-periods, the size of modern ships and the frequency of transit have greatly increased with specialized ports evolving (71). While many ships are specialized to carry specific types of cargo, the ports themselves have evolved different practices to accommodate the role that the products moving in their regional trade (71). These changes in maritime practices eventually alter the local environment. Variables such as the increasing number of ships, port modernization, and decreases in turn-around times have local ecological effects (71).

### **Marine Growth and Future Projections**

Future projections of American port activity suggest significant growth by the year 2020 and projections have fallen under actual volumes. Former projections of 2000 maritime shipping data in 1985 were significantly lower than actual maritime activity. (Figure 1)

In 1985, Wharton Economic Forecasting Associates predicted that there would be an overall increase in all cargo by 74 percent with containerized activity increasing by 100 percent from 1985 to 2000 in U.S. ports (TRB, 2004, 51). The actual recorded U.S. port growth in shipping activity in all cargo increased by 106 percent with containerized activity increasing by 245 percent (51). Containerized cargo increased by 8.6 percent

annually, and shipping experienced a total increase of all cargo by 4.9 percent annually (51). The 2020 projections show a continued increase in cargo and containerized trade in U.S. ports, but the projections show slower growth similar to the 1985 predictions. Global Insight, Inc. forecasted U.S. international trade to increase 47 percent overall with a 137 percent increase in containerized traffic based on tonnage (51).



**Figure 1: 1985-2020 Projection of US port activity.**  
**Source: Transportation Review Board. (2004) *The Marine Transportation System and the Federal Role: Measuring Performance, Targeting Improvement*. Transportation Review Board Special Report 279. Washington D.C.: Transportation Review Board.**

As an example of port growth in the early years of the new millennium, the Port of Virginia has already experienced significant growth since 2000. From 2000 to 2006, the Port of Virginia’s total cargo tonnage increased 36 percent and containerized cargo (Twenty-foot Equivalent Units) increased by 46 percent (Port of Virginia, 2006). The 2020 projections are not affected by the potential of an Arctic route unless the most extreme warming and melting trend is experienced. In addition, a question remains of whether or not an Arctic route will increase overall shipping activity in the U.S. It is likely that if a polar route provides greater efficiency, then there will be greater activity overall.

## **Chapter 5: Current Ecological Impacts**

The last 50 years have brought greater attention to the impact of human activity on the environment. The National Environmental Protection Act (NEPA) of 1969 directed and drove the American desire to “encourage productive and enjoyable harmony between man and his environment; to promote efforts which will prevent or eliminate damage to the environment and biosphere and stimulate the health and welfare of man; (and) to enrich understanding of the ecological systems and natural resources important to the Nation” (Jenson, M & Bourgeron, P. 2001, 29). In particular, NEPA directed attention to preserving marine life and ecosystems from human activity.

Marine conservation biology, which is an activist movement of science, has emphasized a need to understand human impacts before they result in irreversible damage in marine ecology. Shipping and its supportive infrastructure create a disturbance to local ecosystems and a vector for biological invasion (R. Mann, 2006, 28). Marine shipping therefore has influenced the biogeography since the beginning of shipping practices (25). Because maritime shipping is concentrated in specific ports where items are exchanged, the coastal and estuarine environments and ecosystems endure the majority cumulative abuse (25). In fact, marine transportation imposes many different types of abuses on a local ecosystem. Invasive species, petroleum pollution, marine litter, port run-off, and anti-fouling chemicals make maritime transportation a noxious use. However, individually a single ship will not have as great of an impact unless there is a significant event or catastrophe, like the moderate spill of the *Exxon-Valdez*. The ecological impacts are often a result of the concentration of shipping activity in a specific confined area.

Ports and the surrounding areas receive the brunt impacts of marine transportation pollution.

### **Oil and Litter**

Oil and litter are two particularly byproducts of marine transportation. Oil in the ecosystem can be from many sources from cargo spills, to slow leaks, discharges from ships, and the pavement on the port's parking lot. While oil spills attract the media's attention, spills contribute to two percent of the total oil pollution in U.S. waters (Ocean Studies Board and Marine Board, 2003). The larger contributors to aquatic oil pollution include discharges from vessels and run-off from terrestrial sources. Oil often forms tar when discharged into the sea (Galil, 2006, 43). Even smaller concentrations of tar can negatively affect on marine biota. Aquatic life such as turtles and seabirds ingests tar (44). Higher concentrations of oil and oil spills can lead to smothering and other toxicity issues. Chronic effects can create difficulties for marine biota to reproduce and alter feeding habits and abilities (44). Additional impacts include abnormal growth, behavior, and susceptibility to disease that could cause changes in the distribution of marine species (45).

In addition, marine pollution includes several concerns over marine debris. Ship generated litter is a persistent but overlooked problem for marine ecosystems worldwide, and acknowledged only in recent decades (Galil, 2006, 47). The exact amount of marine debris is difficult at determine, but plastics consist of the majority of marine debris (LukeReilly, 2005, 3). Comprising 60 to 80 percent of marine debris, plastic's prevalence is attributed to the increase of use compared to other types of material (Derraik, 2002, 842). A 1982 estimate suggested that 639,000 plastic containers per day were released by

merchant vessels (Horsman, 1982, 167). In addition, the dumping of litter and debris is increasing and is often concentrated near specific ports, canals or other marine transportation structures (Derraik, 2002, 844). The impacts of marine debris are substantial but are often dismissed on some level because of the vastness of the oceans. As a result, the problem is becoming concentrated in specific areas. The longevity of modern marine debris is contributing to an overall increase in litter. Plastics can remain for hundreds of years, four to five times longer than aluminum and hundreds of times longer than paper products (LukeReily, 2005, 3).

The slow rate of decomposition, plastics have a substantial impact on marine biota. Plastics are often ingested by organism, particularly birds which mistake the plastic for potential food sources (Derraik, 2002, 844). If plastics or other forms of marine litter settle to the ocean floor, then there is the potential for colonization of hard substrate benthic organisms exists, where only soft bottom benthic organisms existed prior to the settling.

Marine debris is an important vector for invasive species. Floating debris may accumulate various organisms over time. As a result, drifting debris introduces some types of aquatic organisms. (847). Plastics are a major component of marine debris pollution and contribute to the potential spread of invasive species, but comparatively, marine debris does not have the same ability to transport large numbers of organisms compared to container ships.

### **Invasive Species**

The term “invasive species” is not a standardized term with the same meaning in all literature. Instead, like many terms such as exotic species, introduced species, non-

native, imports, or weeds, it is a general term that describes the process whereby human activities transport organisms (Ruiz and Carlton, 2003, ix). Invasive species are sometimes regarded as specific species, which are able to produce self-sustaining populations or colonies, and then spread to other regions (xi).

Invasive species represent a unique challenge when compared to other forms of pollution. In one sense, the transport of species does not exactly damage the environment. Rather, it changes the environment and the changes are often valued differently. In addition, there are instances of perceived benefits from the introduction of specific species which provide a desirable function. When a species is introduced and the desired effects are not beneficial, then the species might cause a significant problem if it reproduces and spreads. Species with higher reproduction rates, greater resistances to environmental conditions, or greater competitiveness than local species are difficult to eradicate. An established exotic species may be considered one of the most permanent forms of pollution.

Modern transportation allows for a greater likelihood of introduced species to colonize new environments. While there is a natural process by which species migrate, the advancements of human transport creates processes where species can be transported rapidly around the world, both deliberately and accidentally (Galil and Minchin, 2006, 71). In addition to the increased ability of the transport of species, an increase in the numbers and impacts of invasive species have continued to rise. (Ruiz and Carlton, 2003, ix) Faster transportation results in higher survival rates for hitchhiking or transported organism. Consequently, species redistribution as a process of global trading patterns has

homogenized many areas of the global biogeography through movements of biota to locations outside their normal ranges (R. Mann, 2006, 25).

The greatest mechanism for the transport of invasive or non-native species is transport by marine vessels (Siguan, 2003, 183). Of all 316 nonnative invertebrate species in North America, amounting to 52 percent are identified as the direct result of shipping with an additional 21 percent of species that were probably introduced by shipping in the past (Fofonoff et al., 162).

Means of transport is through attachment to the surface of a vessel such as the hull of the ship. Organisms transported by attaching to the structure of a ship, or fouling, are normally small in size (Siguan, 2003, 186). The second means of transport is by the ship's ballast tank or tanks, which collects water and therefore various species from one area and discharge them in another through the process of balancing the ship. Seventy-nine million metric tons of ballast water are released annually into U.S. waters and over 300 million tons worldwide. (Siguan, 2003, 188-189) In addition, ballast transportation as a vector for biological invasion is not selective of the species transported. Unlike fouling which requires a prolonged attachment to the surface of a hull or rudder, ballasts can take in several different types of organisms. While some species do not survive ballast transport, planktonic species, cysts, spores and other resistant forms can undergo ballast transportation (190). As a result, ballasts can only transport specific species, but it is less selective than fouling transport.

Marine transportation has been estimated to contribute to 59 percent of the non-native aquatic plant population (Siguan, 2003, 187). The redistribution of animal species is likely to show a similar effect. Invasive species are going to continue to pose different



challenges to various environments depending on the speed and concentration of the introduced species.

## **Chapter 6: Connecting Climate Change, Shipping Practices and the Ecology**

The literature supports a consensus that the climate is changing in a warming trend. In addition, models show a high probability that the climate change will affect the Arctic region, which have already experienced rapid change and melting. Furthermore, human productivity is another global trend that parallels climate change and changes in the Arctic. Global human activity has increased significantly in the past century. This activity has resulted in the globalization of many economies. The globalization is supported by the high-volume, cheap, and relatively-fast ability for transoceanic shipping to move goods. Shipping activity has increase in the United States, often much more quickly than predictions indicated. Tonnage and container traffic have more than doubled between 1985 and 2000. This doubling is due to the global economy and greater efficiency in the marine freight industry.

Increases in ship size, design, organization and speed have transformed how quickly humans can impact themselves and the world. The increased human activity has had environmental consequences that have multiplied over the last few decades. Oil pollution, marine debris, and invasive species are effects of the global shipping practices. While climate change, Arctic melting, globalization, and ecological effect are substantial topics, today, there is a future consideration of the effects of climate change, globalization, and marine pollution that have yet to be addressed. Current research has not addressed how these global changes will affect the local environment.

Future global shipping patterns resulting from climate change will affect local ecosystems just as increased maritime activity has historically had substantial ecological

consequences. There is a need to synthesize and project the known impacts of climate change, ice melting, shipping activity, and shipping pollution with potential scenarios of future conditions.

## **Chapter 7: Methodology**

The objective of this research is to produce a long-ranged projection of future marine shipping patterns for Pacific and Atlantic ports based on existing climate knowledge and research as to assess of the potential effects of global warming on Arctic shipping and local shipping corridors. The “local” shipping corridors are defined as regions that major ports operate. For this study, the Atlantic seaboard ports of the metropolitan regions of New York/New Jersey, Hampton Roads, Charleston, and Savannah, are the primary ports of interest. The Ports of Los Angeles, Long Beach, Oakland, Tacoma, and Seattle will represent the major West Coast ports. The study did not analyze the Gulf Coast ports, such as Houston because many of the Gulf ports have concentrated on the transport of non-containerized bulk cargo such as crude oil. Furthermore, the Gulf ports do not easily serve as potential destinations for trans-Arctic routes. The inland ports, Hawaii and Puerto Rico are excluded since these ports have special factors affecting their trading patterns.

The first object of this research project is to identify the future activity of maritime shipping for the U.S. The basis for the projection is tonnage and twenty-foot equivalent units projected based on extrapolation techniques on past data. Total U.S. tonnage, U.S. containerized and individual ports future volumes are extrapolated from the 1956 through 2003 data for tonnage and 1980 through 2006 data for containerized units. The trans-Arctic scenario based on a percentage redirection of TEU volumes.

Historical and recent growth trends of cargo measured in metric tonnage and twenty-foot equivalent units, commonly referred to as (TEUs) . Although modern shipping practices have moved to using forty-foot containers, the twenty-foot equivalent

units are still used to measure port activity volume. As a result, forty-foot containers are often counted as two TEUs. While twenty-foot equivalent units do not measure actual ship activity, TEU data is easily accessible and normally has about ten to fifteen years of records. Both tonnage and twenty-foot equivalent units will be projected based on non-component projections. Previous patterns of TEU increase will provide an historical pattern to the model and allow changes between port patterns.

In addition to the tonnage and twenty-foot equivalent unit projections, this research project will identify trends in how marine transportation is changing as well as factors contributing to the increase in maritime activity. A multiple regression of the variables that may affect marine transportation will examine the factors driving the growth of maritime freight transportation and explain the strength of any relationships. In order to assess the changing size of marine vessels this research project utilized a trend analysis to determine future shipping size based on recent orders placed for new vessels.

Existing research into the effects of marine transportation will determine the ecological risk that future shipping might cause. Effects such as oil, litter, dredging, and introduction of non-native species will be loosely based on S. J. Tuner and Alan Johnson's (2001) theoretical framework for ecological assessments. This research will address both the current impacts of marine transportation on the environment. The physical, chemical, and biological pollution will be individually assessed in both the current context and the context in which it will likely evolve by the time the trans-Arctic route becomes feasible.

The ports' activity is likely to grow based on projections such as Global Insight, Inc.'s projections for the year 2020. (TRB, 2005, 51) This growth will determine the

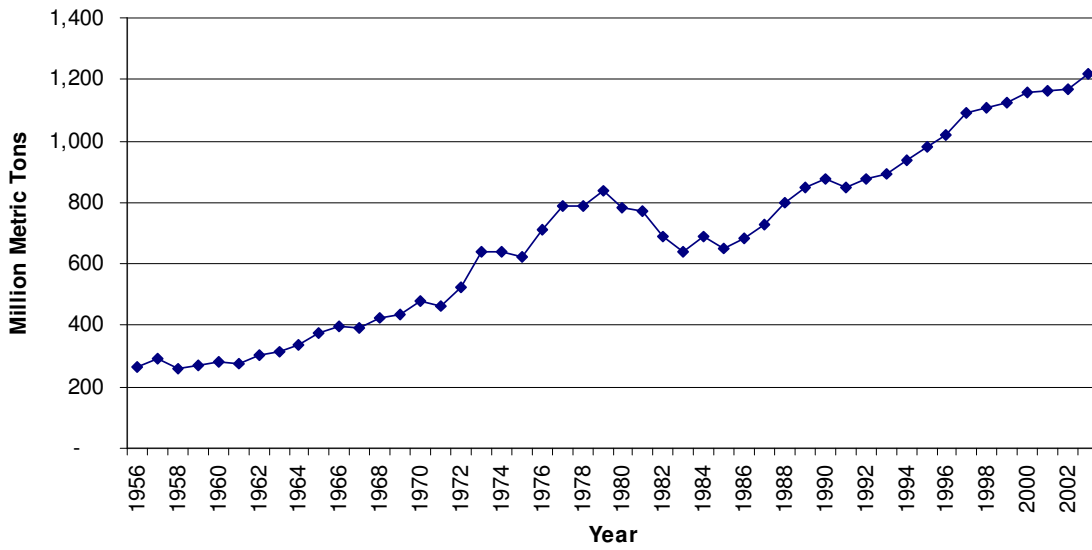
future impact of the port to the local systems. To combat the problem of forecasting port demand 12, 20 or 32 years into the future, a range of potential scenarios with varying growth predictions will develop many alternative options. The study projected the 2007 anticipated growth in maritime shipping through 2040 to assess the status of maritime shipping on the anticipated eve of the opening of a viable trans-Arctic route. Ultimately, the majority of this research is to predict the future shipping patterns of transoceanic shipping into the eastern United States. The secondary purpose of this project is to identify the potential ecological impacts of change in global shipping. Both aspects look at the potential changes several decades into the future and may have a wide scope of possible outcomes, but combined, the two analyses will exhibit how human activity will continue to affect the future ecosystem.

