

Did the 2011 Tohoku Tsunami increase the risk of species invasions along the Gulf of
Alaska?

Sebastien Clos-Versailles

A thesis
submitted in partial fulfillment of the
requirements for the degree of

Master of Marine Affairs

University of Washington

2016

Committee:

Ryan P. Kelly

Thomas M. Leschine

Program Authorized to Offer Degree:

Marine and Environmental Affairs

©Copyright 2016
Sebastien Clos-Versailles

University of Washington

Abstract

Did the 2011 Tohoku Tsunami increase the risk of species invasions along the Gulf of Alaska?

Sebastien Clos-Versailles

Chair of the Supervisory Committee:
Assistant Professor, Ryan P. Kelly
School of Marine and Environmental Affairs

On March 11, 2011, a 9.0 magnitude earthquake struck 80 miles off the Pacific coast of Tohoku, Japan, triggering a tsunami. This tsunami washed over 5 million tons of debris away from Japan. 1.5 million tons of that marine debris remained afloat and was set adrift in the Pacific Ocean, much of it projected to make landfall along the west coast of North America. Marine debris, both natural and man-made, has a long history as a pathway for invasive species, which have the ability to inflict significant ecosystem harm. Such non-native and known invasive species have arrived along the west coast of North America attached to tsunami debris.

Models predicted tsunami debris to make landfall along the Gulf of Alaska (GoA), and debris has been arriving since early 2012, bringing with it various species non-native to North America. This influx of non-native species has the potential to cause significant ecological and economic harm, making proper management and prevention critically important.

This study aims to determine whether Alaska is at an increased risk of species invasion from the Japanese tsunami marine debris (JTMD) field by comparing debris in pre-tsunami (2010-2011) and post-tsunami years (2012-2014). Four categories of marine debris increased across the entire GoA, with the trend driven largely by debris in the eastern half of the GoA. These results—particularly the observed increases in foam and float debris in the eastern GoA—indicate that Alaska is at an increased risk of species invasion from the JTMD field. With a limited budget, management could increase the impact of preventative measures against invasive species from tsunami debris if focused along the eastern GoA.

Table of Contents:

List of Tables and Figures.....6

Acknowledgements.....8

Introduction.....9

Methods.....13

Results.....16

Discussion.....20

Conclusion.....22

References.....23

Appendices.....29

 Appendix 1.....29

 Appendix 2.....32

 Appendix 3.....35

 Appendix 4.....36

List of Tables:

Table 1: Summary of organizations.....15

Table 2: Mean debris densities for entire Gulf of Alaska.....29

Table 3: Mean debris densities for eastern Gulf of Alaska.....30

Table 4: Mean debris densities for western Gulf of Alaska.....31

List of Figures:

Figure 1: Locations of debris cleanups.....14

Figure 2: Categories with significant changes in debris density along the entire Gulf of
Alaska.....16

Figure 3: Average change in debris density for all debris categories along the entire Gulf
of Alaska.....17

Figure 4: Categories with significant changes in debris density along the eastern Gulf of
Alaska.....18

Figure 5: Average change in debris density for all debris categories along the eastern Gulf
of Alaska.....18

Figure 6: Categories with significant changes in debris density pre- vs. post-tsunami
along the western Gulf of Alaska.....19

Figure 7: Average change in debris density for all debris categories along the western
Gulf of Alaska.....20

Figure 8: Rarefaction analysis for significant debris categories along the entire Gulf of
Alaska.....32

Figure 9: Rarefaction analysis for significant debris categories along the eastern Gulf of Alaska.....33

Figure 10: Rarefaction analysis for significant debris categories along the western Gulf of Alaska.....34

Figure 11: GNOME model predicting the path of the Japanese tsunami debris field.....35

Figure 12: SEA-GEARN/MOVE-K7 model predicting the path of the Japanese tsunami debris field.....35

Acknowledgements:

I thank my thesis committee, Ryan Kelly and Tom Leschine, for their invaluable input, feedback and support throughout this entire process. I additionally thank the other advisees in my thesis groups, Erin Ryan Peñuela, Max Mossler and Gretchen Thuesen for their insight and feedback over the past couple years on my thesis.

Thank you to my fellow SMEA cohort students for making my time here at SMEA so memorable and supporting me during my time here. I would not have been able to enjoy my time as much without them. Another thanks goes out to the other professors in SMEA for equipping me with the knowledge I need to go out and be successful in the field of marine and environmental affairs. I thank Tiffany Dion who helped me administratively during my time at SMEA.

I thank Allen Pleus at the Washington Department of Fish and Wildlife for helping steer me toward the topic of marine debris and giving me a platform on which to begin this journey. Thank you to the other professionals and professors who helped give me insight on my thesis, including invasive species expert Professor Julian Olden and the Alaska Marine Debris Program Coordinator, Peter Murphy.

Additionally, I acknowledge all crews and organizations in Alaska cleaning up and recording data on marine debris along the Alaskan coast, as this study could not have happened without their incredible efforts. Thank you to all other organizations for providing me with the necessary data and responding to my inquiries.

Finally, I thank my family and friends, with special appreciation to Haley Hamlin for constantly supporting me and pushing me toward my goal.

Introduction:

On March 11, 2011, a 9.0 magnitude earthquake struck 80 miles off the Pacific coast of Tohoku, Japan (Mori et al., 2011; NOAA, 2014). The triggered tsunami reached a maximum run-up height of 39.7 meters and flooded over 200 square miles of land (Mori et al., 2011; NOAA, 2014). It resulted in massive loss of life, property and environmental damage, and washed out over 5 million tons of debris (Murray et al., 2015, NOAA, 2014). The Japanese government estimated that roughly 30% of the debris, or 1.5 million tons, remained afloat and was set adrift in the Pacific Ocean (NOAA, 2014; Japan Ministry of Environment, 2014).

The Japanese tsunami marine debris (JTMD) field was projected to first make landfall along the west coast of North America in March, 2012 (Showstack, 2011; Murray et al., 2015), with higher windage¹ items arriving first (NOAA, 2014). In Alaska, the debris field was projected to make landfall only along the Gulf of Alaska (GoA) coastline (Bagulayan et al., 2012; Maximenko et al., 2015). GNOME (General NOAA oil monitoring environment), an oil slick model adapted for marine debris, and SEA-GEARN/MOVE-K7, a combined north pacific ocean circulation and particle dispersion model (Maximenko et al., 2015), show the tsunami debris field reaching as far west as the Aleutian Islands, with higher levels projected to hit along the eastern GoA (NOAA, 2014; Maximenko et al., 2015). In winter of 2011/2012, the JTMD field made its first confirmed landfall along the Alaskan coastline, where it continues to arrive today (Alaska Department of Environmental Conservation, 2013; Murray et al., 2015).

The National Oceanic and Atmospheric Administration (NOAA) defines marine debris as “any persistent solid material that is manufactured or processed and directly or indirectly, intentionally or unintentionally, disposed of or abandoned into the marine environment...” (NOAA, 2016). Marine debris has long plagued our ocean and coastal ecosystems. Impacts range from entanglement and ingestion by wildlife (Blight & Burger, 1997; EPA, 2011; Gall & Thompson, 2015; Laist, 1997; Raum-Suryan et al., 2009; Simmonds, 2012), reduced tourism (Jang et al., 2014; McIlgorm et al., 2008; Ofiara & Brown, 1999), smothering (EPA, 2011; Gregory, 2009), ghost fishing (Macfadyen et al., 2009; McIlgorm et al., 2008; Mouat & Lozano, 2010), damage to

¹ Windage is defined as the surface [of an object] exposed to the wind. (windage, 2015)

industries such as shipping and fishing (McIlgorm et al., 2008), and aiding in the transport of non-native species (Barnes, 2002; Barnes & Fraser, 2003; Bax et al., 2003; Derraik, 2002; Gregory, 2009; Masó et al., 2003, Zettler et al., 2013).

Marine debris has long been identified as a vector for non-native species to invade new habitats (Barnes, 2002; Barnes & Fraser, 2003; Bax et al., 2003; Derraik, 2002; Gregory, 2009; Masó et al., 2003, Zettler et al., 2013). A non-native species is any species outside of its natural range or habitat; an invasive species that is any species outside of its natural range or habitat that has become established and spread (Manchester & Bullock, 2000; Ricciardi, 2012). The term “invasive species” is heavily politicized as well due to high political and economic consequences, and is defined as a non-native species whose introduction does or is likely to cause economic or environmental harm or harm to human health (Clinton, 1999).

The increased presence of persistent man-made debris has further increased the risk of marine debris-related species invasions (Barnes, 2002). Barnes (2002) found man-made debris doubles the propagation of species in the subtropics and more than triples it in the higher latitudes (50°-60°). Higher propagation levels can increase propagule pressure to putatively invadable ecosystems (Fine, 2002; Simberloff, 1989; Simberloff, 2009). Propagule pressure is defined as the total number of individuals introduced at a given location (Williamson, 1996). With more individuals introduced into a given location, the likelihood that one of these propagules becoming established is higher. Therefore, with more man-made marine debris and a higher amount of species being transported, ecosystems are at an increased risk of marine debris-related species invasions (Fine, 2002; Simberloff, 1989; Simberloff, 2009).

While some invasive species, such as biological controls² and crops, can have positive impacts (Culliney, 2005; Müller-Schärer et al., 2004; Schwörer et al., 2012), many have significantly negative consequences for native ecosystems and for human wellbeing (Ricciardi, 2012). Ecosystem impacts include altered community composition, physical habitat structure, nutrient cycling, hydrology, primary production, and

² Biological Control – the reduction in numbers or elimination of pest organisms by interference with their ecology (as by the introduction of parasites or diseases) (biological control, 2015)

disturbance regimes (Brooks et al., 2004; Croll et al., 2005; Mack et al., 2000; Ricciardi, 2012; Simberloff, 2011). Invasive species can shift food webs and interfere with mutualistic interactions among various endemic species (Ricciardi, 2012; Spencer et al., 1991), and consequently are also one of the leading causes of global animal extinction (Gurevitch & Padilla, 2004). In the U.S. alone, invasive species pose a threat to nearly half of all species on the U.S. Endangered Species Act (Union of Concerned Scientists, 2005). In 2005, Pimental et al. conservatively estimated that the United States spends roughly \$120 billion annually in the eradication and management of invasive species.