## **Chapter 8: Existing Conditions of Maritime Shipping**

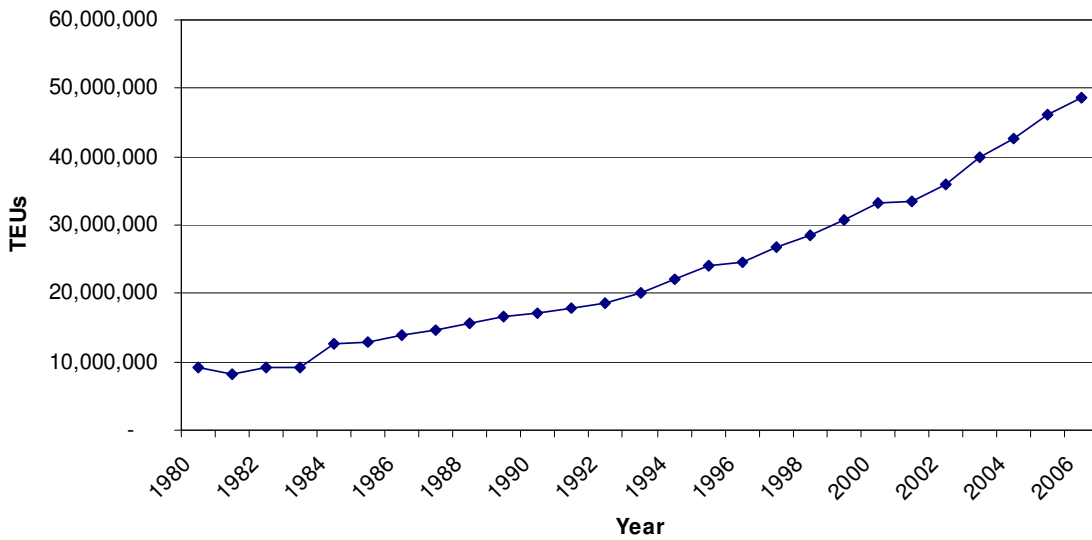
Currently, maritime freight and marine ports are an expanding industry. In the last twenty years, there has not been a decrease in containerized traffic entering American Ports and only one year of declining tonnage. Furthermore, there has only been one time since 1956 that the United States experienced a multiple-year decrease in total cargo tonnage. Overall, marine shipping is a relatively stable and growing practice. Marine shipping's stability is associated with the overall world economy. A single financial crisis in one country will not necessarily cause a decrease in shipping traffic. The faster the world's economy grows, the faster maritime freight will expand. This chapter addresses the current factors affecting maritime transportation and the first objective of the research project.

### **Current Marine Shipping Conditions**

Both containerized traffic and total tonnage of maritime trade has increased over the past decades. Total tonnage has increase about 3 percent or 23.3 metric tons per year for the last 50 (Figure 2) years while containerized traffic increased 7 percent or 1.52 million twenty-foot equivalent unit containers a year since 1980 (Figure 3). Furthermore, the number of twenty-foot equivalents has doubled every ten years since 1983. For comparison, the annual growth of containerized traffic is roughly equal to the total containerized traffic for the Port of Houston in the year 2006. This rate of growth is likely to increase in the next few decades, especially if a current trend in the globalization of traded commodities continues.



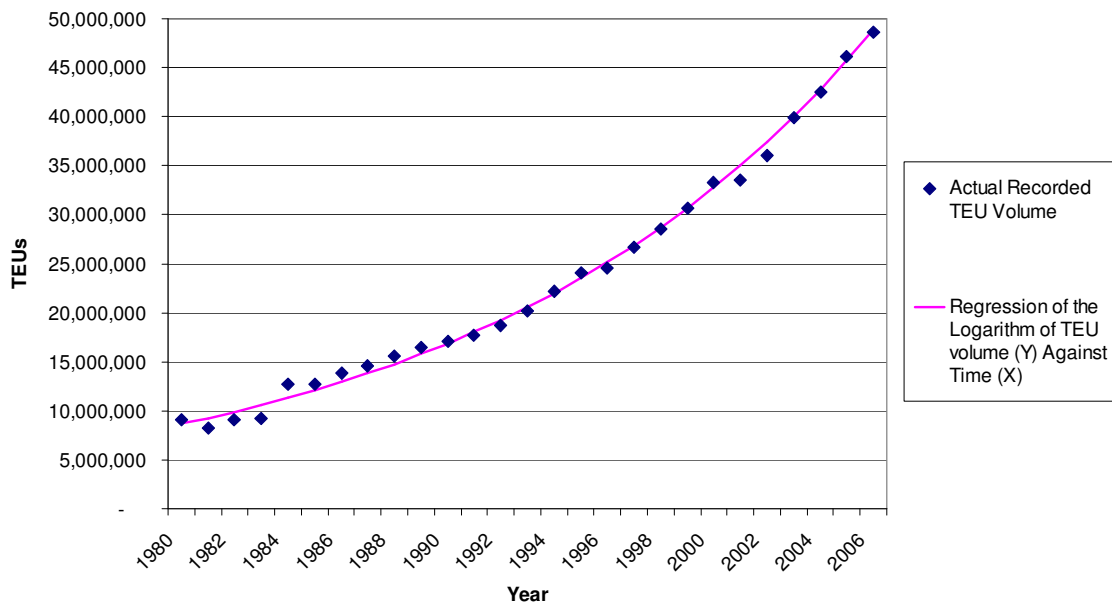
**Figure 2: Annual Increase of Total Tonnage for American Maritime Trade**  
 Source: U.S. Maritime Administration, Waterborne Databanks



**Figure 3: Twenty-foot Equivalent Units Traffic Since 1980**  
 Source: American Association of Port Authorities, Port Industry Statistics



The trade of commodities in twenty-foot equivalent units has increased faster than total tonnage of all maritime trade including cargo containers, roll-on roll off vehicles (ro-ros), bulk, and crude oil. While the total tonnage of maritime freight appear to have a roughly linear growth pattern, (Figure 2) containerized maritime freight or twenty-foot equivalent units have experience a nearly exponential growth curve. (Figure 4) This difference between the growth rates of total tonnage and containerized cargo is now affects how shipping practices are conducted for demand in both the short-term and long-term period demand.



**Figure 4: Actual Recorded Volume of Twenty-foot Equivalent Units Compared to a Projected Regression of the Logarithm of Twenty-foot Equivalent Units Against Time.**

**Factors affecting Marine Freight**

Data of the U.S. shipping tonnage, U.S. gross domestic product, U.S. population, world population, and world production all show a long and steady period of growth between 1960 and 2003. Traded tonnage demonstrated a similar trend and showed strong

correlation (Table 2) with world production (0.95097), world population (0.93649), and U.S. gross national product (0.92752).

**Table 2: Factors Correlating with Total Tonnage in Maritime Trade 1980 through 2003**

|                                 | <i>US Pop</i> | <i>GNP<br/>(In Billions)</i> | <i>World<br/>Population</i> | <i>Shipping<br/>Tonnage</i> | <i>World Product<br/>(in Trillions)</i> |
|---------------------------------|---------------|------------------------------|-----------------------------|-----------------------------|---|
| US Pop                          | 1             |                              |                             |                             |   |
| GNP<br>(In Billions)            | 0.70329       | 1                            |                             |                             |   |
| World<br>Population             | 0.70090       | 0.98065                      | 1                           |                             |   |
| Shipping<br>Tonnage             | 0.61629       | 0.92752                      | 0.93649                     | 1                           |   |
| World Product<br>(in Trillions) | 0.69941       | 0.99189                      | 0.99310                     | 0.95097                     | 1                                       |

Source: U.S. Maritime Administration, U.S. Census, Earth Policy Institute.

To understand the interaction of these variables and association between freight tonnage and global factors, several multiple regressions showed a strong relationship with the variables. A multiple regression of four variables, the gross national product, world population, gross national product multiplied by world production, and world population multiplied by world production accounts for 93 percent of all variation in the data.

**Equation 1: Regression to Forecast U.S. shipping Tonnage Based on Data from 1956 through 2003**

$$\begin{aligned}
 \text{Shipping Tonnage} = & 2168.29776997909 \\
 & 0.116920582(\text{GNP}) \\
 & - 0.0000000913598(\text{WorldPop}) \\
 & - 0.005717181(\text{GNP} \cdot \text{WorldPop}) \\
 & - 0.00000000028337(\text{WorldPop} \cdot \text{World Prod}) \\
 & + \varepsilon
 \end{aligned}$$

Furthermore, all variables exceeded a 95 percent confidence interval with the exception of the gross domestic product that attained a 94.6 percent confidence.

Furthermore, a multiple regression of the data with the same variables that occurred in only the last twenty years accounted for over 99 percent of the variation of the data with

all variables being above 99 percent confidence interval. The model shows that the population and the economy contribute to the shipping activity.

$$\begin{aligned}
 \text{Shipping Tonnage} = & 3283.54128535403 \\
 & + 0.378616346(\text{GNP}) \\
 & - 0.000000116979(\text{WorldPop}) \\
 & - 0.007385834(\text{GNP} \cdot \text{WorldPop}) \\
 & - 0.00000000016245(\text{WorldPop} \cdot \text{World Prod}) \\
 & + \varepsilon
 \end{aligned}$$

Equation 2: Regression to Forecast U.S. shipping Tonnage Based on Data from 1983 through 2003

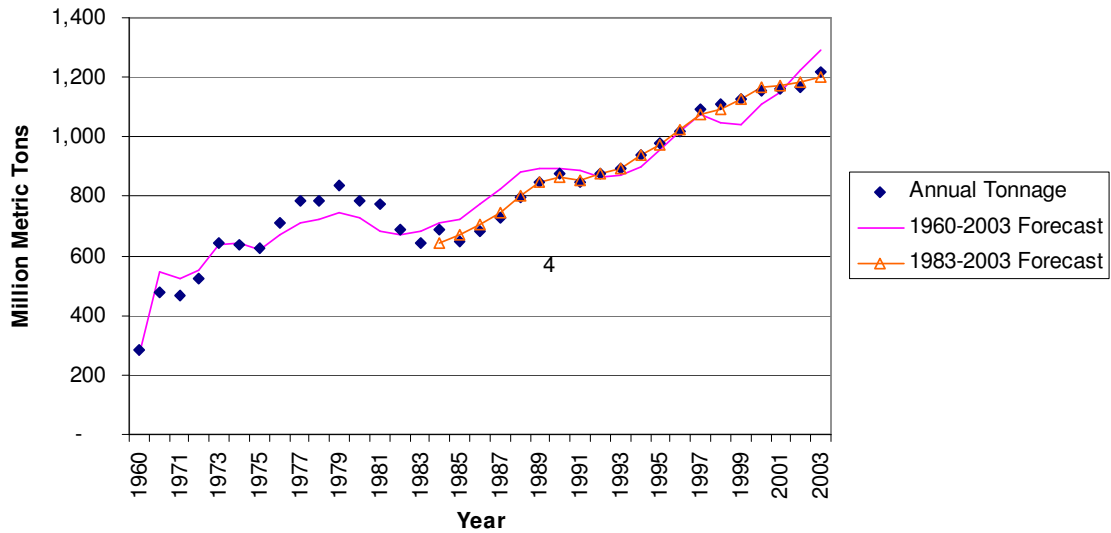


Figure 5: Actual Shipping Tonnage and Forecasts bases on Population and Production Trends

In particular, Equation 2 shows the U.S. gross national product having a positive relationship with total tonnage. In addition, the world population multiplied by world production shows a positive relationship. Therefore shipping activity increases as these variables increase. Interestingly, the world population variable appears as an inverse relationship. This inverse relationship suggests that as world population decreases, shipping would counter intuitively increase or vice versa ,but both world population and

shipping are likely to increase. Furthermore, while shipping has a few years of decreasing tonnage, U.S. population, U.S. gross national product, world population, and world production did not have any declining years. The discrepancy might be that the model does not distinguish between populations in developed, developing, and undeveloped countries. Poverty exists in underdeveloped countries, where most population growth is occurring; therefore, increased world population might not correlate with lower economic status.

### *Vessel Size*

The late 1970s and the early 1980s was the birth of modern containerization. While standardizing cargo containers or boxes was established before the current form of metal containers, the use and the recording of twenty-foot and forty-foot containers did not become dominant until about 1980. Since the 1980s, maritime freight increased the global commodity trade. As a result, the containerized process might have initiated a portion of the process of mass globalization and this economic force.

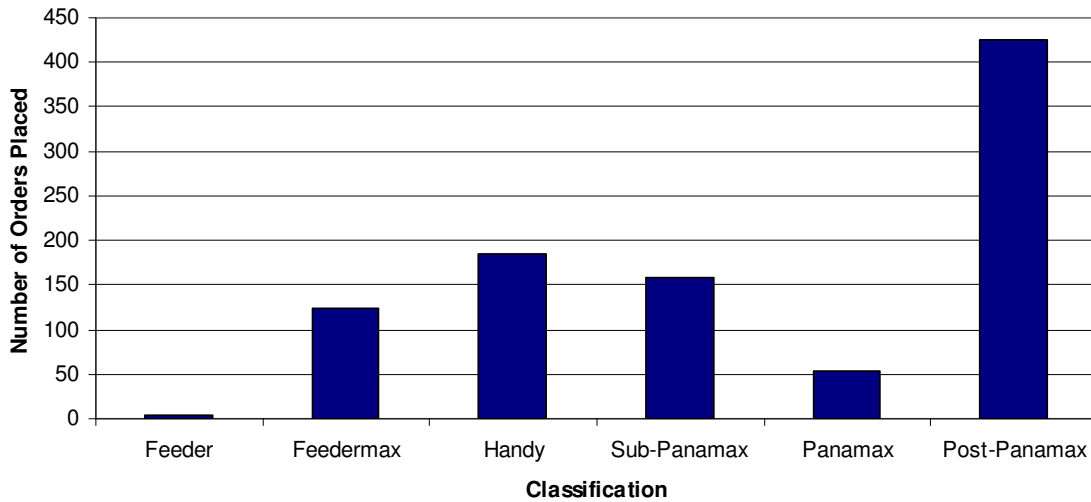
The exponential growth observed in containerized traffic (Figure 4) has changed the shape and design of cargo ships. From 2001 through 2004, the size of container ships increased and the types of ships increased. The classifications of cargo ships are dependent on two factors. The load, which the ship can carry, and the ability of the ship to pass through certain canals such as the Panama Canal. The types of ships from smallest to largest include: Feeders, Feedermax, Handy, Sub-Panamax, Panamax, and Post-Panamax. Feeders are the smallest cargo ships normally utilized in trade to and from American ports. Feeders normally do not hold more than 500 twenty-foot equivalent units. (U.S. Maritime Administration, 2005, 2) The next class of vessel is the feedermax

class which holds between 500 and 1,000 twenty-foot equivalents 2). The Handy class is larger than the feeder classes with a maximum capacity of 1,000 to 2,000 twenty-foot equivalents (2). The next few classes of vessels are based on their capacity as well as their relation to the Panama Canal. The Sub-Panamax and Panamax are able to utilize the Panama Canal while the Post-Panamax is too large. The Sub-Panamax can hold between 2,000 and 3,000 twenty foot equivalent units and the Panamax holds between 3,000 and 4,000 units (2). Finally, the Post-Panamax ships can hold well over 4,000 twenty-foot equivalent units and is unrestricted in size because it no longer attempts to conform to the requirements of the major canals (2).

The increasing demand for goods shipped in containerized units has caused an increase in the number of containerized units imported and exported from American Ports. Furthermore, this increase in the number of containers has led to a drastic increase in the size and number of containerized vessels, particularly in transoceanic shipping. Just the four years from 2001 to 2004 saw a dramatic change in the types of vessel used in maritime freight trade, leading a significant shift in marine transportation.

The overall capacity and size of the ships increased in order to carry more containers per trip.(Figure 7) While Sub-Panamax ships outnumbered the larger ships by three vessels to one, the smaller ships only carried about 44 percent of the world total in containerized cargo in 2004. Furthermore, that percentage has decreased significantly since 2001 when smaller ships accounted for over 55 percent of containerized cargo. The number of Panamax and Post-Panamax ships increased over the four years period by 45 percent, and the tonnage increased by 55 percent. The Post-Panamax ships carried 31 percent of all containerized traffic in 2001, but the shipping industry has been increasing

the size and number of Post-Panamax vessels, resulting in an increase their world cargo share to 42 percent in 2004. The continued growth in the size and capacity of container carrying vessels is likely to continue based on orders placed from 2001 through 2004.

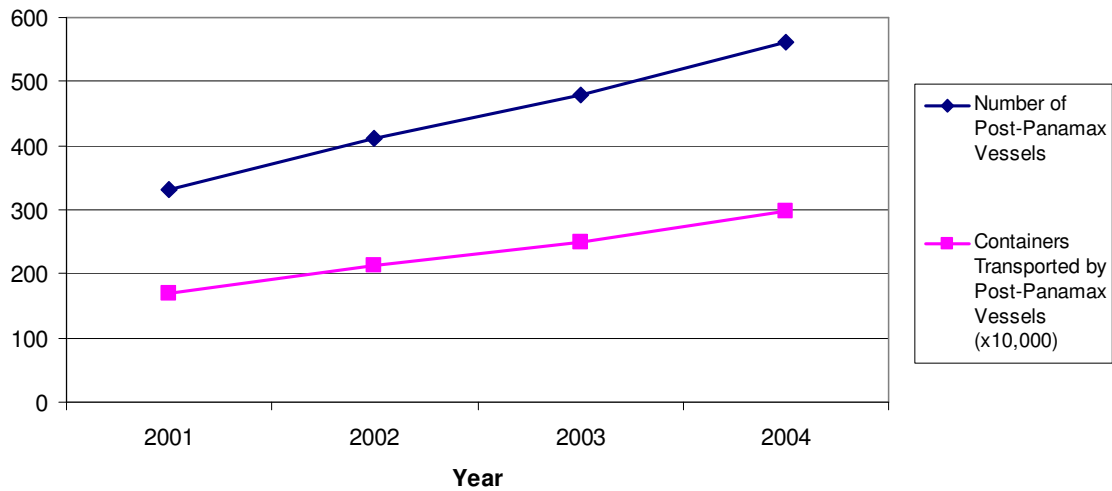


**Figure 6: Orders of New Ships from 2001-2004**

Source: U.S. Maritime Administration. *Containership Market Indicators*. August 2005.

Orders for new ships placed between 2001 and 2004 showed a strong demand for large ships, particularly Post-Panamax vessels. Within the four-year period, Post-Panamax orders comprised 44 percent of all new ship orders.

The Post-Panamax class is projected to carry 74 percent of all twenty-foot equivalent units of carried by new vessels. This increase in the orders for new vessels will further increase the percentage of all containerized cargo transported by Post-Panamax vessels. Designs for future Post-Panamax ships are 40 percent larger than the current largest container ship, the Regina Maersk.



**Figure 7: Post-Panamax Vessels and Containers 2001-2004**  
**Source: U.S. Maritime Administration. *Containership Market Indicators*. August 2005.**

The increase of the number of Post-Panamax vessels has yet to reduce the total number of containerships. The total number of containerships increased from 2,895 to 3,375 or 16.5 percent from 2001 through 2004. While the number of operating vessels smaller than Post-Panamax continues to increase, in number and containers transported, smaller vessels' overall market share of the containerized cargo is decreasing worldwide.

## **Chapter 9: Future Human Conditions**

The future state of world conditions is important in determining the future for marine shipping. The physical condition of the polar sea routes and the status of the world economy are the two factors that influence trans-Arctic shipping. While climate change models suggest a navigable Arctic passage could be feasible by as early as 2040, there must be a market demand for the transport of goods before any freight activity begins in the Arctic Ocean. This chapter explores different ways to forecast maritime activity and identify criteria for selecting likely scenarios.

### **Growth of Worldwide Gross Domestic Product**

World productivity and gross domestic product of the industrialized and developing countries dictate demand for international trade and therefore marine shipping. Strong trading activity is often a sign of a strong economy while weak trading usually suggests a struggling economy. For this reason shipping and economic activity normally function in a similar pattern. Unfortunately, there are few long-term forecasts for global economic activity and current models only project to the year 2015. (IPCC, 2005, 3.3.3) However, the Intergovernmental Panel on Climate Change has adopted a model for long-term economic growth as a means of forecasting potential carbon dioxide levels. The Intergovernmental Panel on Climate Change predicts that between the years of 1990 and 2020, the worldwide average for gross domestic product will increase between 0.5 and 2.6 percent a year with industrialized and developing countries' gross national products increasing 1.5 and 3.5 percent per year. (IPCC, 2005, 3.3.3) The increase in the average gross domestic product will continue from 2020 through 2050.



Furthermore, the yearly percent growth will increase to an average of 1.9 to 3.9 percent.

(3.3.3) Industrialized and developing countries will continue to have a greater growth rate.

### **World Population**

World population indirectly influences shipping activity, but population has a significant role in world productivity and, in some cases, the U.S. gross domestic product. Most population projections forecast an increase in the world population in the first half of the 20<sup>th</sup> century. (8.1) Two scenarios are possible; either the global populations continues an uninterrupted growth rate for the next 50 years or that sometime in the next 50 years, the global population will peak, and then level off with little future growth when the earth can no longer support the human population expansion. (8.1) Regardless of these scenarios, the world population will be greater than its current population. The Intergovernmental Panel on Climate Change predicts that the global population in 2050 will be between 7.1 billion and 15 billion individuals. (IPCC, 2005, 8.1) Furthermore, the average per capita income is increasing, driving the demand for goods from around the world.

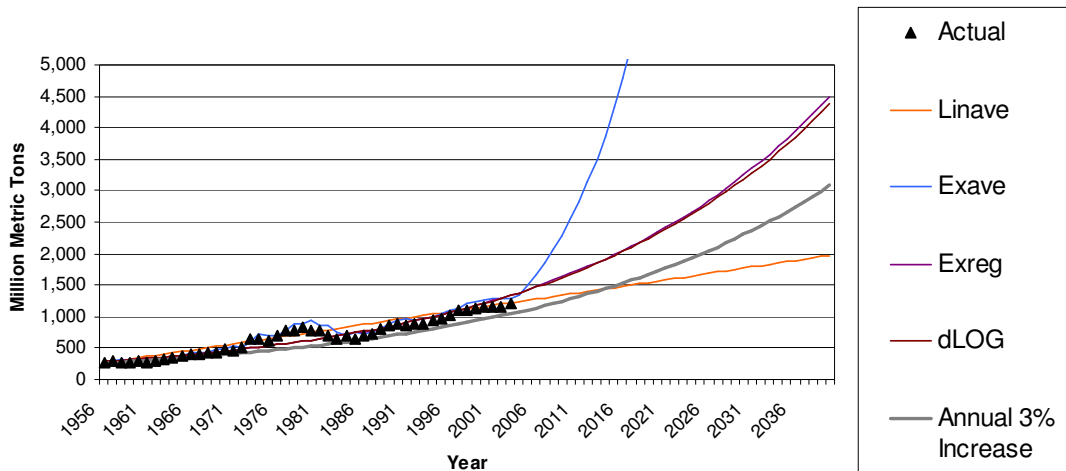
Human activity is increasing and the actions and consequences will increase as well. The global population is increasing dramatically. Building on the population boom, the rate of world production grows with the global average gross national product. Marine shipping and port activity will continue to grow for as long as the global economy remains productive.

### **Growth of Maritime Shipping 2007 to 2040**

The first half of the twenty-first century will bring one of the greatest accelerations of maritime trade. While the last two decades saw the birth and growth of containerized shipping, the pace of growth in the first few years of the new millennium appears to be quickening. Even with recent questions on the health of the economy, 2007 was a record year for some ports handling containerized traffic. (Jeff Berman, 2008) This growth in marine freight will increase because of a growing global economy, particularly in Asia, and shipping companies and ports are increasing capacity accordingly.

### **Future Tonnage**

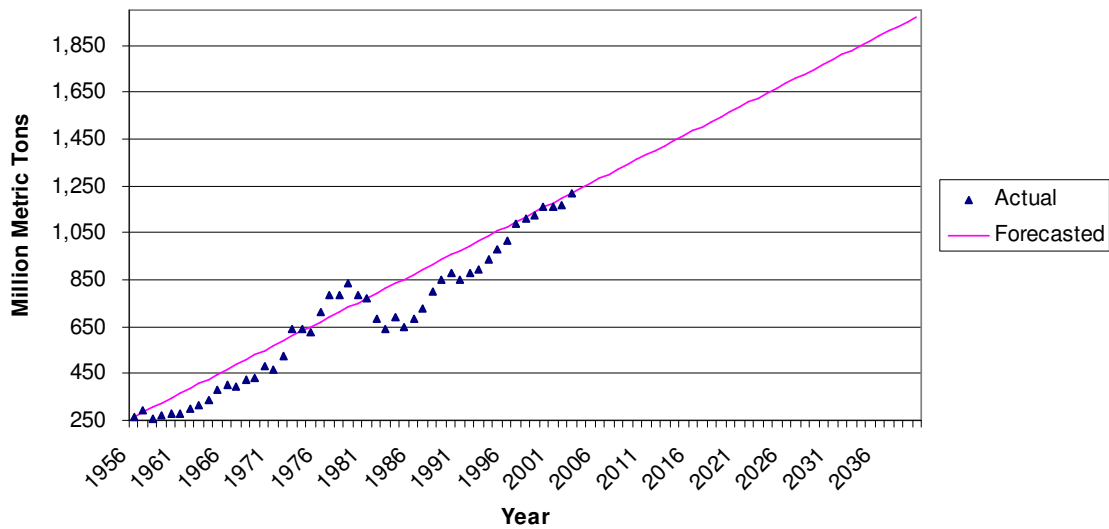
Future total tonnage will increase at a slower rate than containerized cargo, but it will increase significantly by 2040. Tonnage appears to have followed a linear growth pattern, particularly since the early 1980s. However, it might have a shallow slope exponential long-term projection. Figure 8 summarizes all of the projected growth scenarios that are discussed in the next several subchapters. Most of the exponential projections based on the past data depict a strong increase in tonnage, but this increase is unlikely since moving large amounts of mass will require ships and port infrastructure beyond likely technology. Furthermore, many of the goods transported across the seas are becoming lighter, especially with electronics becoming a more common commodity. Therefore, tonnage will grow more slowly in comparison to the amount of containerized traffic. The likely scenario is an annual growth rate in tonnage between 2 to 6 percent a year. This growth will lead to a projected tonnage of between 2 and 3.5 billion metric tons by 2040.



**Figure 8: Seven Projections of Total U.S. Tonnage**  
**Linave:** Average of Absolute Change over time  
**Exave:** Average Rate of Change over time  
**Exreg:** Regression of the Logarithm of Tonnage over Time  
**dLOG:** Regression of the Logarithm of Tonnage Against the Logarithm of Time

*Average of the Absolute Change in U.S. Tonnage over Time*

The average of the absolute change of total tonnage over time is the projection of a linear increase in tonnage based on the historical average from 1956 through 2003. It projects an average increase of 20.3 million metric tons a year (Figure 9). According to this rate of growth, U.S. tonnage should grow to 1.97 billion metric tons by 2040. This rate of growth is reasonable; however, it might be the slowest likely growth rate of all of the projections with 1.7 percent growth rate in 2007 declining to a 1.03 percent growth rate in 2040.



**Figure 9: Average of the Absolute Change in U.S. Tonnage over Time**

The average change over time projection does provide a decent slope for the overall growth from 1956 through 2003, but it does not quite fit with the years of either tremendous growth or years of decline.

The regression of tonnage against time shows a slower potential growth rate of 1.9 billion tons by 2040 than the average change of tonnage over time. Because it fits neither the actual rate of growth between 1956 and 2003 nor the likely growth projection, this extrapolation was not included in the potential scenarios.

*Average Rate of Change in U.S. Tonnage over Time*

The average rate of change in tonnage over time is the most aggressive growth scenario. While Figure 10 does not appear to be the best long-range projection, Figure 11 does provide an accurate estimation of previous years. While With an aggressive upward slope, the average rate of change over time tends to over estimate the actual growth. In addition, it estimates a temporary lull in growth for 2004 that was not the actual pattern.