Alaska has a long history of both intentional and accidental species invasions dating back to the mid-18th century (Ebbert & Byrd, 2002). The introductions of various fox, squirrel, and rat species triggered massive declines in the once prosperous marine bird populations along nesting sites in what later became the Alaskan Maritime National Wildlife Refuge (AMNWR) (Croll et al., 2005; Ebbert & Byrd, 2002). In some instances, certain marine bird populations were extirpated on several islands along the Alaskan coast as a direct result of these invasions (Denlinger, 2006; Ebbert & Byrd, 2002), highlighting the extinction of native fauna as one of the key dangers of an increase in invasive species. Reductions in nesting bird populations secondarily impacted vegetation as a result of reduced fertilization from bird guano (Croll et al., 2005; Ebbert & Byrd, 2002). Later introductions of ungulate species, such as cattle and reindeer, led to further reductions in vegetation across many of these islands, which increased levels of erosion (Ebbert & Byrd, 2002). Aquatic invasive species, such as northern pike, are especially harmful in Alaska due to the potential threat they pose to the aquatic environment, notably to the valuable salmon industry (Schrader et al., 2005; Union of Concerned Scientists, 2005).

A notable portion of the Alaskan economy depends upon tourism (and its system of national parks) and fisheries (Union of Concerned Scientists, 2005). In 2014-2015, tourism accounted for 39,700 jobs in a state of only 738,432 residents (U.S. Census Bureau, n.d.), leading to a labor income of \$1.39 billion (McDowell Group, 2016). This is in response to a visitor volume of 2.07 million tourists, who spent \$4.17 billion for the 2014-2015 year (McDowell Group, 2016). Tourism played the largest role in Southeastern Alaska, accounting for 21% of employment, as compared to the rest of

Alaska (9% of employment statewide) (McDowell Group, 2016). A 2001 visitor-opinion survey, sent out by the Alaska Visitor Statistics Program, showed that over 80% of visitors who came to the state prioritized Alaska's wilderness characteristics and ability to spend time in the wilderness (Colt & Fay, 2014). Commercial and recreational fisheries further brought in over \$4.8 billion in sales and provided over 61,000 jobs in 2012 alone (NOAA, 2015).

The presence of invasive species can further do significant damage to an extremely valuable industry due to its ability to greatly alter ecosystem dynamics (Union of Concerned Scientists, 2005). Examples of this include the Zebra mussel in the Great Lakes and the New Zealand mud snail in the Great Lakes and western United States, both of which have the ability to severely alter native ecosystems, tourism and fisheries industries (Union of Concerned Scientists, 2005).

Zebra mussels have shifted the Great Lakes from predominately turbid and silty to a clearer and more macrophyte-dominated system (Ludyanskiy et al., 1993). As effective filter feeders, zebra mussels have removed both food and oxygen from the water column, consequently threatening the higher trophic level species and fisheries (Ludyanskiy et al., 1993). Zebra mussels are additionally highly effective colonizers and settle on anything from native onionid species to water intake valves (Ludyanskiy et al., 1993; Pimentel et al., 2005). Control costs associated with removing zebra mussels from water pipes and intake valves reach about \$1 billion/year (Pimentel et al., 2005).

Invasive New Zealand Mud Snails (NZMS) threaten fisheries in the Pacific Northwest by replacing the native nutritious food supply and consequently reducing the growth rate of rainbow trout (Vinson & Baker, 2008). This is a result of both the increased consumption of NZMS and the inability of rainbow trout to properly digest them (Vinson & Baker, 2008).

With such a reliance on wilderness-based tourism and fisheries, Alaska must be especially careful to manage and prevent harmful impacts from potential invasive species. The state's remote and rugged coastline adds a further challenge for invasive species managers in the Alaskan Department of Fish and Game (ADFG), as marine debris removal can be quite costly and difficult.

JTMD has already brought several non-native species to North American beaches (Calder et al., 2014; Choong & Calder, 2013; NOAA, 2014). The most dramatic example, surely, was the Japanese dock that washed ashore along Oregon in 2012 carrying more than 100 different non-native marine species, several of which were known invasive species recognized to cause economic harm (Lam et al., 2015; NOAA, 2013).

I aim to investigate whether debris landings increased post-tsunami in Alaska, as it did in Washington, Oregon, Hawaii and British Columbia (Murray et al., 2016). Due to a lack of sufficient data along the Alaskan coast, especially before the 2011 Tohoku tsunami, few studies exist on marine debris landings before this one. Furthermore, this study aims to determine how 13 different types of debris changed in density along the entire GoA, the eastern and the western part of the GoA, pre- vs. post-tsunami. Given that marine debris potentially increases invasive propagule pressure, this analysis of where marine debris abundance changed post-tsunami along the GoA can help inform invasive species managers where to concentrate their limited budget in order to most effectively reduce the threat of potential invasive species.

I hypothesize the GoA, especially the eastern GoA, to be at increased risk of species invasion post-tsunami as compared to pre-tsunami as a result of increased marine debris making landfall. This influx of marine debris represents a pathway by which non-native species can invade new habitats. The idea that species invasion risk is correlated with marine debris landings suggests that invasive species managers may be able to more efficiently focus their own efforts by targeting regions where marine debris landings are highest.

Methods:

Various organizations across Alaska have been involved in beach cleanups along the Alaskan coast since at least 2003, with beach surveys dating back as early as the 1970s (Merrell Jr., 1980). The Alaskan Marine Stewardship Foundation (AMSF) database (now found at the Sitka Sound Science Center) (SSSC, 2016) contains beach cleanup reports and aerial survey data from across the state. With the models projecting

JTMD landfall only along the GoA in Alaska, this study focused only on beach cleanup data along that range. Figure 1 shows each of the data cleanup points along the GoA.

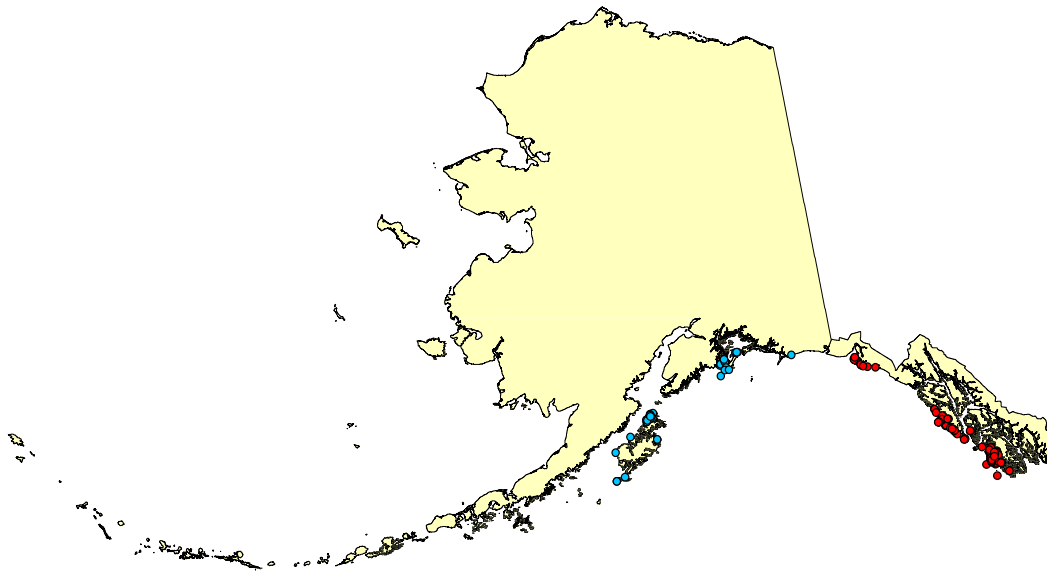


Figure 1: All cleanup sites along the GoA from 2010-2014, with the eastern GoA sites in red and the western GoA sites in blue. (Data retrieved from: <http://www.sitkascience.org/research/marine-debris/reports>)

The AMSF database provided beach cleanup data from eight different organizations across the GoA, operating over various years (Table 1). Each report contains information on several different types of debris (e.g., weight of debris removed), as well as the total length of the beach covered. The different types of debris categories included: 1) All Line, 2) Domestic Gill Net, 3) High Sea Drift Net (HSDN), 4) Other Net, 5) Banding, 6) Other Fishing Related, 7) Plastic Beverage Bottles, 8) Other Plastic, 9) Metal, 10) Foam, 11) Floats, 12) Non-Vessel Related, and 13) Total Debris (As defined in Appendix 4).

Using Microsoft Excel (for Mac 2011, version 14.4.2), I organized and compiled all datasets. I then converted the data for each debris category from pounds to kilograms by dividing each data point (debris removed in pounds) by 0.453592. Once in kilograms, I divided values by the length of the beach (horizontal distance covered) and multiplied by 100 to convert each data point in kg/100 meters (as similarly used by (Murray et al., 2016)), thus controlling for area cleaned.

Upon conversion, I then compared pre-tsunami values (2010-2011) to post-tsunami values (2012-2014) across the entire GoA, the eastern region of the GOA and the western region of the GoA. I separated regions from east to west based on longitude with data within 133°W - 142°W and 143° W - 154° W, being east and west, respectively. This was performed to further determine whether models were accurate in predicting higher levels of JTMD along the eastern GoA.

Once data were compiled, I ran unpaired, one-tailed, t-tests for each of the 13 debris categories 1) across the entire GoA, 2) for the eastern portion of the GoA, and 3) for the western portion of the GoA, to determine if the density of debris increased across any of these regions in the years just following the tsunami. Because I was analyzing multiple independent variables (debris types), I corrected my alpha value using a Bonferroni Correction. I divided a significant alpha value of 0.05 by the number of different independent variables (13), yielding a new alpha value of 0.0038. Additionally, I rarefied the post-tsunami data for each focal debris category to control for effort and ensure the statistically significant trends were not a result of a change in sampling effort (Appendix 2). The rarefaction analysis subsamples the post-tsunami dataset for each category and runs a t-test 1000 times to compare the pre- and post-tsunami datasets. The resulting histogram shows all 1000 t-statistics and a line for the critical t-value, which allows me to determine whether a majority of the t-values are significant or not, and hence gauge the effect of differential sampling depth on the results.

Organization	Year(s)	Region/Location
Blue Fox Bay Lodge	2012-2014	Afognak and Shuyak Islands
Cape St. Elias Lightkeepers Association	2013	Lost Coast (Cape Suckling to Seal River)
F/V Otter Beachcomer	2014	Southern Chatham Strait and Kuiu Island
Gulf of Alaska Keeper	2010-2012	Prince William Sound, Kenai Peninsula, Montague Island
Island Charters	2010-2013	Craig
Island Trails Network	2010-2012	Kodiak Island
Sitka Sound Science Center	2012-2013	Sitka
Yakutat Salmon Board	2010-2012	Yakutat

Table 1: The various organizations conducting beach cleanups across the GoA, the years they conducted them and their locations within the GoA. Data reports acquired from AMSF database. (Data retrieved from: <http://www.sitkascience.org/research/marine-debris/reports>).

Results:

Of the 13 categories analyzed, “Total Debris,” “Foam” and “Floats” debris categories saw significant increases across the entire GoA ($p=0.000027$, $p=0.000030$, $p=0.0021$) (Figure 2). Mean debris values (in $\log(\text{kg}/100 \text{ meters})$) pre-tsunami (2010-2011) and post-tsunami (2012-2014) are found in Table 2 (Appendix 1), and categories with significant changes pre- vs. post-tsunami can be visualized in Figure 2. Figure 3 shows the change in average debris density from pre- to post-tsunami for all 13 debris categories.

Despite these significant increases, rarefaction analysis showed only “Foam” debris density to increase significantly pre- vs. post-tsunami (Appendix 2). This suggests that the increased effort post-tsunami had an impact in determining significance for both “Total Debris” and “Floats” density.

The other eight debris categories showed no significant change in debris abundance post- vs. pre- tsunami.

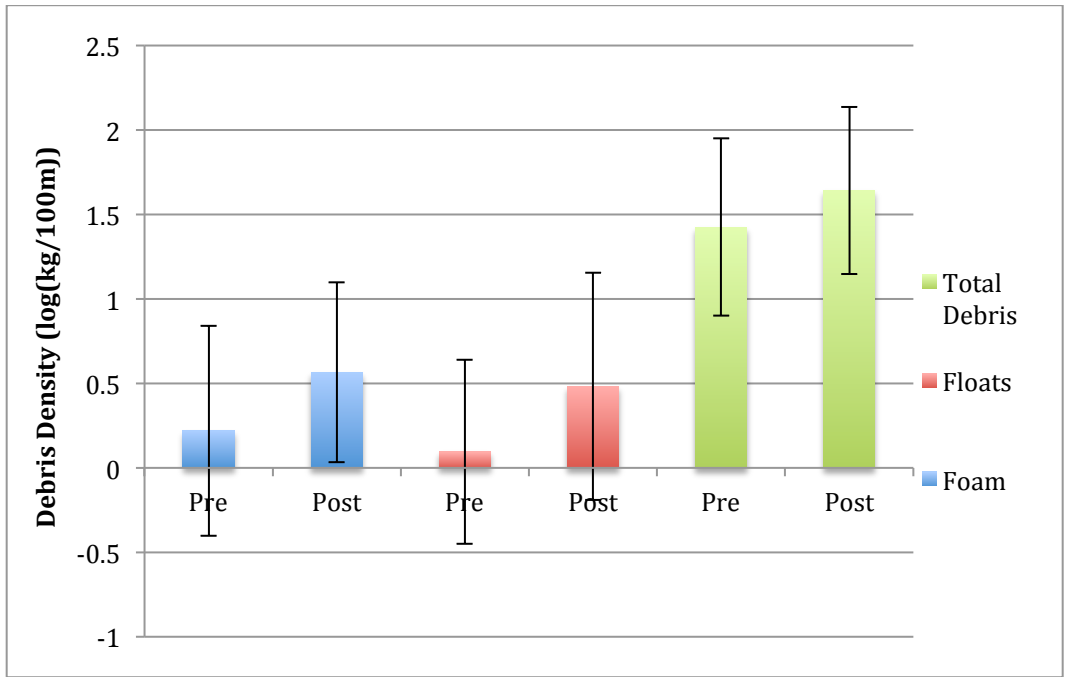


Figure 2: Significant changes in Total, Foam, and Floats debris density across the entire GoA pre- vs. post- tsunami. Error bars represent the standard deviation (as found in Table 2).

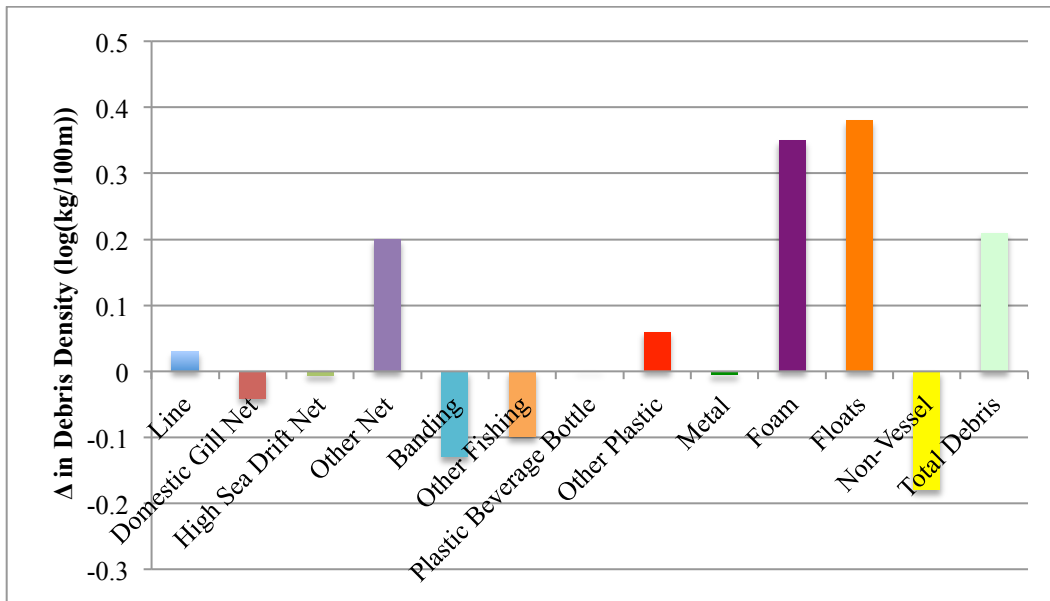


Figure 3: Changes in debris density for all debris categories post vs. pre tsunami along the entire GoA. Values above the x-axis represent increases in debris density post-tsunami and those below the x-axis represent decreases in debris density post- vs. pre- tsunami.

“Other Net,” “Foam,” “Floats” and “Total Debris” saw significant increases ($p < 0.0038$) along the Eastern GoA ($p = 0.0025$, $p = 2.0 \times 10^{-8}$, $p = 7.7 \times 10^{-5}$, and $p = 0.00011$ respectively). Significant increases in “Foam,” “Float” and “Total Debris” along the eastern GoA largely explain the significant increases found across the entire GoA. These increases are visualized in Figure 4. Table 3 (Appendix 1) shows mean debris abundance values pre- and post-tsunami and corresponding p-values from one-tailed unpaired t-tests. No other debris categories saw significant changes along the Eastern GoA.

Of the four debris densities that saw significant increases in debris density categories in the t-test analysis, rarefaction analysis found only “Foam” and “Total Debris” densities to be unlikely to be due to a sampling artifact (Appendix 2). Rarefaction analyses showed a majority of t-statistics to be significant for “Foam” and “Total Debris” densities, suggesting the resulting significance was not a result of increased cleanup efforts post-tsunami. Increase cleanup effort post-tsunami, thus, did influence increases in “Other Net” and “Floats” densities post-tsunami.

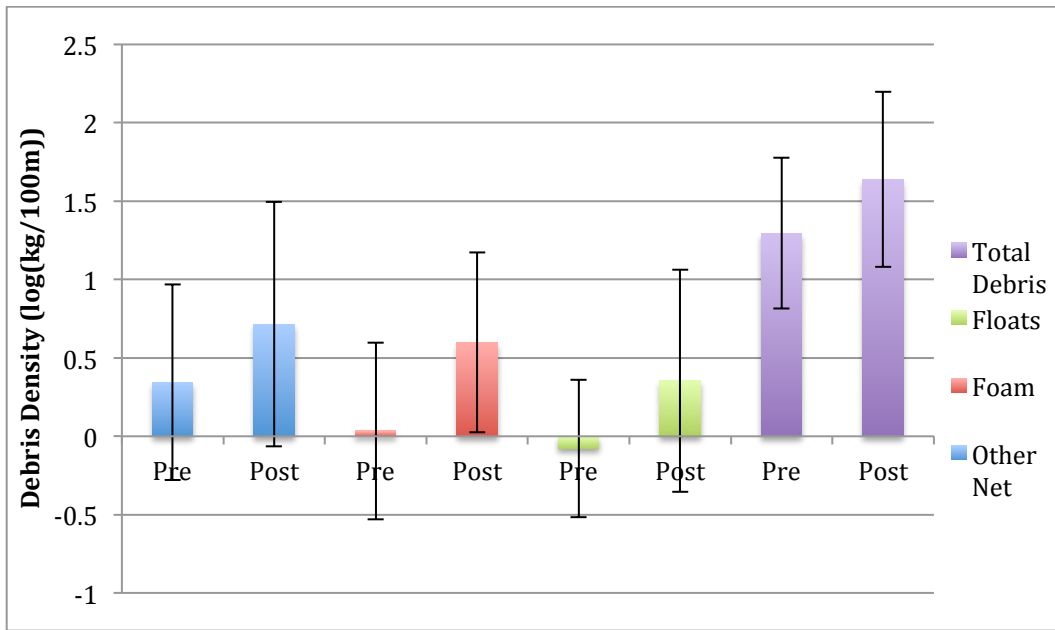


Figure 4: Significant changes in “Other Net,” “Foam,” “Floats” and “Total Debris” density across the eastern GoA pre- vs. post- tsunami. Error bars represent standard deviation (as found in Table 3).