As the rate of change is projected further into the future, the growth become less realistic and the final projected tonnage for 2040 of nearly 60 billion tons is not likely.

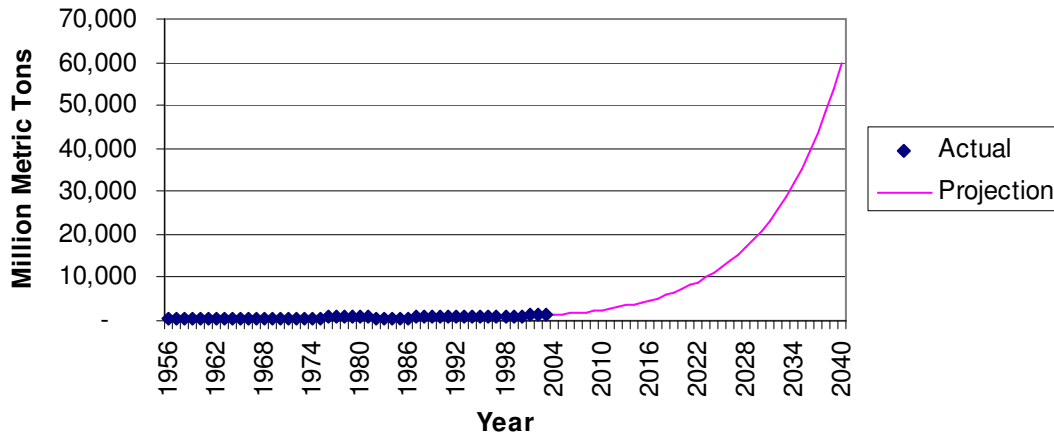


Figure 10: Average Rate of Change in U.S. Tonnage over Time 1956-2040

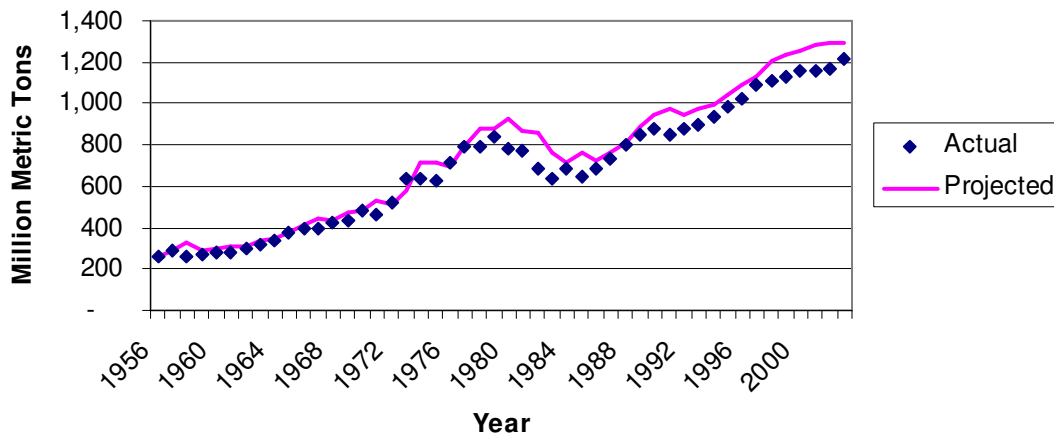
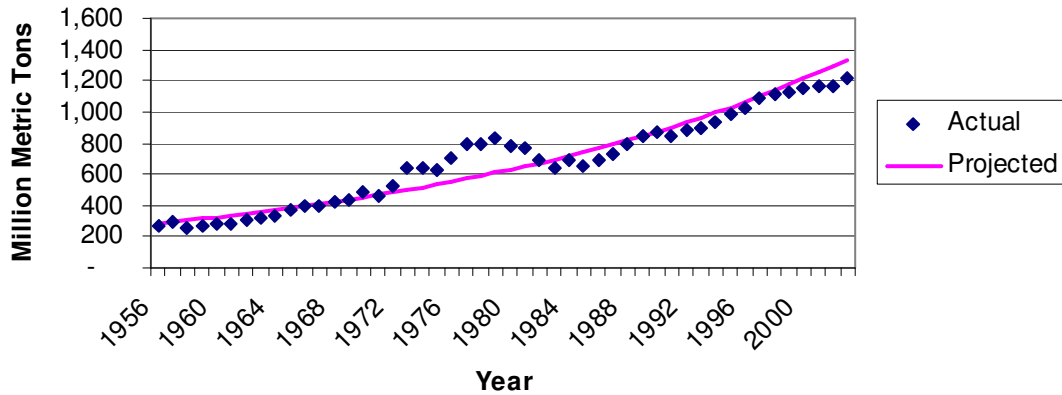


Figure 11: Average Rate of Change in U.S. Tonnage over Time 1956-2004

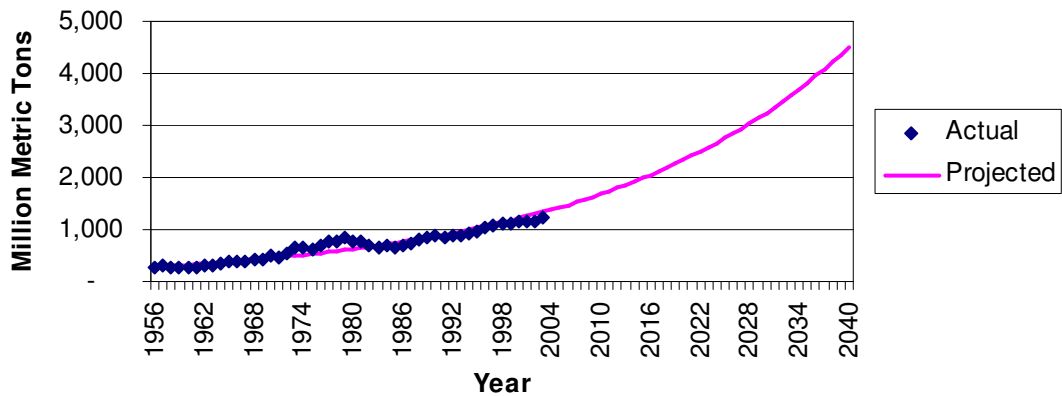
*Regression of the Logarithm of U.S. Tonnage Against Time*

Figure 12, the regression of the logarithm of U.S. tonnage against time, provides a good growth estimation of historical patterns compared to the actual tonnage. The model may suggest stronger increases in. However, Figure 12 does not suggest any temporary decline in shipping activity and cannot account for growth rates exceeding the mean growth rate.



**Figure 12: Regression of the Logarithm of U.S. Tonnage Against Time 1956-2003**

AS displayed in Figure 13, tonnage projected by regression of the logarithm against time suggests a potential likely rate of growth. An increase from 1.4 billion metric tons to 4.5 billion metric tons would be an aggressive, but plausible scenario. While it might not provide the best projection for years with exceptional growth or decline, the model is a strong projection based on historical trends.

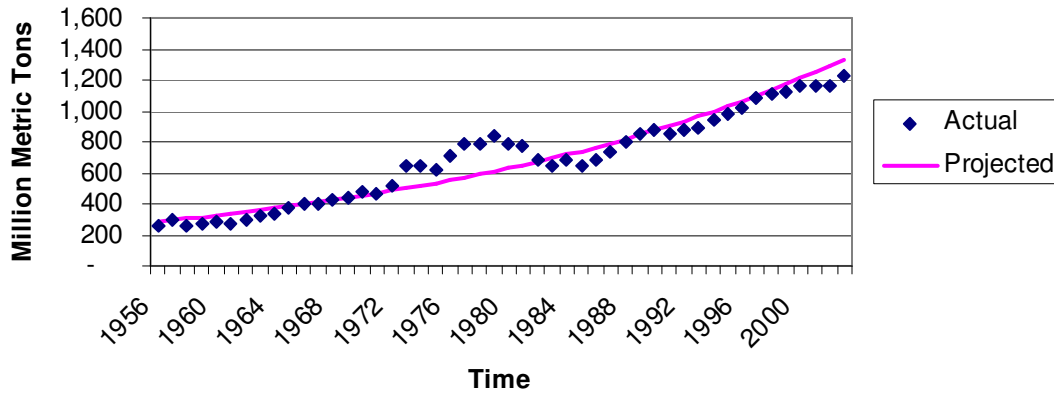


**Figure 13: Regression of the Logarithm of U.S. Tonnage Against Time 1956-2040**

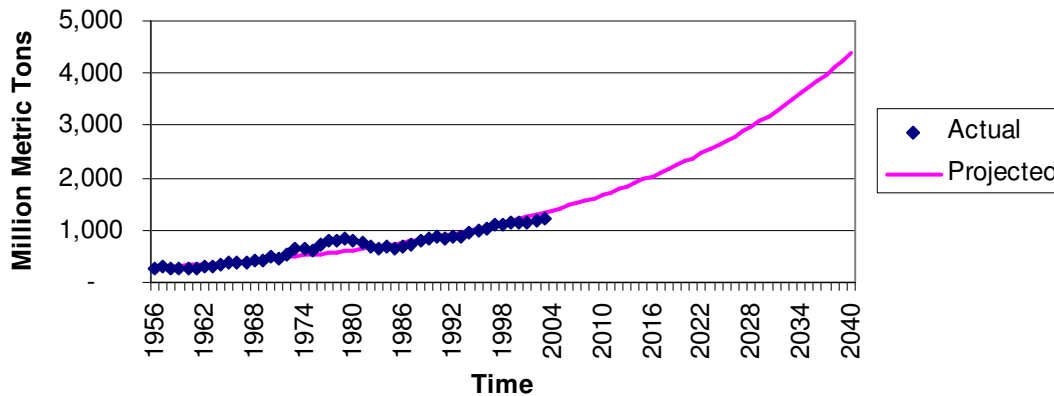
*Regression of the Logarithm of U.S. Tonnage Against the Logarithm of Time*

Figures 14 and 15 show the regression of the logarithm of U.S. tonnage against time, which yields a more likely scenario than the figure 10. The projection show a lightly less aggressive growth rate between 2006 and 2040 than regression of the logarithm of U.S. tonnage against time. The regression projects a total annual tonnage of

4.38 billion metric tons by 2040. While this increase in tonnage is possible, it remains, like the regression of the logarithm of U.S. tonnage against time, an aggressive growth scenario depending on stable growth in the U.S. and world economy.



**Figure 14: Regression of the Logarithm of U.S. Tonnage Against the Logarithm of Time 1956-2003**

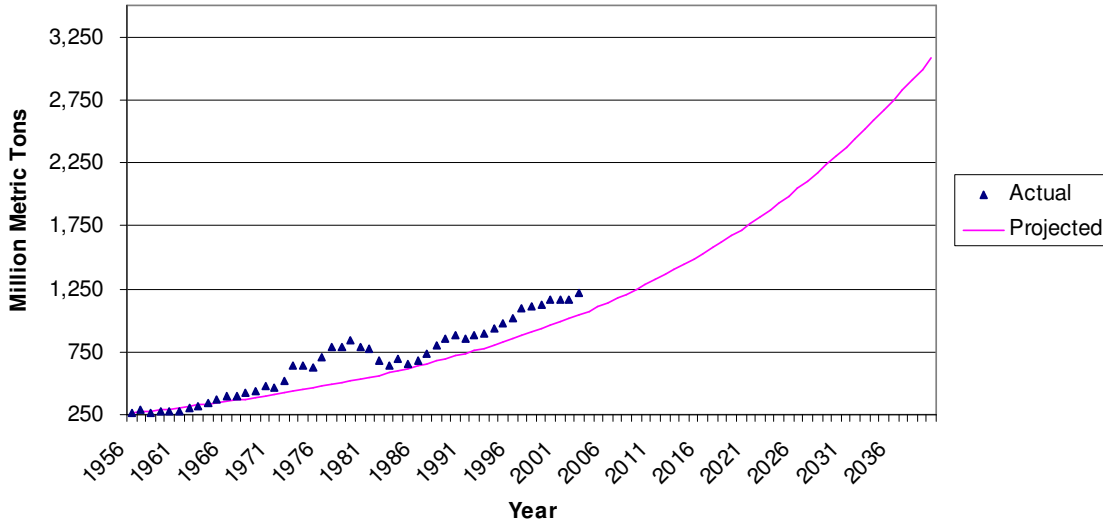


**Figure 15: Regression of the Logarithm of U.S. Tonnage Against the Logarithm of Time 1956-2040**

*Annual Increase of Three Percent*

Figure 16 is the projection of the 1956- 2003 average growth rate of three percent annually. An average of three percent growth is a reasonable growth rate for marine tonnage; however, the historical data do not support this pattern of growth. The projected growth curve is well below most of the data points for actual tonnage (Figure 16). The years with recorded growth are often above three percent, but the addition of years with negative growth reduced the overall average. As a result, years with economic and

shipping expansion are faster growing than projected. The long-term projection of maritime traffic into the year 2040 is a reasonable estimate. If maritime shipping tonnage increase three percent for the next 32 years, then U.S. ports will handle 3.08 billion metric tons. A 162 percent increase over 32 years would be a mid-point between the fastest and slowest growth projection.



**Figure 16: Annual Increase of Three Percent 1956-2040**

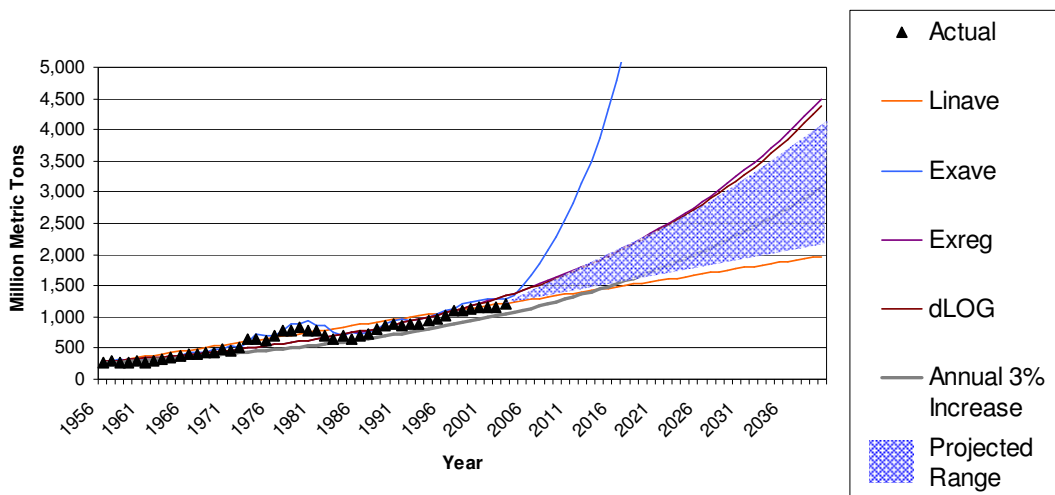
*Preferred Model and Growth Range*

The regression of the logarithm of tonnage over time and the regression of the logarithm of tonnage against the logarithm of time provide the strongest models but both appear to assume a very significant rate of growth. Both of the model provide strong estimates compared to the historical data and form a strong best-fit line. However, the overall growth might be to fast. While the actual future growth rate may have a exponential curve, it is like to have a shallower slope and reside somewhere between the linear projection and the logarithmic projections.