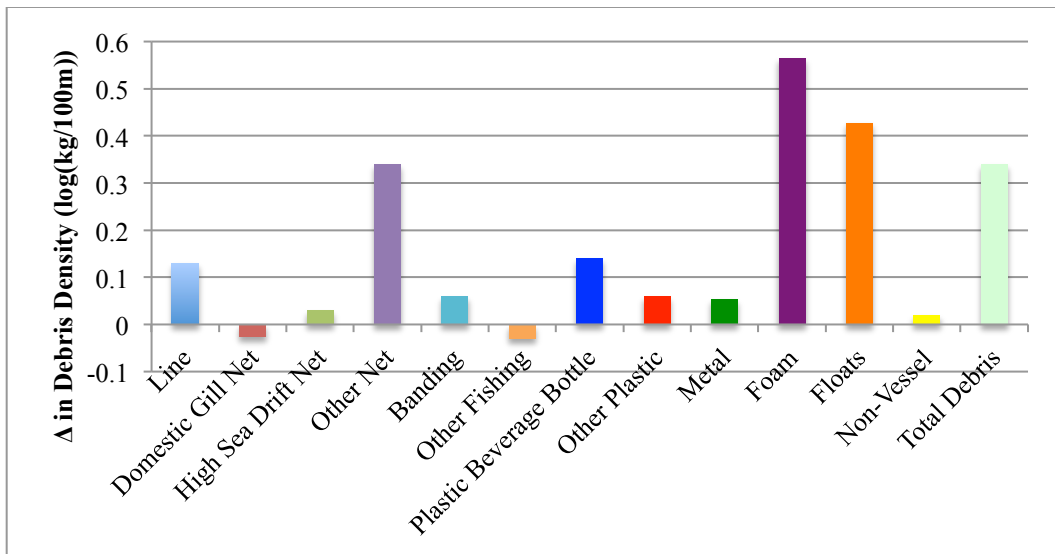


Figure 5: Changes in debris density for all debris categories post- vs. pre- tsunami along the eastern GoA.

Unlike the eastern GoA, the western GoA saw significant decreases in a variety of different debris categories ($p < 0.0038$). “Non-Vessel,” “Plastic Beverage Bottle” and “Banding” debris density decreases significantly ($p = 0.00012$, $p = 0.00087$, and $p = 0.00000075$ respectively) post-tsunami as compared to pre-tsunami levels. All other debris categories failed to change significantly. Table 4 (Appendix 1) shows the mean

debris abundance values and corresponding levels of significance and Figure 4, above, shows the debris categories that significantly changed pre- vs. post-tsunami.

Rarefaction analyses confirmed a majority of the t-test statistics for “Non-Vessel” and “Banding” debris density categories to have significantly decreased (Appendix 2). Effort or sampling bias is, thus, not responsible for the significance results yielded in the t-tests. “Plastic Beverage Bottle” density, however, was influenced by increased effort post-tsunami. This can be seen as 76.3% of t-statistics were not seen to be significant in the rarefaction analysis.

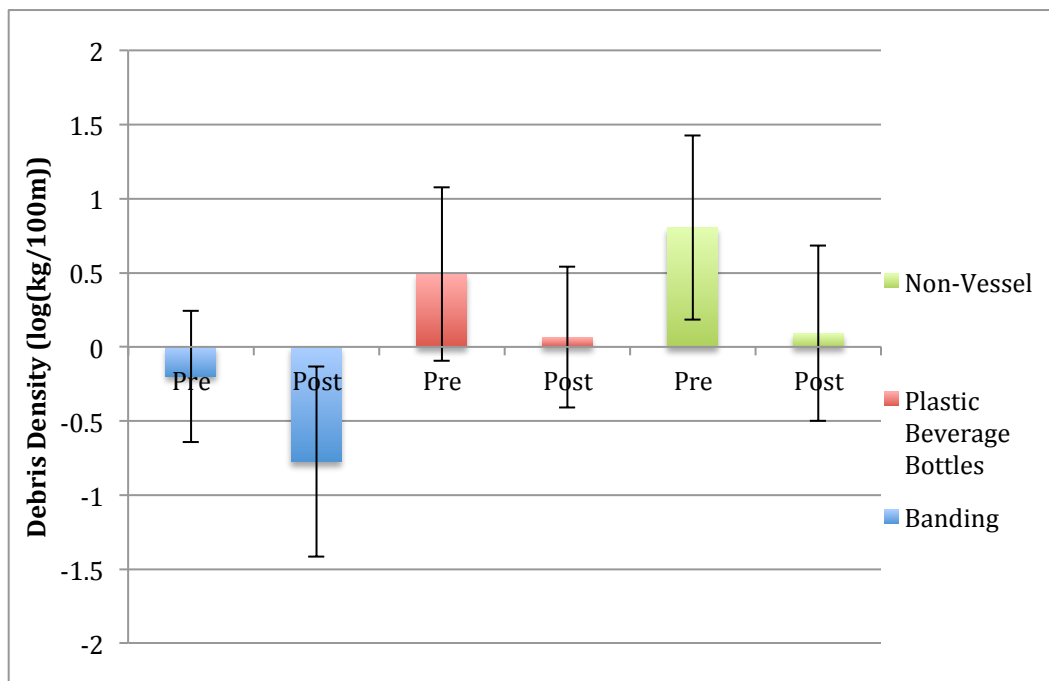


Figure 6: Significant changes in “Non-Vessel,” “Plastic Beverage Bottle” and “Banding” debris density across the western GoA pre- vs. post- tsunami. Error bars represent standard deviation (as found in Table 4).

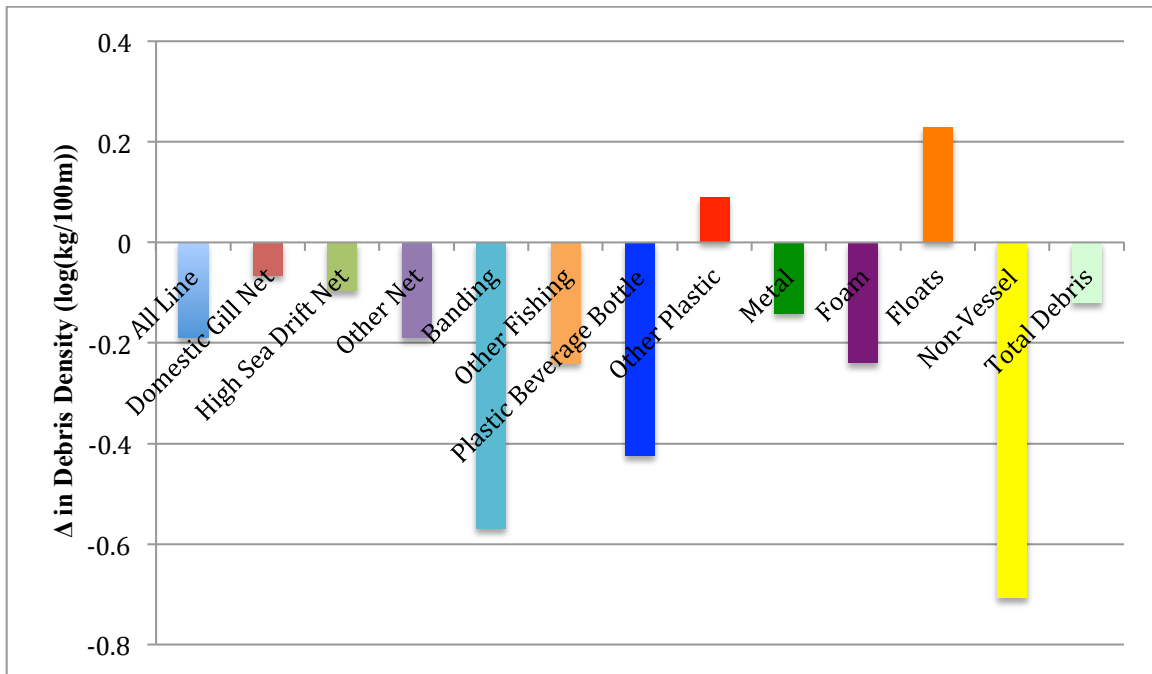


Figure 7: Changes in debris density for all debris categories pre- vs. post- tsunami along the western GoA.

Discussion:

Results show significant increases in the debris density post-tsunami vs. pre-tsunami of some, but not all categories of, debris types (“Total Debris,” “Foam” and “Floats”) across the GoA coastline, driven largely by increases along the eastern GoA. Increases in “Total” and “Foam” debris are consistent with anecdotal evidence post-tsunami (ODFW, 2012). Greater increases along the eastern vs. western GoA are consistent with GNOME and SEA-GEARN/MOVE-K7 model predictions of JTMD landings along Alaska (Bagulayan et al., 2012; NOAA, 2014; Maximenko et al., 2015).

Despite overall increases along the entire GoA and eastern GoA, the western GoA saw decreases in debris density post-tsunami as compared to pre-tsunami (“Non-Vessel,” “Plastic Beverage Bottle” and “Banding”). The combination of decreases in background (or non-tsunami related) debris levels and the possible failure of significant amounts of tsunami debris actually to reach the western GoA may explain this reduction in debris densities. Model predictions (Appendix II) can explain the lack of an increase in debris density as the western GoA appears to be at the edge of the predicted coastline expected to receive JTMD (Bagulayan et al., 2012; NOAA, 2014; Maximenko et al., 2015).

Nevertheless, significant increases of various types of debris categories, namely “Total Debris,” “Foam,” and “Floats”, across the GoA, put Alaska at an increased risk of species invasions by increasing propagule pressure to the Alaskan coast.

As previously mentioned, marine debris is a known pathway by which non-native species can travel (Barnes, 2002; Barnes & Fraser, 2003; Bax et al., 2003; Derraik, 2002; Gregory, 2009; Masó et al., 2003, Zettler et al., 2013). This has further been seen with tsunami debris as confirmed JTMD has been shown to carry numerous and potentially harmful non-native species to North American coastlines (Lam et al., 2015; NOAA, 2013). Barnes (2002) found that despite colder temperature at higher latitudes, fauna was still found to colonize marine debris until about 60° N and S latitude (Barnes, 2002). Given that the Gulf of Alaska is south of 60° N, marine debris reaching this coastline remains as a pathway for potential species invasions.

With increases in debris density found only along the eastern GoA (as compared to the western GoA), this region is at a higher risk of species invasions from the incoming JTMD. Due to the lack of funding in Alaska for the state’s invasive species program (ADFG, 2002), it is important to maximize the impact of every dollar in the prevention of species invasions. Between 2007-2011, Alaska spent roughly \$5.8 million dollars on invasive species management, only 8% of which was on marine plants and animals (Schwörer et al., 2012). Focusing more heavily on prevention and management of invasive species along the eastern GoA would, according to this study, more effectively reduce the likelihood of marine debris-related species invasions. Hence, management would be focusing its attention on a region with a higher propagule pressure from marine debris. This would further reduce the potential damage invasive species can impose on Alaska’s ecosystem and economy. Costs and losses associated with a single harmful invasive species have the potential to exceed \$100 million (Union of Concerned Scientists, 2005). The tourism and fisheries industries would be among those most affected by invasive species (Union of Concerned Scientists, 2005). Potential costs of impacts from invasive species far outweigh the management costs aimed to prevent species invasions (Pimentel et al., 2005; Union of Concerned Scientists, 2005).

Due to the relatively concentrated cleanup sites across the expansive GoA, there is likely some spatial sampling bias influencing the aforementioned results. That said,

this underscores the difficulty of knowing exactly where to focus in an invasive species management program because of patchy volunteer cleanup coverage across the GoA and other difficult to control factors. Additionally, while the results provide invasive species managers with the opportunity to focus efforts to combat marine debris-related species invasions along the eastern GoA, this phenomenon remains a threat to various other regions of the Alaskan coastline as well.

Finally, the JTMD event provides invasive species managers with the chance to further their understanding of how non-native species hitchhiking on marine debris can impact the Alaskan coast.

Conclusion:

My results indicate that an increase of JTMD along the Alaskan coastline increases the risk of marine debris-related species invasions in the GoA. Increases in marine debris density along the entire GoA post-tsunami are largely driving the increases in debris density seen along the eastern GoA. This highlights the need for invasive species management officials to concentrate their efforts along the eastern GoA to effectively prevent marine debris-related species invasions as best as possible, despite a likely spatial sampling bias in the data. Given that the eastern GoA has a total debris density 1.36 times higher --and a foam debris density 2.34 times higher--than the western GoA post-tsunami as compared to pre-tsunami levels, management should concentrate their efforts proportionately on the eastern GoA. While this effect is expected to be a one-time difference until tsunami debris stops washing ashore, without effective management and preventative measures along this region, critically important economic industries, like tourism and fisheries, could face severe consequences. Management costs associated with prevention and early detection would be considerably lower than the ongoing management costs associated with control and additional direct and indirect economic harm caused by species invaders. Prevention of marine debris-related species invasions is critical given the sharp increase in various types of marine debris as a result of the 2011 Tohoku tsunami and must be managed with the utmost care.

References:

- Alaska Department of Environmental Conservation, Division of Environmental Health. (2013). Tsunami Marine Debris 2012 Report. Retrieved from <http://dec.alaska.gov/eh/marine-debris/docs/Tsunami%20Marine%20Debris%20in%20Alaska%20Annual%20Report%20for%202012.pdf>
- Alaska Department of Fish and Game (ADFG). (2002). *Alaska Aquatic Nuisance Species Management Plan* (RIR 5J02-10). Juneau, AK.
- Alaska Marine Stewardship Foundation (AMSF). (2014). *Marine Debris Data Collection and Recording Protocol*. Auke Bay, Alaska. Retrieved from: <http://www.alaskamsf.org/wp-content/uploads/2014/12/AMSF-Marine-Debris-Categories-Discussion-Paper.pdf>.
- Bagulayan, A., Bartlett-Roa, J. N., Carter, A. L., Inman, B. G., Keen, E. M., Orenstein, E. C., Patin, N. V., Sato, K. N. S., Sibert, A. E., Simonis, A. E., Van Cise, A. M., & Franks, P. J. S. (2012). Journey to the Center of the Gyre: The Fate of the Tohoku Tsunami Debris Field. *Oceanography*, 25(2), 200–207. <http://doi.org/10.5670/oceanog.2012.55>.
- Barnes, D. K. (2002). Biodiversity: invasions by marine life on plastic debris. *Nature*, 416(6883), 808–809.
- Barnes, D.K.A, & Fraser, K.P.P. (2003). Rafting by five phyla on man-made flotsam in the Southern Ocean. *Marine Ecology Progress Series*, 262, 289-291.
- Bax, N., Williamson, A., Agüero, M., Gonzalez, E., & Geeves, W. (2003). Marine invasive alien species: a threat to global biodiversity. *Marine Policy*, 27(4), 313–323. [http://doi.org/10.1016/S0308-597X\(03\)00041-1](http://doi.org/10.1016/S0308-597X(03)00041-1).
- biological control. 2015. In *Merriam-Webster.com*. Retrieved June 13, 2016, from <http://www.merriam-webster.com/dictionary/biological%20control>.
- Blight, L. K. & Burger, A. E. (1997) Occurrence of Plastic Particles in Seabirds from the Eastern North Pacific. *Marine Pollution Bulletin*, 34(5), 323-325.
- Brooks, M. L., D'Antonio, C. M., Richardson, D. M., Grace, J. B., Keeley, J. E., DiTomaso, J. M., Hobbs, R. J., Pellant, M., Pyke, D. (2004). Effects of Invasive Alien Plants on Fire Regimes. *BioScience*, 54(7), 677. [http://doi.org/10.1641/0006-3568\(2004\)054\[0677:EOIAP0\]2.0.CO;2](http://doi.org/10.1641/0006-3568(2004)054[0677:EOIAP0]2.0.CO;2).
- Calder, D., Choong, H., Carlton, J., Chapman, J., Miller, J., & Geller, J. (2014). Hydroids (Cnidaria: Hydrozoa) from Japanese tsunami marine debris washing ashore in the northwestern United States. *Aquatic Invasions*, 9(4), 425–440. <http://doi.org/10.3391/ai.2014.9.4.02>.

- Clinton, W. J. (1999). Invasive Species. *Other Publications in Wildlife Management*. Paper 25. <http://digitalcommons.unl.edu/icwdmother/25>.
- Choong, H., & Calder, D. (2013). *Sertularella mutsuensis* Stechow, 1931 (Cnidaria: Hydrozoa: Sertulariidae) from Japanese tsunami debris: systematics and evidence for transoceanic dispersal. *BioInvasions Records*, 2(1), 33–38. <http://doi.org/10.3391/bir.2013.2.1.05>.
- Colt, S., & Fay, G. (2014). Economics of Wilderness: Contribution of Alaska Parks and Wilderness to the Alaska Economy. *Alaska Park Science*, 13(1), 35-39.
- Croll, D. A., Maron, J. L., Estes, J. A., Danner, E. M., & Byrd, G. V. (2005) Introduced Predators Transform Subarctic Islands from Grassland to Tundra. *Science*, 307(5717), 1959-1961.
- Culliney, T. W. (2005). Benefits of Classical Biological Control for Managing Invasive Plants. *Critical Reviews in Plant Sciences*, 24(2), 131–150. <http://doi.org/10.1080/07352680590961649>.
- Denlinger, L. (2006). *Alaska Seabird Information Series (ASIS)*. US Fish and Wildlife Service, Migratory Bird Management, Nongame Program.
- Derraik, J. G. (2002). The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin*, 44(9), 842–852.
- Ebbert, S. E., & Byrd, G. V. (2002). Eradications of invasive species to restore natural biological diversity on Alaska Maritime National Wildlife Refuge. *Turning the Tide: The Eradication of Invasive Species (CR Veitch and MN Clout, Editors)*. IUCN Invasive Species Specialist Group, Gland, Switzerland and Cambridge, United Kingdom, 102–109.
- Environmental Protection Agency. (2011). *Marine Debris in the North Pacific: A Summary of Existing Information and Identification of Data Gap*. San Francisco, CA.
- Fine, P.V.A. (2002). The invasibility of tropical forests by exotic plants. *Journal of Tropical Ecology*, 18(5). <http://doi.org/10.1017/S0266467402002456>.
- Gall, S. C., & Thompson, R. C. (2015). The impact of debris on marine life. *Marine Pollution Bulletin*, 92(1-2), 170–179. <http://doi.org/10.1016/j.marpolbul.2014.12.041>.
- Gregory, M. R. (2009). Environmental implications of plastic debris in marine settings--entanglement, ingestion, smothering, hangers-on, hitch-hiking and alien invasions. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364(1526), 2013–2025. <http://doi.org/10.1098/rstb.2008.0265>.

- Gurevitch, J., & Padilla, D. (2004). Are invasive species a major cause of extinctions? *Trends in Ecology & Evolution*, *19*(9), 470–474. <http://doi.org/10.1016/j.tree.2004.07.005>.
- Jang, Y. C., Hong, S., Lee, J., Lee, M. J., & Shim, W. J. (2014). Estimation of lost tourism revenue in Geoje Island from the 2011 marine debris pollution event in South Korea. *Marine Pollution Bulletin*, *81*(1), 49–54. <http://doi.org/10.1016/j.marpolbul.2014.02.021>.
- Japan Ministry of the Environment. March 2014. A report on forecasts of tsunami driftage location. 7 pp. http://www.kantei.go.jp/jp/singi/kaiyou/hyouryuu/qanda_eng/gaiyou.pdf.
- Laist, D. W. (1997). Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records. In *Marine Debris* (pp. 99–139). Springer. Retrieved from http://link.springer.com/chapter/10.1007/978-1-4613-8486-1_10.
- Lam, J., Chan, S., Hansen, G., Chapman, J., Miller, J., Carlton, J., Boatner, R., Cooper, R., Kight, P., Siemens, T., Martin, K., & Corcoran, J. (2015). Key Aquatic Invasive Species Watch: Japanese Tsunami Marine Debris in the Eastern Pacific. Retrieved from: <http://seagrant.oregonstate.edu/sgpubs/key-aquatic-invasive-species-watch-japanese-tsunami-marine-debris-eastern-pacific>.
- Ludyanskiy, M. L., McDonald, D., & MacNeill, D. (1993). Impact of the Zebra Mussel, a Bivalve Invader. *BioScience*, *43*(8), 533–544. <http://doi.org/10.2307/1311948>.
- Macfadyen, G., Huntington, T., & Cappell, R. (2009). *Abandoned, lost or otherwise discarded fishing gear*. Rome: United Nations Environment Programme : Food and Agriculture Organization of the United Nations.
- Mack, R. N., Simberloff, D., Lonsdale, W. M., Evans, H., Clout, M., & Bazzaz, F. A. (2000). Biotic Invasions: Causes, Epidemiology, Global Consequences, and Control. *Ecological Applications*, *10*(3), 689. <http://doi.org/10.2307/2641039>.
- Manchester, S. J., & Bullock, J. M. (2000). The impacts of non-native species on UK biodiversity and the effectiveness of control. *Journal of Applied Ecology*, *37*(5), 845–864.
- Masó, M., Garcés, E., Pagès, F., & Camp, J. (2003). Drifting plastic debris as a potential vector for dispersing Harmful Algal Bloom (HAB) species. *Scientia Marina*, *67*(1): 107-111.
- Maximenko, N., MacFadyen, A., & Kamachi, M. (2015). Modeling the drift of marine debris generated by the 2011 tsunami in Japan. *PICES Press*, *23*(2), 32.