Figure 18 is the range of the average of the absolute change in U.S. tonnage over time, average rate of change in U.S. tonnage over time, regression of the logarithm of



U.S. tonnage against time, regression of the logarithm of U.S. tonnage against the logarithm of time, and the annual increase of 3 percent. Ranging the projections with the larger exponential growth curves with the projections with the slower linear curves creates a moderate growth curve. While this projection might be slightly aggressive in the rate of growth in marine tonnage, a 3.2 billion metric tonnage projection for 2040 may be the upper limit for realistic port growth. Furthermore, the ranged projected growth to the year 2020 of 44 percent is nearly equal with the Global Insight Inc. forecasted 47 percent and the growth rate between 2020 and 2040 (TRB, 2004, 51). As a result, an increase of tonnage traffic of 116 percent by 2040 is on par with other projected growth curves. As a result, the most likely scenario projects about 2.6 billion metric tons being processed an U.S. ports in 2040.

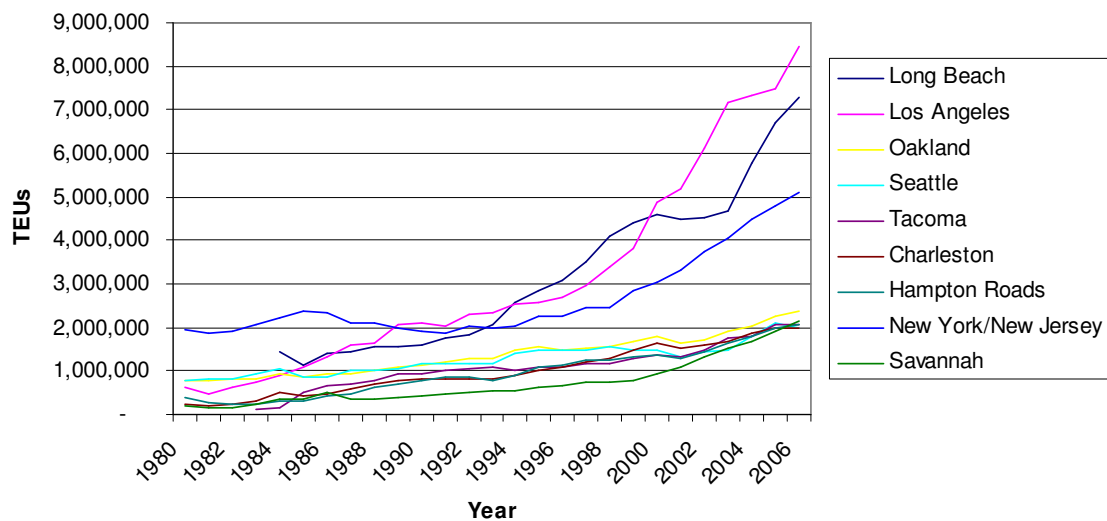


**Figure 17: Projected Range**

**Future Containerized Traffic**

The traffic of containerized cargo has increased dramatically in the last 28 years. Containerized traffic increased from slightly over 9 million twenty-foot equivalents to over 48 million units. In 1980, the Port of New York/New Jersey was the only port in the

United States handling over one million twenty-foot equivalent units a year. Currently, there are twelve ports handling over one million twenty-foot equivalent units, with many other ports handling hundreds of thousands of units. As the twenty-first century progresses, the growth of containerized traffic will increase.



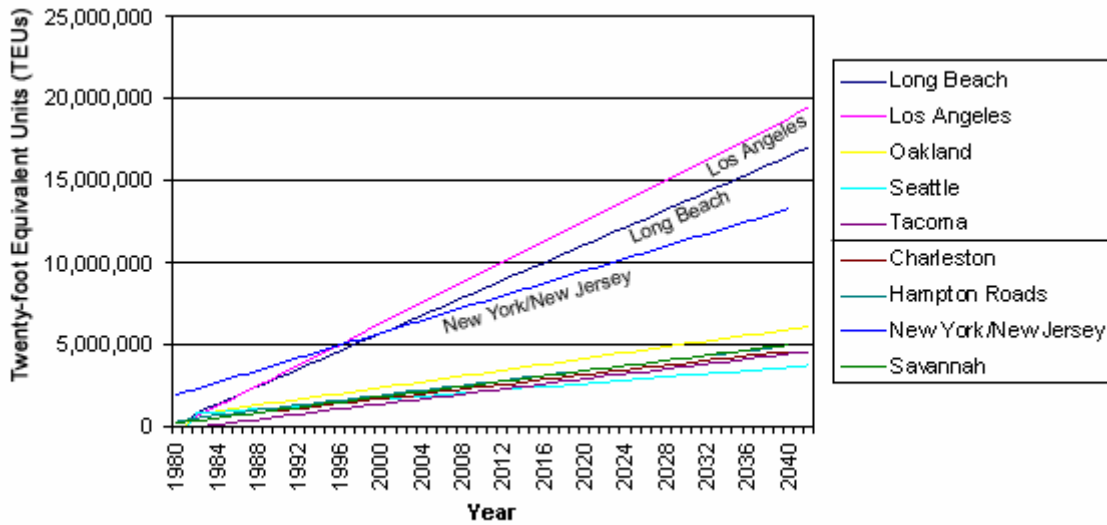
**Figure 18: 1980-2006 Containerized Traffic**  
**Source: U.S. Maritime Administration.**

Future U.S. containerized traffic is likely to be between 100 million and 250 million units by 2040. This is an increase of about 106 percent to 432 percent over the next 32 years. This projected growth rate is similar to other 20-year projections of over 150 percent growth by 2020 (TRB, 2004, 51). The growth rate will not be universal among the various U.S. ports. Current data supports that the growth in volume for the three larger ports will continue to increase at a faster rate than other major ports. The Ports of Los Angeles, Long Beach, and New York/New Jersey have distanced themselves from the other major ports. Because of the difference between the three ports and the other major ports, this study will divide the ports into two groups: the top tier and the second tier. The other major ports in the second tier show significant growth, however their have been relatively similar in growth and traffic since 1980. As a result, it is

expected that the top tier will continue to outpace the second tier in growth, but it might be expected for a second tier to experience rapid growth and become a top tier port.

*Average of the Absolute Change in Containerized Traffic over Time*

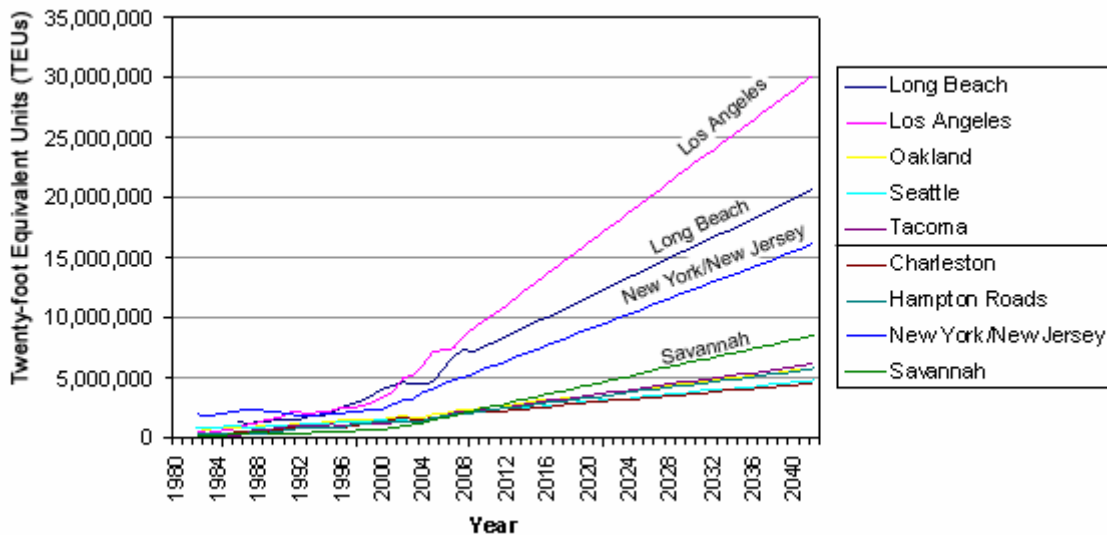
Figure 20 is a linear average of containerized growth. It depicts the steady increase in containerized traffic based on average increases in containers. The model suggests substantial increase in the top-tier ports while the second-tier ports remain similar in size. The projection displays the fast growth for California ports, but overall, this model projected the lowest possible volumes of future containerized traffic. The linear average projects a growth rate of 81 to 119 percent for the second tier ports while the top-tier ports have a growth rate of 94 to 117 percent, giving the top-tier ports an increasing share of the total freight market.



**Figure 19: Average of the Absolute Change in Containerized Traffic over Time 1980-2040**  
 Ports ordered by coast (West, East) then in alphabetical order.

*Regression of Total Containerized Units Against Time*

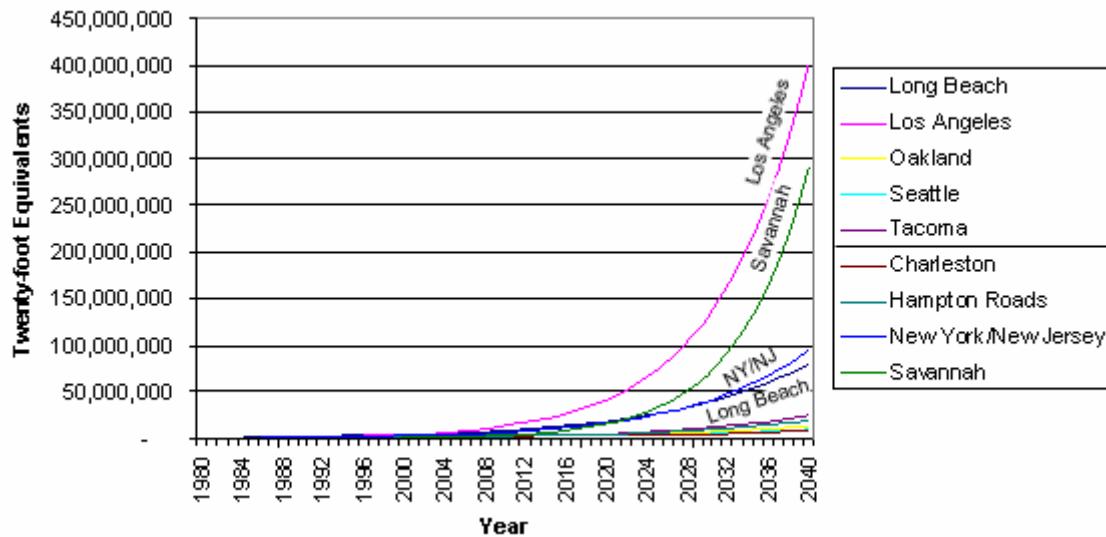
Figure 21 shows a linear growth line greater than the model represented in Figure 20. The regression of containerized units against time maintains a fast growth rate for the top-tier ports, and the difference of the rate of growth between tiers is slightly more apparent. The Port of Los Angeles increases volume to handle over 30 million twenty-foot equivalent units per year. In addition, Figure 21 shows the Port of Savannah growing faster than the other second tier ports. Despite the large growth of some ports, this projection is a more conservative estimate. Historical data shows an exponential growth curve and this pattern would have a greater growth rate than what Figure 21 provides. Despite the linear projection, this rate of growth for top tier ports is between 130 percent and 190 percent by year 2040. The second tier ports will grow 143 percent and 300 percent for Savannah.



**Figure 20: Regression of Total Containerized Units Against Time 1980-2040**

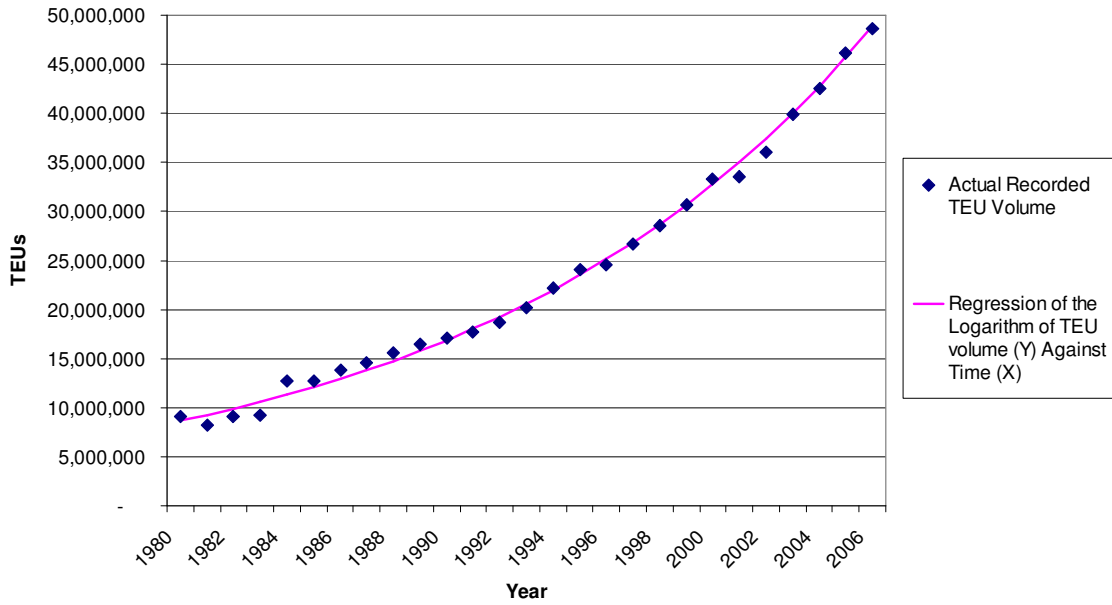
*Regression of the Logarithm of Containerized Units Against Time*

Figure 22 provides an exponential growth projection that is beyond plausibility. While currently the U.S. processes just over 48 million twenty-foot equivalent units, the regression of the logarithm of containers against time projects the Port of Los Angeles to have over 400 million twenty-foot equivalent units passing through the port per year. This projection is not realistic even with an aggressive growth projection for the U.S. and world economy.