- McDowell Group. (2016). Economic Impact of Alaska's Visitor Industry: 2014-15 update. Retrieved from:
https://www.commerce.alaska.gov/web/Portals/6/pub/TourismResearch/AVSP/Visitor%20Impacts%202016%20update%204_15_16.pdf.
- Merrell Jr., T. R. (1980). Accumulation of Plastic Litter on Beaches of Amchitka Island, Alaska. *Marine Environmental Research*, 3, 171-184.
- Mori, N., Takahashi, T., Yasuda, T., & Yanagisawa, H. (2011). Survey of 2011 Tohoku earthquake tsunami inundation and run-up: Survey of 2011 Tohoku Earthquake Tsunami. *Geophysical Research Letters*, 38(7), L00G14. doi: 10.1029/2011GL049210
- Mouat, J., & Lozano, R. L. (2010). Economic Impacts of Marine Litter. Retrieved from http://www.noordzee.nl/wp-content/uploads/2011/06/1_Economic_impacts_of_marine_litter_KIMO.sept_2010.pdf.
- Müller-Schärer, H., Schaffner, U., & Steinger, T. (2004). Evolution in invasive plants: implications for biological control. *Trends in Ecology and Evolution*, 19(8), 417-422. <http://dx.doi.org/10.1016/j.tree.2004.05.010>.
- Murray, C. C., Bychkov, A., Therriault, T., Maki, H., & Wallace, N. (2015). The impact of Japanese tsunami debris on North America. *PICES Press*, 23(1), 28.
- Murray, C. C., Maximenko, N., NOAA (2016). *The influx of marine debris from the 2011 Great Japan Tsunami to North American Shorelines*. Manuscript in Preparation.
- National Oceanic and Atmospheric Administration (NOAA). (2013). *Severe Marine Debris Event Report: Japan Tsunami Marine Debris*. Retrieved from: http://marinedebris.noaa.gov/sites/default/files/Japan_Tsunami_Marine_Debris_Report.pdf.
- NOAA. (2014). *Proceedings of the Japan Tsunami Marine Debris Summary Meeting* (Technical Memorandum NOS OR&R 50). Silver Spring, MD.
- NOAA. (2015, June 24). Invasive Impact: What's the Status of Invasive Species in Alaska? Retrieved from: http://www.fisheries.noaa.gov/stories/2015/06/06_24_15invasive_species_in_alaska.html
- NOAA (2016, March 31). What is Marine Debris? Retrieved April 5, 2016, from <http://marinedebris.noaa.gov/discover-issue>.

- Ofiara, D. D. & Brown, B. (1999). Assessment of Economic Losses to Recreational Activities from 1988 Marine Pollution Events and Assessment of Economic Losses from Long-Term Contamination of Fish within the New York Bight to New Jersey. *Marine Pollution Bulletin*, 38(11), p.990-1004.
- Oregon Department of Fish and Wildlife (ODFW). (2012). Status Update on Japan Tsunami Marine Debris. Retrieved from: http://www.dfw.state.or.us/conservationstrategy/invasive_species/docs/082312_JTMD_Update_Notes.pdf.
- Pimentel, D., Zuniga, R., & Morrison, D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological Economics*, 52(3), 273–288. <http://doi.org/10.1016/j.ecolecon.2004.10.002>.
- Raum-Suryan, K. L., Jemison, L. A., & Pitcher, K. W. (2009). Entanglement of Steller sea lions (*Eumetopias jubatus*) in marine debris: Identifying causes and finding solutions. *Marine Pollution Bulletin*, 58(10), 1487–1495. <http://doi.org/10.1016/j.marpolbul.2009.06.004>.
- Ricciardi, A. (2013). Invasive Species. In R. Leemans (Ed.), *Ecological Systems* (pp. 161–178). New York, NY: Springer New York. Retrieved from http://link.springer.com/10.1007/978-1-4614-5755-8_10.
- Scheld, A. M., Bilkovic, D. M., & Havens, K. J. (2016). The Dilemma of Derelict Gear. *Scientific Reports*, 6, 19671. <http://doi.org/10.1038/srep19671>.
- Schrader, B., Hennon, P., Goldstein, M., Martin, D., Holsten, E., Kruse, J. (2005). Assessment of Invasive Species in Alaska and its National Forests. Retrieved from http://aknhp.uaa.alaska.edu/wp-content/uploads/2010/11/schrader_hennon_2005.pdf.
- Schwörer, T., Federer, R., Ferren, H., & Center, A. S. (2012). Managing Invasive Species: How Much Do We Spend? Retrieved from <https://scholarworks.alaska.edu/handle/11122/3919>.
- Simberloff, D. (1989). Which Insect Introductions Succeed and Which Fail? Pages 61-75 in Drake, J.A., Mooney, H.A., di Castri, F., Groves, H., Kruger, F.J., Rejmánek, M., & Williamson, M. (eds). *Biological Invasions: a global perspective*. Wiley, Chichester, UK.
- Simberloff, D. (2009). The Role of Propagule Pressure in Biological Invasions. *Annual Review of Ecology, Evolution, and Systematics*, 40(1), 81–102. <http://doi.org/10.1146/annurev.ecolsys.110308.120304>.

- Simberloff, D. (2011). How common are invasion-induced ecosystem impacts? *Biological Invasions*, 13(5), 1255–1268. <http://doi.org/10.1007/s10530-011-9956-3>.
- Simmonds, M. P. (2012). Cetaceans and Marine Debris: The Great Unknown. *Journal of Marine Biology*, 2012, 1–8. <http://doi.org/10.1155/2012/684279>.
- Sitka Sound Science Center (SSSC). (2016). Project Reports. Retrieved February, 2016: <http://www.sikascience.org/research/marine-debris/reports/>.
- Spencer, C. N., McClelland, B. R., & Stanford, J. A. (1991). Shrimp Stocking, Salmon Collapse, and Eagle Displacement. *BioScience*, 41(1), 14–21. <http://doi.org/10.2307/1311536>.
- Union of Concerned Scientists. (2005). Invasive Species: Alaska. Retrieved from http://www.legis.state.ak.us/basis/get_documents.asp?session=26&docid=866
- U.S. Census Bureau (n.d.). Alaska Quickfacts. Retrieved May 24, 2016, from <http://www.census.gov/quickfacts/table/PST045214/02>.
- Vinson, M. R., & Baker, M. A. (2008). Poor Growth of Rainbow Trout Fed New Zealand Mud Snails *Potamopyrgus antipodarum*. *North American Journal of Fisheries Management*, 28(3), 701-709.
- Williamson, M. (1996) *Biological Invasions*. Chapman & Hall, New York.
- windage. 2015. In *Merriam-Webster.com*. Retrieved June 13, 2016, from <http://www.merriam-webster.com/dictionary/windage>.
- Zettler, E. R., Mincer, T. J., & Amaral-Zettler, L. A. (2013). Life in the “Plastisphere”: Microbial Communities on Plastic Marine Debris. *Environmental Science & Technology*, 7137-7146. <http://doi.org/10.1021/es401288x>.

Appendix 1: Summary of mean debris density results for the entire GoA, eastern GoA and western GoA both pre- and post-tsunami.

	All Line	Domestic Gill Net	HSDN	Other Net	Banding	Other Fishing	Plastic Beverage Bottles	Other Plastic	Metal	Foam	Floats	Non-Vessel	Total Debris
Pre (2010-2011)* (n=67)	0.79 ± 0.54	0.024 ± 0.22	-0.093 ± 0.38	0.57 ± 0.71	-0.32 ± 0.52	0.20 ± 0.43	-0.21 ± 0.79	0.52 ± 0.50	-0.061 ± 0.41	0.22 ± 0.62	0.10 ± 0.54	0.40 ± 0.58	1.43 ± 0.53
Post (2012-2014)* (n=137)	0.82 ± 0.73	-0.017 ± 0.17	-0.10 ± 0.44	0.77 ± 0.70	-0.45 ± 0.68	0.10 ± 0.62	-0.21 ± 0.75	0.58 ± 0.56	-0.067 ± 0.58	0.57 ± 0.53	0.48 ± 0.67	0.22 ± 0.60	1.64 ± 0.49
Signif. Change (p < 0.0038) (Y/N)	N	N	N	N	N	N	N	N	N	Y	Y	N	Y
p-value	0.36	0.072	0.45	0.025	0.096	0.14	0.47	0.22	0.47	0.000027	0.00003	0.020	0.0021

Table 2: Mean levels of every type of debris found along the entire GOA, pre- vs. post- tsunami.

*Units in Log(kg/100 meters)

	All Line	Domestic Gill Net	HSDN	Other Net	Banding	Other Fishing	Plastic Beverage Bottles	Other Plastic	Metal	Foam	Floats	Non-Vessel	Total Debris
Pre (2010-2011)* (n=48)	0.67 ± 0.52	0.013 ± 0.089	-0.14 ± 0.36	0.35 ± 0.62	-0.38 ± 0.54	0.19 ± 0.42	-0.49 ± 0.67	0.44 ± 0.50	-0.067 ± 0.39	0.016 ± 0.56	-0.098 ± 0.42	0.24 ± 0.48	1.28 ± 0.48
Post (2012-2014)* (n=97)	0.80 ± 0.83	-0.014 ± 0.11	-0.11 ± 0.49	0.71 ± 0.78	-0.31 ± 0.66	0.17 ± 0.65	-0.33 ± 0.82	0.50 ± 0.60	-0.012 ± 0.60	0.60 ± 0.57	0.35 ± 0.71	0.27 ± 0.61	1.64 ± 0.56
Signif. Change (p < 0.0038) (Y/N)	N	N	N	Y	N	N	N	N	N	Y	Y	N	Y
p-value	0.16	0.071	0.35	0.0025	0.28	0.41	0.12	0.28	0.28	2.0x10 ⁻⁸	0.000077	0.37	0.00011

Table 3: Mean levels of every type of debris found along the eastern GOA, pre- vs. post- tsunami.