**Figure 21: Regression of the Logarithm of Containerized Units Against Time 1980-2040**

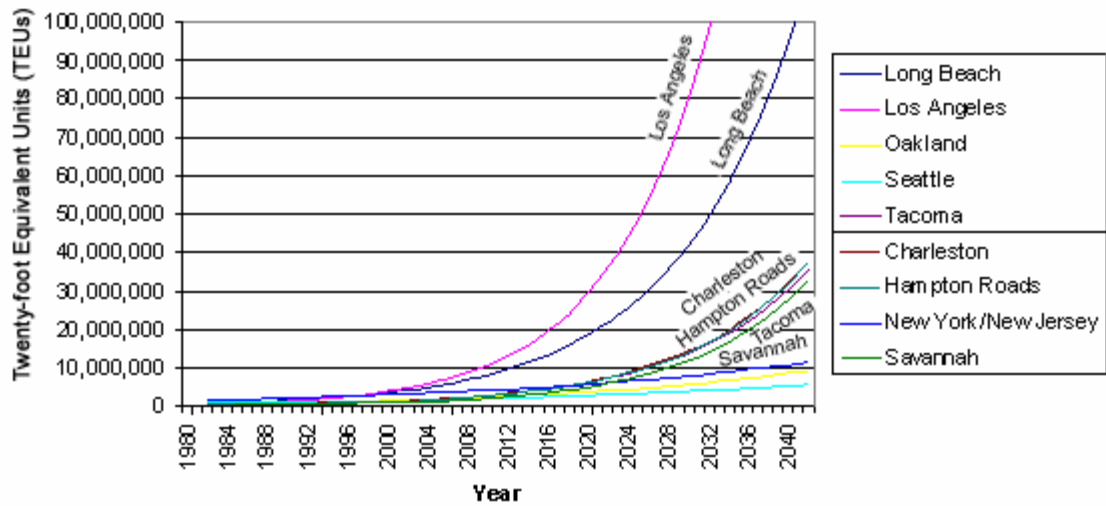
While the 2040 forecast for twenty-foot equivalent units is beyond reasonable capacity, the regression of the logarithm of twenty-foot equivalent units against time corresponds extremely well to actual recorded volumes. As Figure 23 shows, the regression and the actual volume of containers are nearly identical. While this regression is not realistic in long-term forecasting, it is accurate in forecasting against historical data and the immediate future.



**Figure 22: Regression of the Logarithm of Containerized Units Against Time 1980-2006**

*Regression of the Logarithm of Containerized Units Against the Logarithm of Time*

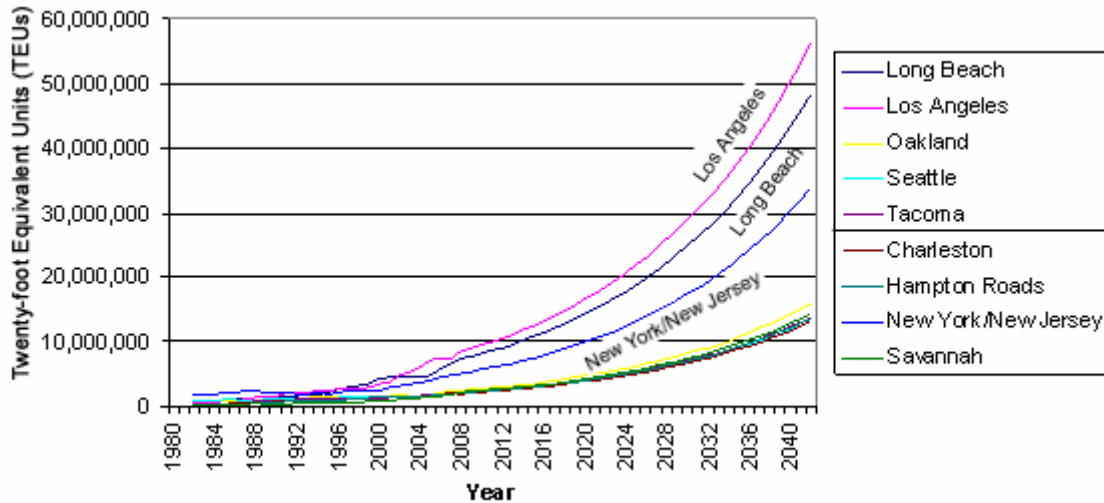
Like the regression of the logarithm of containerized units against time, Figure 24 forecasts an unrealistic scenario of future containerized shipping volumes. While this projection is inaccurate on a whole, it does identify three second tier ports that had considerable growth in comparison to other ports. The Ports of Tacoma, Hampton Roads, and Savannah have created a new mid-tier. While the California ports of Los Angeles and Long Beach grow extremely fast, the three mid-tier ports with a containerized activity of around 33 and 38 million containers might not be an unrealistic possibility if one of these ports becomes the new desired destination by 2040.



**Figure 23: Regression of the Logarithm of Containerized Units Against the Logarithm of Time**

*Share of Total U.S. Containerized Traffic Over Time*

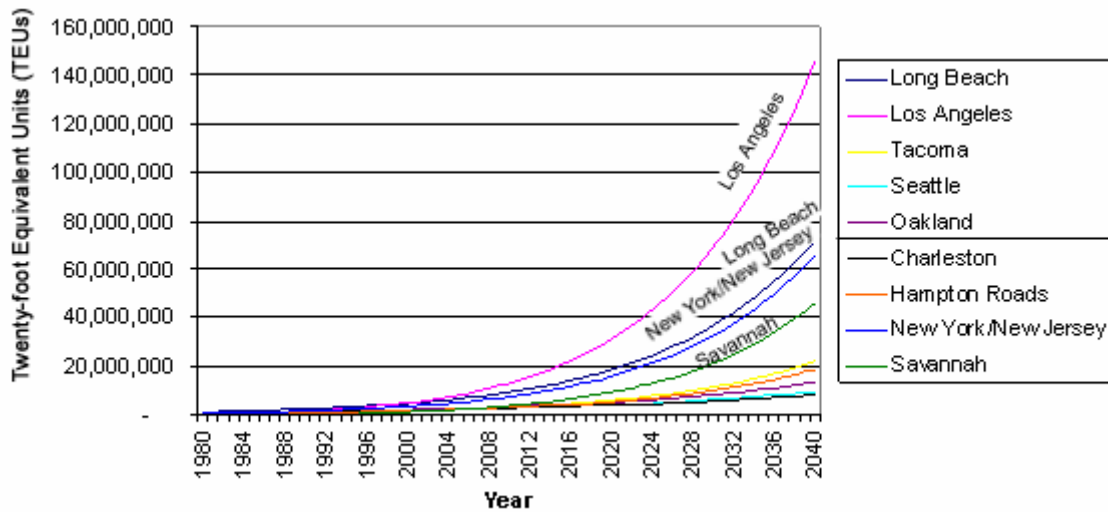
Figure 25 and the share of the total containerized traffic over time may be the most likely scenario. Figure 21 projects a 118 percent increase in containerized traffic by the year 2020 and a 205 percent increase from 2020 to 2040. The model suggests an overall increase of a 529 percent increase over 32 years. While not every port is expected to have the same growth rate, the overall pattern of the projection is the most plausible outcome. This model is a near match to the Global Insight 2020 projection. From 2000 through 2020, the share of the total containerized traffic over time model projected a 20-year increase of 246 percent and Global Insight projected a 247 percent increase (TRB, 2004, 51).



**Figure 24: Share of Total U.S. Containerized Traffic Over Time 1980-2040**

*Regression of the Share of Total U.S. Containerized Traffic Against Time*

Figure 26 is the most aggressive scenario of the likely growth rates. While it projects a much higher growth rate than most scenarios, the potential for ports with the capacity for 60 to 140 million containers a year is plausible. While this scenario is less likely, a strong increase in either the world economy or advancement in technology could have an effect seen in this figure below.

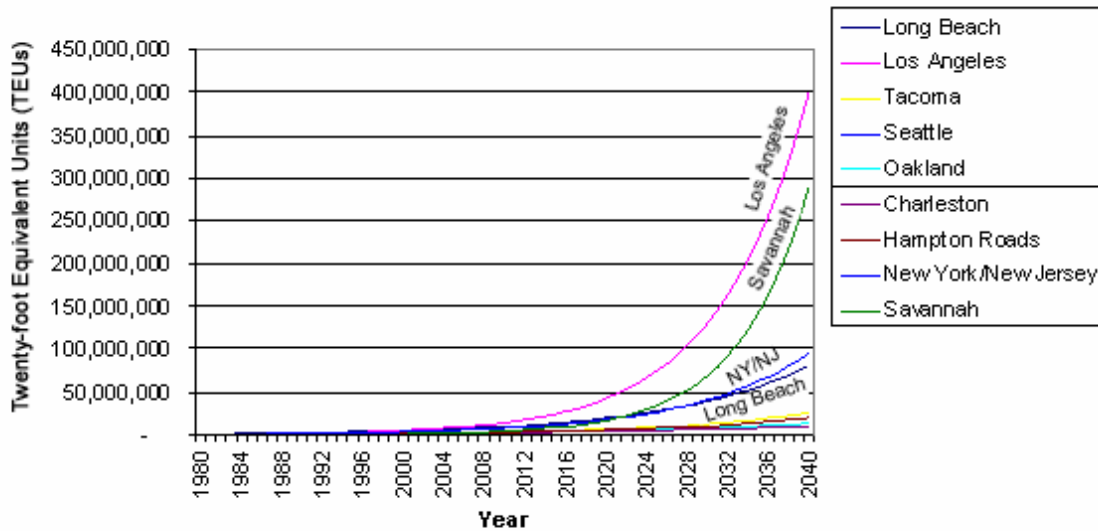


**Figure 25: Regression of the Share of Total U.S. Containerized Traffic Against Time 1980-2040**



*Regression of the Logarithm of the Share of U.S. Containerized Traffic Against Time*

Figure 27 is another projection of an unrealistic growth scenario, however the ranking of the ports have change significantly compared to the other scenarios. This projection shows that Savannah will become the second busiest port based on containerized traffic. Furthermore, New York/New Jersey will become busier than Long Beach. While this model does not project accurate growth rates, it does suggest that the busyness of ports will change based on the historical inputs.



**Figure 26: Regression of the Logarithm of the Share of U.S. Containerized Traffic Against Time 1980-2040**

## **Chapter 10: Effect of the a Trans-Arctic Route 2040-2045**

The climate change models suggest that a trans-Arctic route could become ice-free as soon as 2050 (ACIA, 2005, 193). While this would be the most drastic scenario for ice-loss, maritime trade does not need completely ice-free poles to move ships. Rather, maritime ships only need certain passages with less than 15 percent ice to develop a navigable waterway. Further ice-loss would only allow a greater window for waterways to remain open during the warmer months. As a result, a navigable waterway may be feasible in the first half of the twenty-first century. Then, there will be a considerable change in desired trade designation as Asian ports and goods would no longer be constrained from reaching the eastern United States by canals or long trip distances.

### **Containerized Shipping 2040-2045 without a Trans-Arctic Route**

The 2040 through 2045 growth rate and containerized traffic will be based on the share of total U.S. containerized traffic over time projection. The share of total U.S. containerized traffic over time projection appeared to be the most likely scenario of growth in containerized units and it matched the Global Insight prediction for containerized traffic. Furthermore, the share of total U.S. containerized traffic over time projection reflects the continued growth in activity of Pacific Coast ports as the Asian markets grow. Figure 28 shows the growth rates based on the port share of traffic over time without any shift in traffic as the result of a trans-Arctic route.

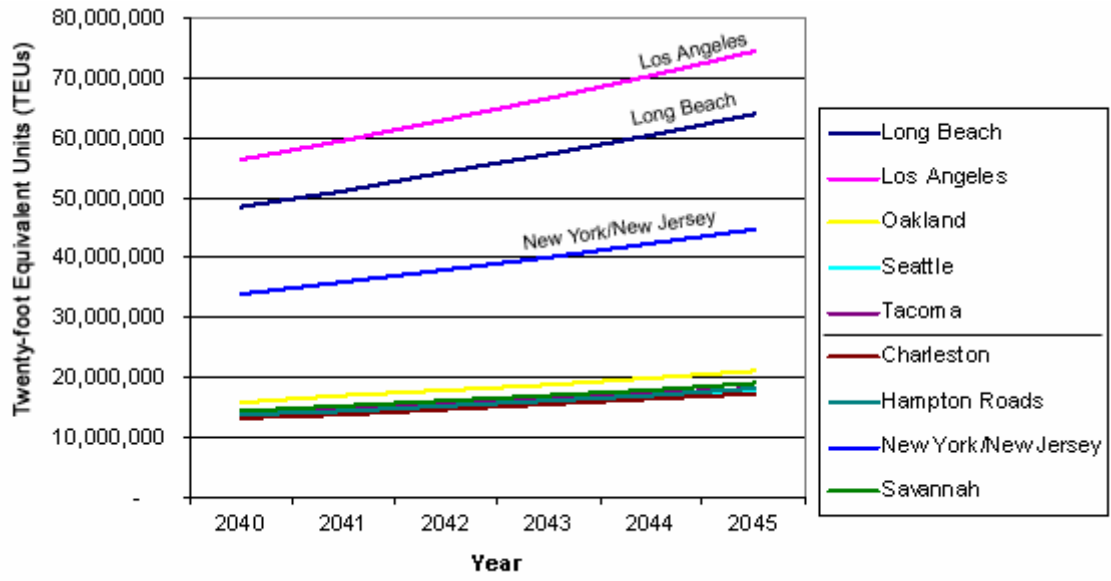


Figure 27: 2040 -2045 TEU Growth Rate without Trans-Arctic Route Shift

**Containerized Shipping 2040-2045 and a Trans-Arctic Route**

The six scenarios will be based on a percent of the top five Pacific port containerized traffic being directed to Atlantic ports based on projected market share. The six scenarios will determine the port activity in containerized cargo. The scenarios are a 10, 15, 20, 30, 50, and a gradual 5 to 30 percent redirection of Pacific bound containers to Atlantic ports. This redirection of containerized traffic will determine the scope of impact of a trans-Arctic route on Atlantic ports.

*Ten Percent Redirection*

If the Pacific ports experience a shift in 10 percent of their projected volume towards east coast ports, then there would be a temporary decrease in annual twenty-foot equivalent units for one year before regaining pre-shift volume. As seen in Figure 29, east coast ports would receive some additional traffic with New York/New Jersey gaining the most traffic. As a whole, the east coast volumes would not outpace the busier west coast

ports. The second tier Atlantic ports will become busier than the second tier Pacific ports. The consequences of a 10 percent redirection of Pacific volume would not cause a dramatic change in the activity of the ports.

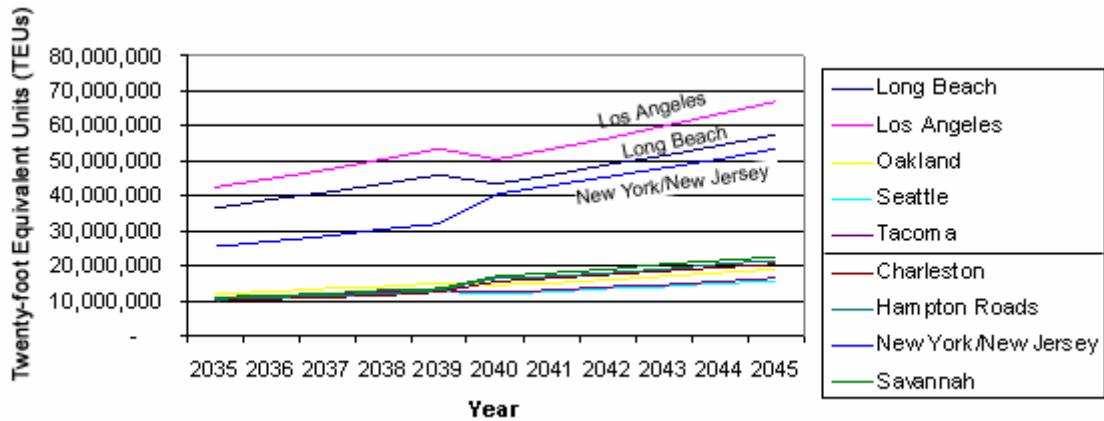
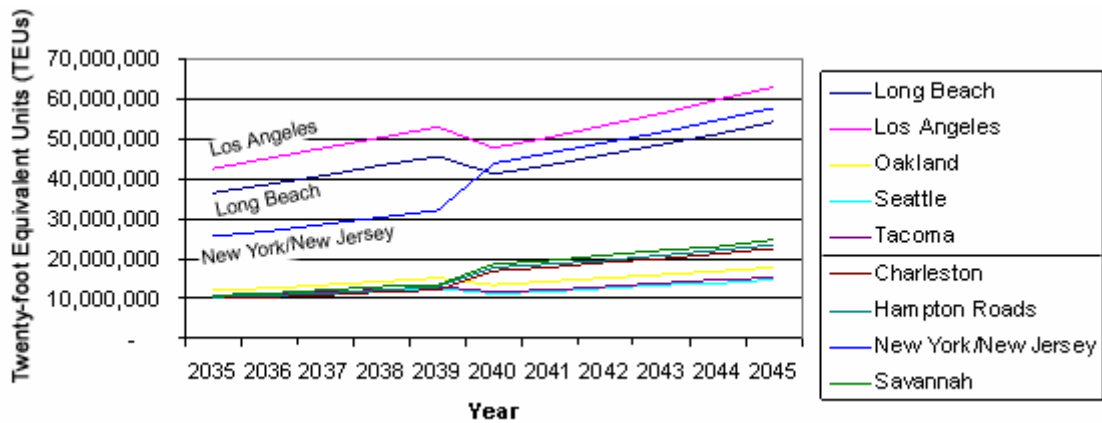


Figure 28: Ten Percent Redirection of Pacific Port Volume to Atlantic Ports

*Fifteen Percent Redirection*

Figure 30 projects that east coast ports would receive 15 percent of the projected west coast containerized traffic. As with a 10 percent increase, a 15 percent increase some additional traffic with New York/New Jersey gaining the most traffic, but it would not significantly change the rank of the major ports with the exception of the Port of New York/New Jersey and Long Beach. New York would become the second busiest port, but Los Angeles and Long Beach would handle significantly more volume than the second tier ports. The consequences of a 15 percent redirection of Pacific volume would cause some change in port activity, but the top tier ports will remain dominant.



**Figure 29: Fifteen Percent Redirection of Pacific Port Volume to Atlantic Ports**

*Twenty Percent Redirection and Thirty Percent Redirection*

Both a 20 and 30 percent redirection of west coast containerized traffic would cause significant redistribution of containerized volumes for the ports involved. As Figures 31 and 32 suggest, the volumes of the ports could increase 100 percent for Atlantic ports. The decline in pacific volumes would only be significant for the Port of Los Angeles and Long Beach. The Pacific second tier ports will not be as affected but will suffer a temporary decline in volume. Unlike the 10 and 15 percent redistributions, the Atlantic ports will either exceed the west coast port or at least narrow the gap. If the trans-Arctic route causes a 20 to 30 percent shift in the destination of containerized in the course of a year, then the impacts on the Atlantic ports will be severe.

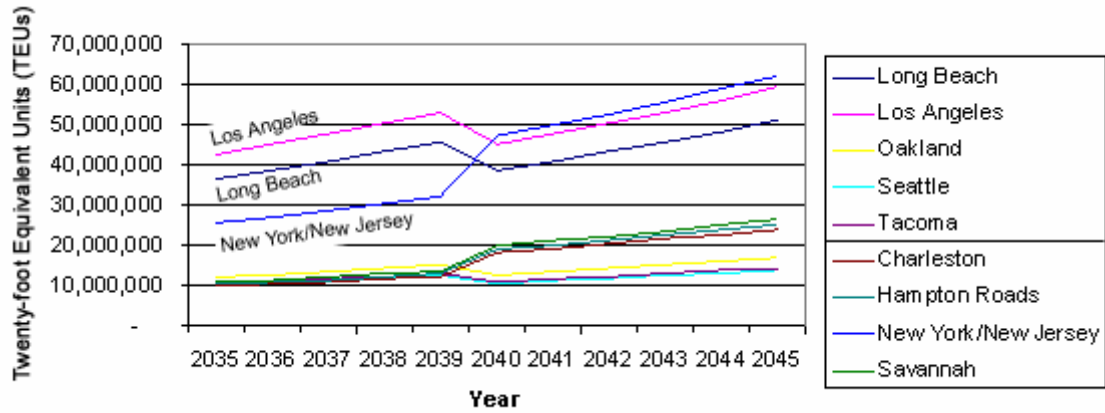


Figure 30: Twenty Percent Redirection of Pacific Port Volume to Atlantic Ports

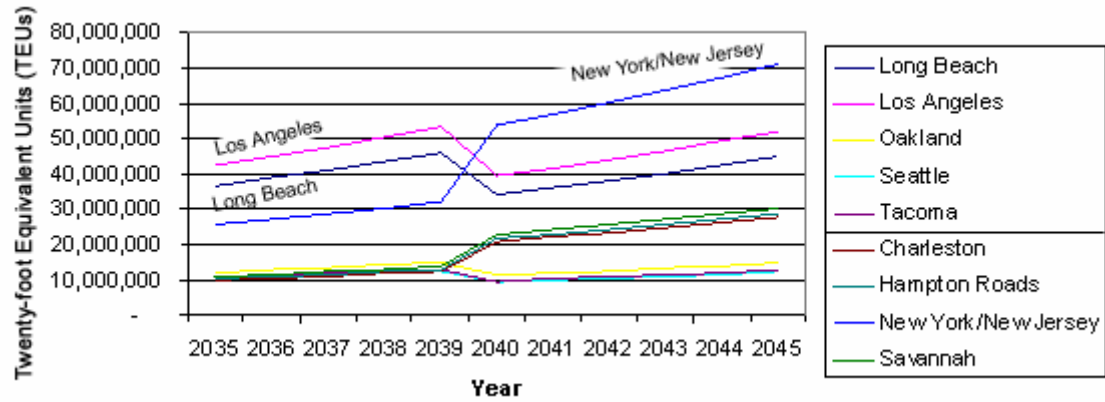
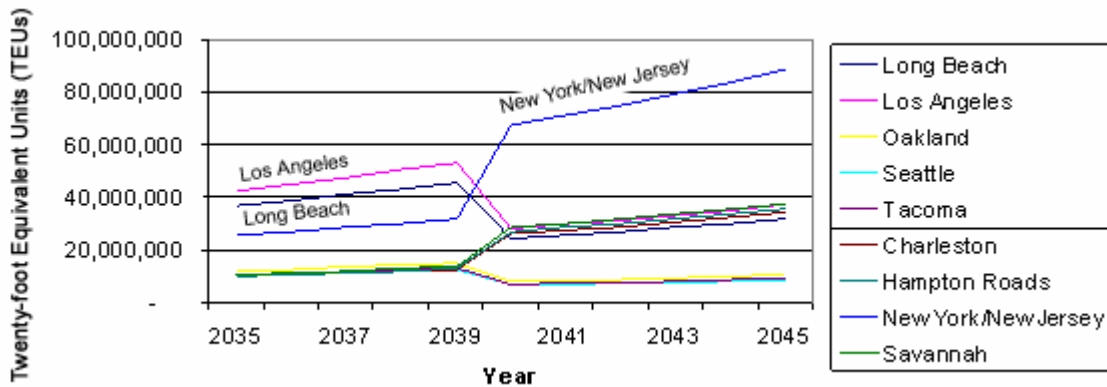


Figure 31: Thirty Percent Redirection of Pacific Port Volume to Atlantic Ports

*Fifty Percent Redirection*

A 50 percent redistribution of Pacific bound containers would cause a dramatic impact on both the shipping industry as well as the local port environment. Fifty percent redistribution in containerized traffic as shown in Figure 33 would result in a significant loss of containerized volume for Los Angeles and Long Beach. On the other hand, the Atlantic Ports would become as busy or busier than their west coast counterparts. In this scenario, New York/New Jersey would become the dominant port while the second tier Atlantic ports would be as productive and the top tier Pacific ports. The second tier Pacific ports would remain active, but their share in the U.S. containerized traffic would

be reduced. While it appears that the Port of New York/New Jersey would become the sole “super port”, another port that this scenario does not support could become the dominant port. As suggested in Figures 24, 26, and 27, the Port of Savannah could be a potential rising top tier port. The strong growth of that port recently suggests that it is trying to capture a significant amount of containerized traffic. Furthermore, as the Atlanta and Southeast region grows, the Ports of Savannah, Charleston or Virginia (Hampton Roads) could receive significant trans-Arctic shipping volume.



**Figure 32: Fifty Percent Redirection of Pacific Port Volume to Atlantic Ports**

*Gradual Redistribution over a Six Year Period*

Figure 34 projects a gradual redirection of Pacific destined traffic to Atlantic ports. The gradual redistribution begins with 5 percent redistribution of Pacific traffic in 2040, increasing by five percent per year until 2045 when the redistribution rate is 30 percent. The gradual shift in containerized trade is likely to occur because the market would require some time to readjust to the new shipping routes. Atlantic ports should increase capacity in time, and be able to capture a greater percent of Asian containerized trade. This gradual increase in the captured Asian market by Atlantic ports will limit the fast growing Pacific ports. While the Pacific ports have been growing rapidly since 1980

with the boom of Chinese, Korean, Japanese and Indian markets, the distance and canal capacity between Asia and the Eastern U.S. seaboard will no longer hinder direct trade. The gradual redistribution of containerized trade will slow Pacific port activity while Atlantic port activity accelerates. After the trans-Arctic route becomes feasible, there may be less difference between Atlantic and Pacific port activity.

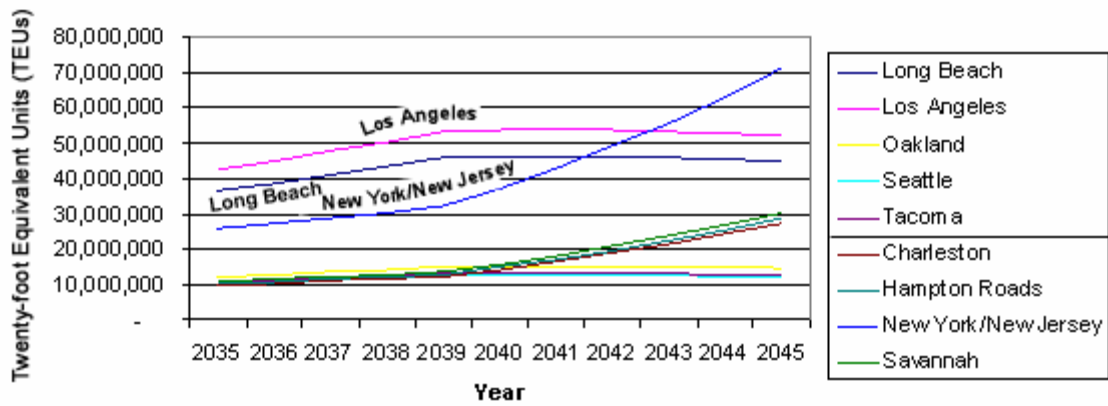


Figure 33: Gradual Redirection of Pacific Port Volume to Atlantic Ports



## **Chapter 11: Future Ecological Concerns**

The future impact of shipping activity on the local ecological systems depends on many factors, both human and natural. The effects of future shipping on the environments are likely to vary as human activity varies. The one certain condition is the growth of human activity as both the U.S. and world population continue to grow along side with the total world productivity. Maritime shipping increase with the growing world productivity; as a result, the areas adjacent to ports receive adverse effects resulting from increasing ship traffic.

The previous chapters have determined that the size and frequency of the ships will increase significantly by 2040, and the potential increase of traffic cause by a trans-Arctic route will only add to the volume of ships entering eastern seaports. Leading up to the year 2040, the west coast ports will receive the greatest increase in ship traffic as the Asian economies continue to grow. The result of this growth will lead to greater impacts on the ecosystems nearby the larger west coast ports of Los Angeles/Long Beach, Oakland, Tacoma, and Seattle. With an increase of traffic between 88 percent to 300 percent for the smaller west coast ports and 111 percent to 500 percent for the larger west coast ports, the potential impacts on the environment will be significant. After the Northwest Passage over the Canadian Archipelago becomes available for direct Asia to Eastern Seaboard traffic, the eastern ports will receive some of the growth in shipping traffic from the western U.S. ports. The east coast's growth is not expected to be as dramatic as its Pacific counterpart leading up to the year 2040, but the subsequent increase in traffic will be substantial. This chapter discusses the likely ecological impacts on port environments due to increased shipping activity.

### **Further Introduction of Non-native Species**

Human beings have been transplanting organisms for many thousands of years, but as the technology of transportation has allowed faster and longer voyages, the rate of distribution of new species has increased. While both human trade and the spread of species are likely to increase, the exact species transported in the future is unknown. The exotic species of the 2030s, 2040s and beyond will be resistant to many different types of environmental or physical conditions, have a high rate of reproduction, have a large range of distribution, and will be successfully transported in large numbers that allows for quick and irreversible colonization. Furthermore, the increased size and speed of vessels might allow other new slightly less hearty invasive species the ability to spread across oceans. The future will also hold the possibility of exchanging hybrid species between continents. Not only will different species travel with cargo ships, but genetic material might be transferred between oceans. While chemical and other physical forms of pollution will have a significant impact on many ecosystems, the invasion by a non-native species will be nearly permanent for as long as the non-native species is able to out-compete native species in an evolutionary niche.