*Units in Log(kg/100 meters)

	All Line	Domestic Gill Net	HSDN	Other Net	Banding	Other Fishing	Plastic Beverage Bottles	Other Plastic	Metal	Foam	Floats	Non-Vessel	Total Debris
Pre (2010-2011)* (n=19)	1.07 ± 0.46	0.043 ± 0.38	0.011 ± 0.42	1.11 ± 0.61	-0.20 ± 0.44	0.19 ± 0.45	0.49 ± 0.59	0.69 ± 0.48	-0.058 ± 0.48	0.72 ± 0.48	0.57 ± 0.53	0.80 ± 0.62	1.77 ± 0.48
Post (2012-2014)* (n=40)	0.88 ± 0.38	-0.023 ± 0.27	-0.086 ± 0.30	0.92 ± 0.43	-0.77 ± 0.64	-0.051 ± 0.53	0.065 ± 0.48	0.78 ± 0.39	-0.20 ± 0.51	0.48 ± 0.41	0.80 ± 0.45	0.092 ± 0.59	1.65 ± 0.29
Signif. Change (p < 0.0038) (Y/N)	N	N	N	N	Y	N	Y	N	N	N	N	Y	N
p-value	0.047	0.22	0.16	0.079	0.00042	0.047	0.0021	0.24	0.16	0.028	0.047	0.000038	0.12

Table 4: Mean levels of every type of debris found along the western GOA, pre- vs. post- tsunami.

*Units in Log(kg/100 meters)

Appendix 2: This appendix shows the results of rarefaction analyses for each significant category from t-tests along the entire GoA, eastern GoA, and western GoA.

Entire GoA:

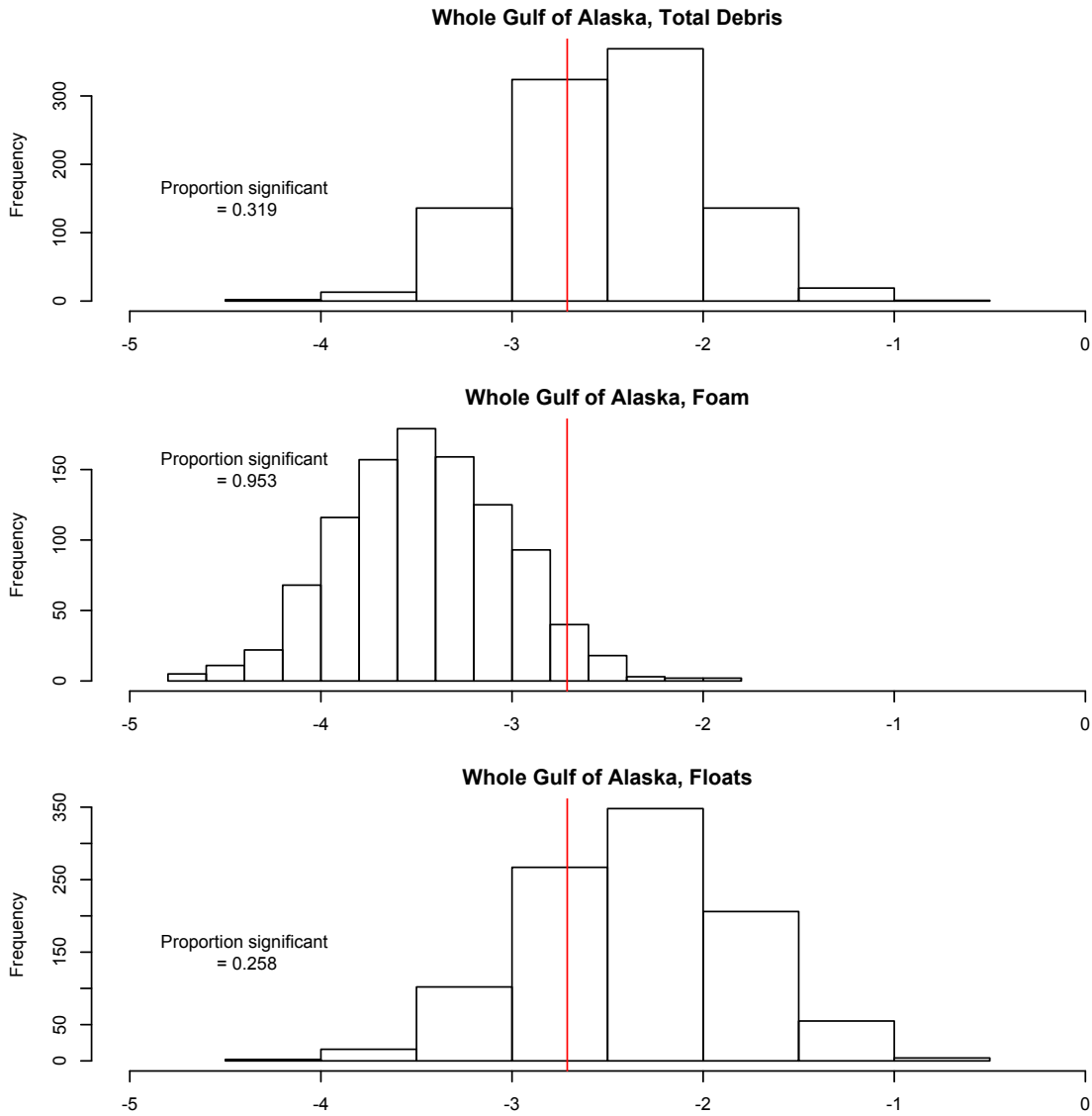


Figure 8: Rarefaction analysis for “Foam,” “Floats” and “Total Debris” density along the entire GoA.

Eastern GoA:

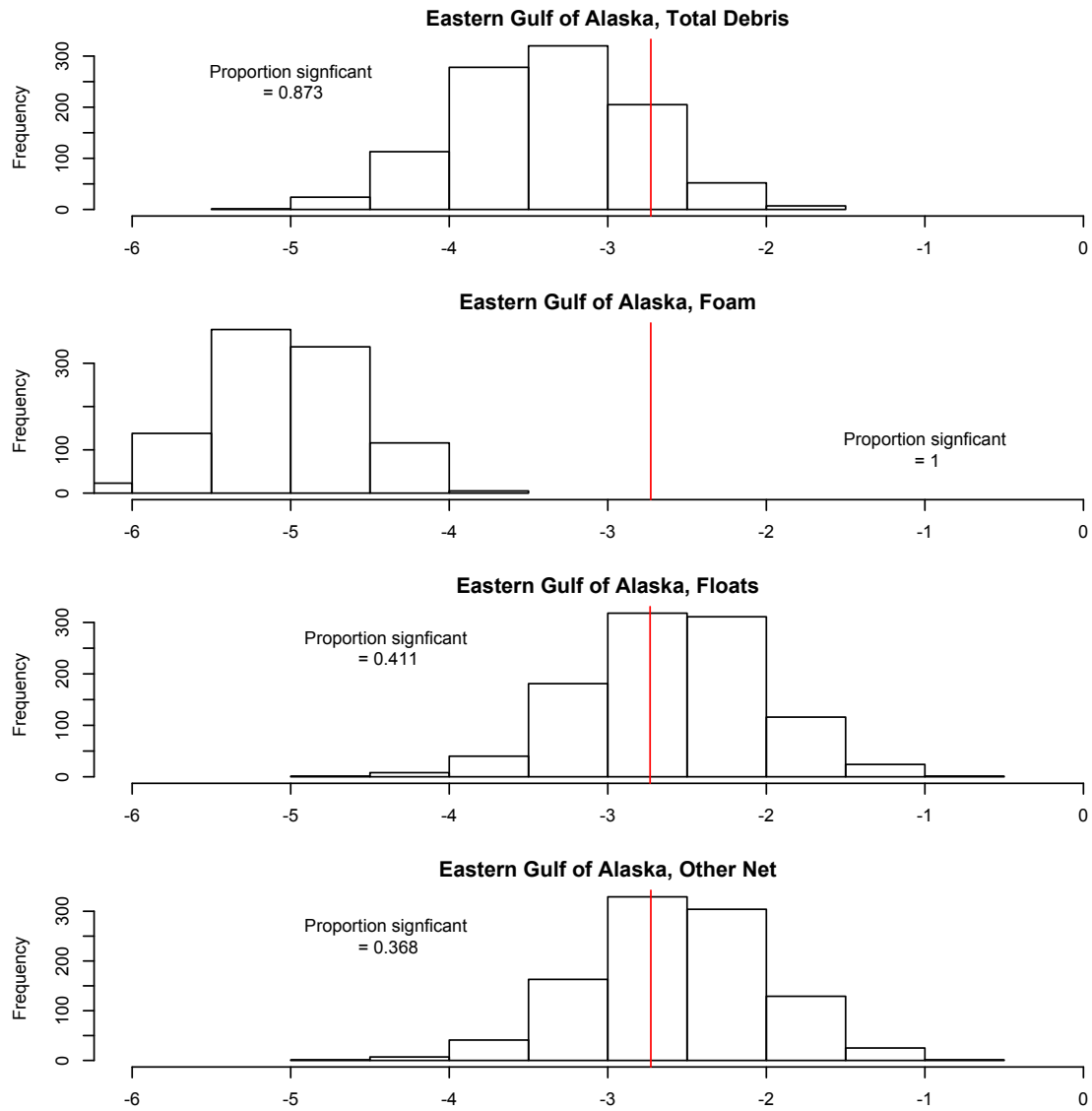


Figure 9: Rarefaction analysis for “Other Net,” “Foam,” “Floats” and “Total Debris” density along the eastern GoA.