The single largest impact of maritime shipping on aquatic ecosystems is the transport of non-native species to other habitats. There have been some efforts to stem the spread of marine species to other parts of the world, but there has yet to be any notable slowdown of transported species. There are roughly 15,000 individual species transported each week because of maritime trade (Carlton and Ruiz, 2005, 126). Ballasting is the uptake and discharge of water into a ship to level the ship in the water. Efforts such as screening or filtering ballast tanks, changing the salinity within the ballast tanks, and

discharging the ballast tanks away from potential habitats has had success in slowing some organisms invasion, but these practices only affect organisms that are either large enough to be screened out or are not well adapted to changing conditions. The transported organisms are likely to be and remain small because of the limitation on size created by screens.

The majority of organisms taken up by ballast tanks are small. The common exotic culprit is planktonic or nektonic ranging from adult stages to juvenile and larval stages. Many of the species transported are bacteria, viruses, and protists. These microbes resist many conditions that might stress larger organisms. As global marine freight continues to expand with new ports in Asia entering the global market then, a new wave of species will likely enter U.S. ecosystems.

As marine ships become larger and general maritime shipping becomes more active, ecosystems near maritime activity will experience a greater influx of exotic species. Because of the increasing ship size, ballast tank volume will increase to accommodate the difference between full and empty loads. As a result, the ballast tanks will be able to transport greater numbers of species. In addition, the larger ballast size along with a shorter distance and travel time between ports might offer a more stable environment within the ballast tanks and increase the likelihood of a successful invasion. While ship size contributes to the likelihood of an invasion, the frequency of ships entering and exiting a port may be a more significant factor for the transfer of species. The increase in ship size may decrease the numbers of ships needed to transport a certain volume of goods in a short timeframe. However, the volume, number, and tonnage of goods

transported are increasing. An increasing number of larger ships will be required to move the demand for goods, creating the opportunity for accelerated transfer of species..

The other major means of species transport affected by the changes in ship size is the amount of surface area available for organisms to attach to ship hulls. As ships size increases, the surface area of the hull increases, resulting in more “real estate” for particular organisms to colonize. While there are procedures attempted to limit the spread of species by ballast water, the attempts to limit organism attaching has declined slightly in some cases. The declining use of anti-fouling paints or treatments to a ships hull might increase the number of potential invasive species. Substances such as tributyl tin (TBT) and other toxic materials are declining in use due to their toxicity to the environment (128). While this practice may reduce the damage of chemical pollutants, it might increase biological pollutants. Even if organisms are physically removed from a fouled vessel, the removal of an exotic species into a new environment may occur as an unintentional consequence.

The increased speed of ships has decreased travel time and as a result, decreased mortality of attached organisms allowing for a greater potential range of an attached organism (Carlton and Ruiz, 2005, 128). Arctic routes might not necessarily facilitate the transfer via attachment due to the severe arctic conditions. Tropical and subtropical organisms might not survive a trans-Arctic voyage.

The spread of non-native species from the Asian Pacific to the Atlantic Ocean has already occurred and changed several ecosystems. Species such as the Asian Crab (*Hemigrapsus sanguineus*), Indian Ocean Isopod (*Sphaeroma terebrans*), Pacific protist (*Haplosporidium nelsoni*), and Asian Sea Squirts (*Styela plicata* and *Styela clava*) have

already altered many Atlantic systems (Carlton and Ruiz, 2005, 136-139). The Asian Crab, (*Hemigrapsus sanguineus*), has become a dominant species replacing many native crab species. The Indian Ocean Isopod burrows into the pneumatophores of Red Mangrove and might limit the growth of mangroves (134). Finally, the Pacific protist, *Haplosporidium nelsoni* and the Asian Sea Squirt affect the Native Atlantic Oyster *Crassostrea Virginica* causing MSX disease and preys on larval oysters respectively (137-138). Expanded shipping will produce further invasions of organisms from the South Pacific and Indian Oceans into the Atlantic seaboard. As both native and non-native species continue to form new ecosystems, the populations of various species are likely to change before the opening of the trans-Arctic route. Some people question whether this issue merits attention given that the existing biota of ecosystems have already been altered to the point that the transfer process is natural and therefore it is not worth protected against further invasions.

By the year 2040, many ecosystems may already be comprised of mostly non-native species. In fact, in some locations, such as the San Francisco Bay area, exotic species already constitute of approximately 97 to 99 percent of the total biomass and 40 to 100 percent of the common species (National Resource Defense Council, 2008). As a result, some port areas with existing invasive species will continue to be a “melting pot” for native, existing non-native, and new non-native species. In addition to outright invasion, there is also a process of hybridization. Hybridization can occur in two different ways: a native and non-native species can hybridize to create new and, more aggressive taxa or two non-invasive exotic species can develop a new species that can out-compete others. (K. A. Schierenbeck and M. L. Ainouche, 2006, 200) One of the drastic examples

of hybridization is that of the Atlantic salt marsh grass *Spartina alteriflora* and the Pacific marsh grass *Spartina foliosa*. (200) The hybrid species has successfully displaced the parent populations. Marine freight movement did not introduce this salt grass, but it is an example of the potential damage that hybridization can create when a species is transported and acclimated to a new environment. If hybridization progresses due to transfer of species, many areas might become less genetically diverse over time. By the year 2040, many ecosystems might be completely comprised alien species and hybrids of native and non-native species. Therefore, future introduction or hybridization might become less of an impact if the potential non-native species are already distributed. However, hybridization and introduction may accelerate as the distance, time, and genetic divisions become smaller between various areas of the world. The potential of a globalized ecosystem with little genetic difference between similar ocean environments is only likely to increase as shipping trade continues to advance.

One last question about the advance of non-native species is how the Arctic ecosystem will change when vessels begin regular traffic through the region. As of now, the Arctic system is isolated compared to other regions of the world. It currently does not have large volumes of commercial traffic, but this current isolation is likely to change. Because of less outside interference and extreme conditions, the Arctic is comprised of many specialized species that fill unusual niches and functions. Climate change will stress the Arctic's current inhabitants, and the change in temperature will destroy and create new niches. As a result, there will be demand for colonization of new niches while existing populations disappear with the old environment. The introduction of new species

might be more severe compared to other areas that have already experienced biological invasions.

The spatial distances between ecosystems will decrease as shipping continues to connect distant places and spread life forms across the globe. As the spatial differences decrease, certain organisms might monopolize ecological functions. Whereas before biological invasion, ecosystems were comprised of specialized species, fewer unique species in a constantly changing system or as hybridizations reduce the genetic diversity. Finally, humans will continue to alter the landscape and seascape by adding hard substrates where there were none or by constantly removing sediment. The alteration will provide benefits to some species while successfully decimating other organisms. Furthermore, as trade constantly adds or removes predators, herbivores, producers and microbes, the roles and functions of organism will change.

Globalization is not only a term for economic activity, but also a general trend that reflects the declining distance between organisms, both spatially and genetically. Because maritime trade is the predominant means of transporting mass between continents, it is also a primary means of transporting biomass between ecosystems.

### **Near-port Environmental Impacts**

As marine freight traffic increases, the supporting infrastructure must increase its capacity to load and unload vessels. The Port of Los Angeles, the largest port in containerized traffic features over 7,500 acres, 226 berths, and 43 miles of waterfront. This facility currently handles over 8.6 million containers a year. If the Port of Los Angeles continues a growth rate of 300 percent every ten years, the port will have to accommodate 250 million containers a year by 2040. While this appears to be an

unthinkable number, the port grew from 800,000 containers in 1980 to 8 million containers in 2007, an increase of 945 percent in 27 years. Even if trade for the Port of Los Angeles occurs at the slower forecasted rates, it would still handle between 30 million and 70 million containers by 2040. For the port to handle the projected traffic, it would likely require an increase in the landside operations. As of 2007, the Port of Los Angeles handles 1172 twenty-foot equivalent units per acre of operation. If the port kept the same ratio of 1172 container/acre, then to handle 70 million containers the port would require nearly 60,000 acres. If the port were to handle 250 million containers, it would require over 213,000 acres, or roughly 27 percent of the total acreage of the state of Rhode Island. Whether or not the port expands to 60,000 acres or 200,000 acres, the land-based impact of the port will be tremendous. There will be increases in impervious surface, the number of berths, and infrastructure relating to other modes of transportation, particularly large truck traffic. As a result, the land-based operations will contribute to an increasing amount of runoff pollutants.

When the Northwest Passage becomes a feasible route, West coast ports will continue to increase in yearly volumes of containerized traffic, but East coast ports are more likely to see an increase in port activity because of trans-Arctic routes. East coast ports are expected to increase their capacity, but the larger demand for capacity might not occur until after 2040. After the Northwest Passage becomes navigable, the decreased distances with no restrictions on vessel size will contribute to increased demand to handle larger ships with a deeper draft at Atlantic Ports. To accommodate these larger vessels, there will need to be an increase in dredging efforts.



Dredging, in general, is a destructive practice that alters two areas: the dredged channel and the site where dredged material, known as spoil, is discarded. Dredging is nearly prohibited by various environmental and political constraints as of today; however, current trends in shipping patterns will continue to conflict with current political restrictions. While dredging is unacceptable now, the long-term demands for larger and heavier ships will likely force some actions to make shipping channels more accommodating for larger vessels. If ports in the United States do not meet the economic of serving large ships, nearby ports in the Bahamas and Latin America countries will take transshipment opportunities. Increasing economic pressures for international competitiveness will affect national and local policies on dredging.

Dredging has decreased since 1963 in terms of total cubic yards dredged per year, and most of the dredging has become maintenance-oriented. Another likely decrease in dredging is like the result of the increasing cost of the practice. It is unclear whether dredging will increase in the total volume based on historical trends. However, the increasing size of vessels since 2000 the current increase in Post-Panamax ships orders will require deeper channels. Currently, the largest vessel, the Regina Maersk has a draft too deep at a full load to enter the Port of Virginia (Hampton Roads). If ships sizes increase by the current order of 40 percent larger than the current largest vessel, then creating larger and deeper channels will be necessary for many ports to accommodate.

The future increase of port activity is going to require an increase in land-based activity as well. An increase in impervious surface, truck and rail traffic, and dredging activity will significantly strain near-port environments. While current and future regulations or practices might reduce some of the impact of port activity on the

environment, the sheer increase in the scope of marine freight traffic will increase environmental stress on nearby systems. After all, ports and shipping channels are a use of a physical environment much like parking lots and roadways on the terrestrial environment. Freight waterways are used and the use is naturally noxious and will have some environmental impact. It might be possible to reduce the impact of each ship entering the system, but if more ships pass through the system, the overall disruption might overwhelm the benefits of ship-by-ship mitigation.

### **Future Impacts of Oil and Litter**

Oil and litter will continue to threaten ecosystems worldwide. As shipping activity increases, the discharge of oil and litter pollution can increase. Fortunately, there has been significant interest in minimizing both forms of pollution. As newer, cleaner, and more efficient vessels enter into service, the new vessels will replace the older and dirtier vessels. Furthermore, better hull designs prevent potential oil spills; however, large spills only account for a fraction of the oil found in the world's oceans. Oil in the aquatic environment depends on the amount of oil released from terrestrial sources. If future land-based operations increase, then oil pollution near ports will increase. However, increasing environmental restrictions will likely reduce this source of pollution. Finally, developed countries and international organizations have placed restrictions on releasing oil into the oceans and seas. These restrictions might slow the affect of oil pollution. It is expected that developing countries might follow suit as environmental concerns become more important.

In contrast, litter will increase despite growing regulation. This increase depends on the time needed for various substances to biodegrade. The long time necessary for

plastics to degrade will keep litter present in the oceans for hundreds of years even if the oceans did not received any new litter. Furthermore, plastics are increasing in use. Because of its long lifespan of plastics and the increasing use, oceanic litter will continue with no foreseeable end in sight.

## **Chapter 12: Conclusion**

Human development and activity create specific ecological impacts. The use of fossil fuels is creating increased levels of carbon dioxide and other greenhouse gases. This activity of combusting raw materials such as petroleum, coal, and other sources has altered the global environment. Global climate change is the Earth's response to modern human activity. However, nature does not react to human activity in isolation. Human activity also reacts to nature, creating a cycle of constant action and reaction. As nature reacts to modern industrialization via climate change, humanity reacts to climate change by altering human activity. While one reaction to climate change is to attempt to reduce the progression of the environmental response through policy protections, another human reaction is to use the change in climate by altering human activity. The possibility of a trans-Arctic shipping route that will connect Asia with the eastern United States is a reaction to the effects of climate change.

Modern human activity is increasing. The human race is experiencing a period of globalization where nations are more interconnected with each other than before. Commodities are traded thousands of miles while ideas can be transferred in seconds. Maritime shipping and containerization has helped create this form of a globalized economy. The growth of containerization has increased dramatically. The United States experienced an increase the number of containers moving through American ports by over 500 percent over the course of 25 years, and this research has demonstrated likely growth in containerized traffic between 300 to 600 percent by 2040. The tonnage of goods has increased as well and will continue to increase between 80 and 140 percent. The increasing world production and population will continue to fuel U.S. and world

maritime trade. The next few decades of the twenty-first century will likely continue the expansion of tonnage and container trade via ever increasing marine vessels. Because of the fast expansion of the maritime industry and the slow process of building, mitigating and planning process, the maritime stakeholders should begin the dialogue of how to accommodate the future volumes quickly. A slow response will limit economic activity and possibly the ability to mitigate environmental challenges.

Human activity is growing. Humanity is trading more tons, greater volumes across greater distances with larger and faster ships. Thus, humanity is putting a greater impact on the environment that hosts this activity. As the climate patterns change, the pattern of human activity will change. Once the Arctic shipping lanes open, humanity will find some benefit or advantage of this new unexploited area. Not surprisingly, change in the Arctic will create changes around the world. Some areas will experience increased economic activity while other areas might see a small decrease in production. While the Pacific coast ports have experienced a great increase as Asian economies have become more productive, many Atlantic ports have experienced less growth. As shipping patterns change, the port activity will change, but just as importantly, the local ecosystems will also change.

With human activity globalizing and linking distant populations, human have also begun globalizing the populations of many aquatic species. The introduction of non-native species has brought a new type of pollution to humanity's extensive array of chemical and physical means of environmental degradation. While there have been some efforts by some societies to reduce the impact of human activity in the environment, the attempt has not been universal. Some actions might pollute less, but as humanity

increases the frequency of the actions, it reducing the benefit of the attempt to minimize pollution. Once Arctic shipping routes become feasible, there will be a secondary reaction to this new human activity, and there is some uncertainty of how the natural environment will react. The ecosystems will continue to change as human activity changes, but the exact changes in nature can only be inferred by the previous patterns of change.

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