Western GoA:

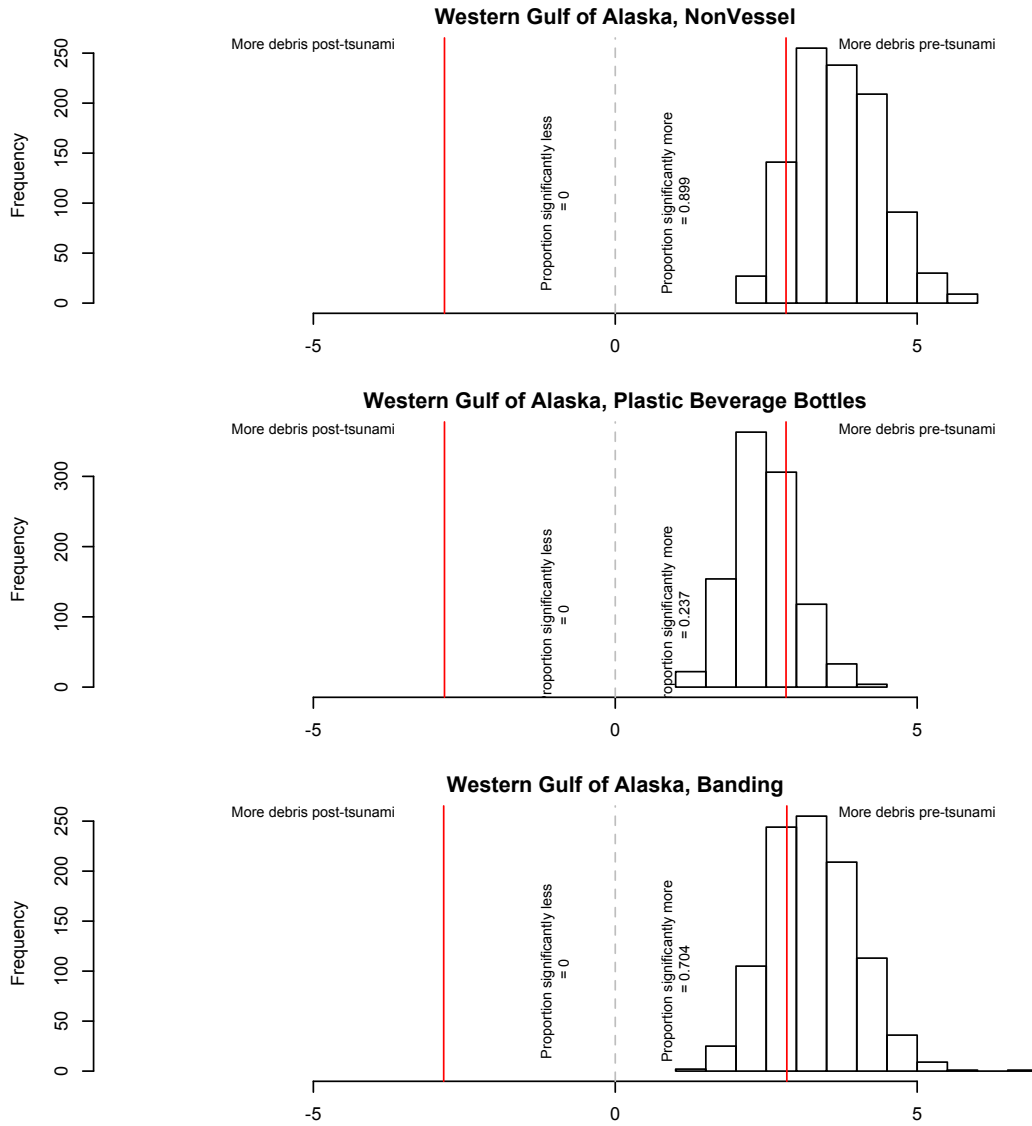


Figure 10: Rarefaction analysis for “Banding,” “Plastic Beverage Bottles” and “Non-Vessel” density along the western GoA.

Appendix 3: This appendix shows the images from the GNOME and SEA-GEARN/MOVE-K7 model predictions.

GNOME:

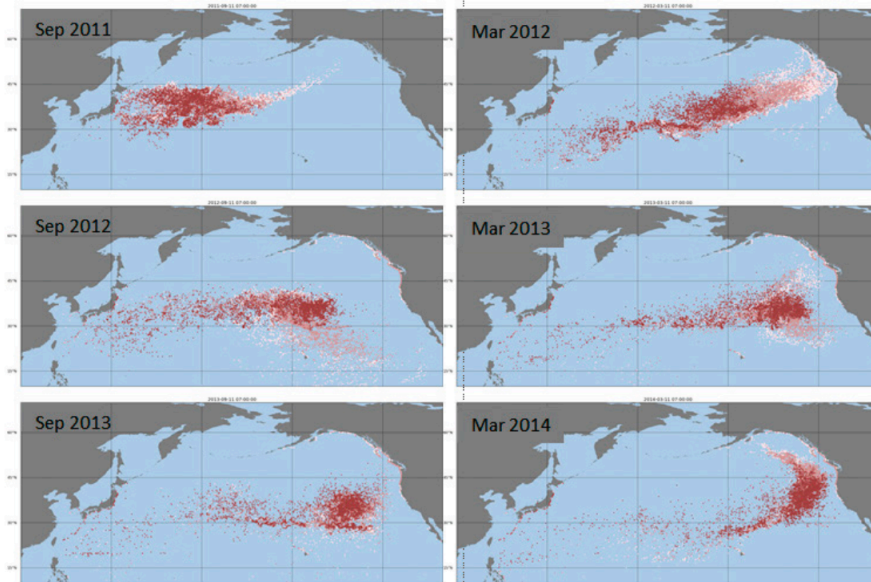


Figure 11: This image shows the predicted path of JTMD from NOAA's GNOME model. High windage objects are shown as white and low windage objects are shown in red (Maximenko et al., 2015).

SEA-GEARN/MOVE-K7:

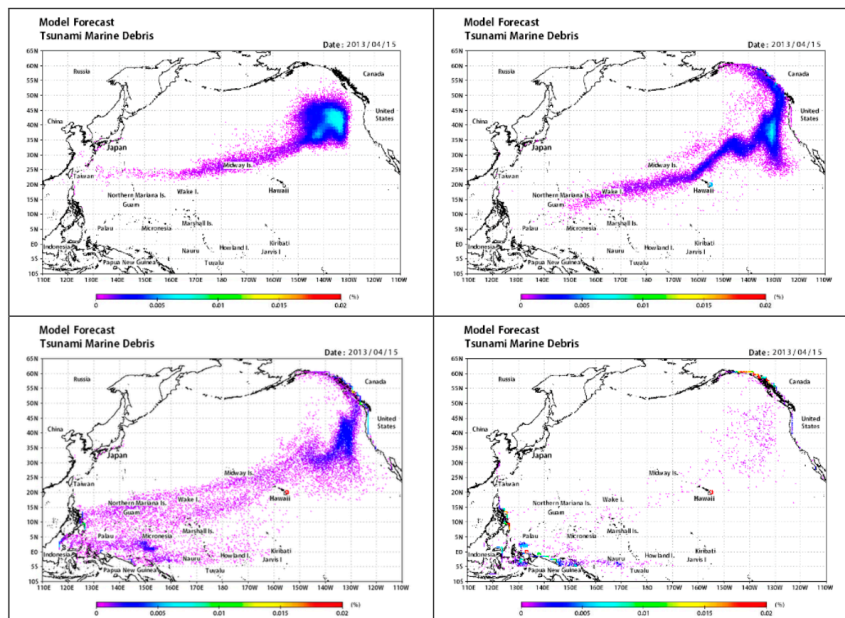


Figure 12: This model shows the distribution of JTMD particles for four different windage values (0, 2.5, 3.5 and 5%) on April 15, 2013. The colors indicate different levels of concentrations (Maximenko et al., 2015).

Appendix 4: This appendix defines all 13 different marine debris categories according to the Alaskan Marine Stewardship Foundation (AMSF, 2014).

All Line:

Lines or ropes were one of the most common items found during early cleanups. They are used for many things, both on land and water but are particularly common on the water. Pieces of all lengths are found and vary primarily in the type of material and thickness. Crab lines were previously in their own category, however, they were difficult to determine unless attached to a float. Given that all lines entangle wildlife and crab lines were especially difficult to identify without being attached to a float, crab lines were merged with all other lines. Several reports include crab line as a separate category but were combined with other line to make an All Line category.

Domestic Gill Net:

There are two types of domestic gillnet used in Alaska: herring and salmon. Herring DGN are usually made of single strand monofilament. All salmon gillnets are made from an opaque multifilament web. The web must have at least 30 filaments or have 6 filaments, each of which must be at least 0.20 mm in diameter. Legal mesh size varies by area and may be restricted by the Alaska Department of Fish and Game. It may be as small as $4 \frac{3}{8}$ inches, but nowhere may it be greater than 8 inches. One style of float is used on gillnets throughout Alaska. They are typically oval shaped, approximately $5 \frac{1}{2}$ inches long, with a single cork line passing through the center.

High Sea Drift Net (HSDN):

Used exclusively by foreign fleets, high seas drift nets (HSDN) are another unique type of net. The nets are typically made of single strand monofilament and have larger mesh sizes than domestic herring gillnets. The mesh sizes range from 100 mm (4 inches) in the squid fisheries to 180 mm (>7 inches) in the tuna and billfish fisheries. The surest way to identify HSDN is when the floats are attached.

Other Net:

Trawl, seine and cargo nets.

Banding:

Plastic banding is commonly used to bundle items for handling and shipping, as well as seal boxes and attach items to pallets, skids and crates. Banding is typically plastic webbing between $\frac{1}{2}$ inch to $\frac{3}{4}$ inch wide and less than $\frac{1}{8}$ inch deep. It occurs in tangles of pieces that have been cut, in loops that have been removed from a box, or at times, in a roll for use in wrapping boxes.

Other Fishing Related:

There are a large variety of other fishing related materials. Any identifiable piece of fishing apparatus is included in this category, including all bait containers, gaffs, pieces of capture gear (crab, shrimp, and hagfish pots and/or pieces), crab measurers, government pot identification markers, and gloves.

Plastic Beverage Bottles:

Plastic beverage bottles, as the title implies, are bottles that typically hold beverages. The most common type found are commonly sold clear water bottles. Origin of some caps and bottles may be inferred from language written on it.

Other Plastic:

Simply put, anything that is made of plastic and does not fit into any of the other categories (floats, other fishing related material, bottles or banding) falls into this category.

Metal:

Anything made of metal that does not fit into any of the other categories (floats and other fishing-related materials) is put into this category. Most frequently, metal debris comes from local and non-marine sources.

Foam:

This category includes non-float items made of foam. Typically large pieces (2 x 1 x 8 feet) from docks or flotation in vessels are found as well as pieces of foam from which shoe and sandal bottoms are cut. It will persist in the environment for a long time, and may eventually degrade into ingestible pieces similar to plastic.

Floats:

Floats are used to mark fishing gear for retrieval such as crab and shrimp pots and longline fisheries, or to provide flotation for the gear itself as in gillnets and trawls. There is a large variety of float shapes and materials. The shape may be that of the domestic gillnet float earlier described, the common buoy float used in the crab fisheries, or the more compact version of the gillnet float used in the seine fishery. The material may be hard or soft plastic, aluminum, steel, wood, cork, or foam.

Non-Vessel:

This is a catch-all category used when an item clearly does not fit into any of the other categories.

Total Debris:

This category is the compilation of all other 12 debris categories.