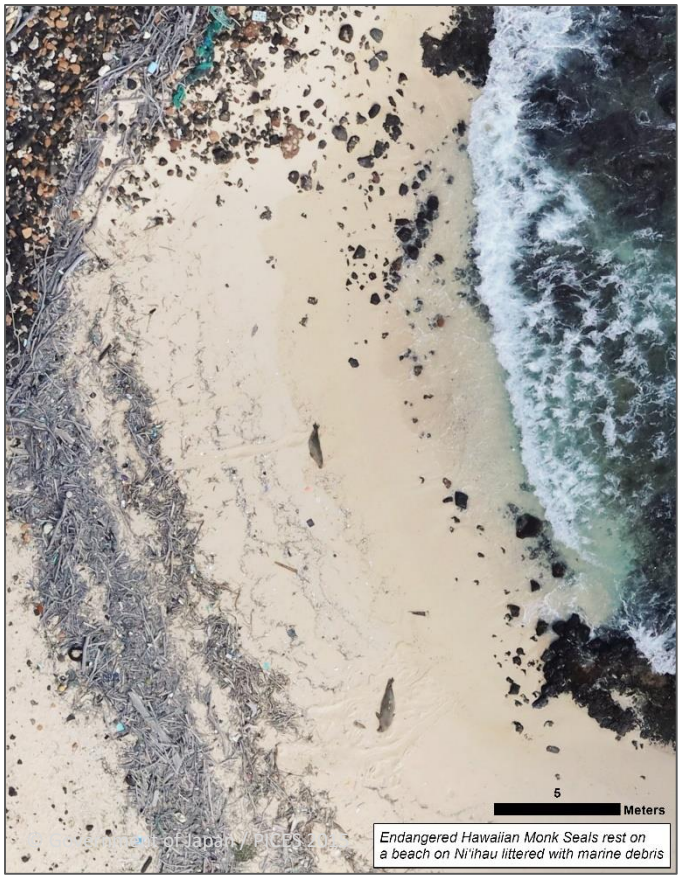

Endangered Hawaiian Monk Seals rest on a beach on Ni'ihau littered with marine debris

FINAL REPORT

Japanese Tsunami Marine Debris Aerial Imagery Analysis and GIS Support in the Main Hawaiian Islands

APRIL 2016

Hawai'i Coral Reef Initiative

This publication is a result of funding from the Ministry of the Environment of Japan, through Hawai'i Department of Land and Natural Resources (DLNR) and the North Pacific Marine Science Organization (PICES), under an award to the University of Hawai'i, Social Science Research Institute, Hawai'i Coral Reef Initiative.

Japanese Tsunami Marine Debris Aerial Imagery Analysis and GIS Support in the Main Hawaiian Islands

April 2016

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Page 3 Photo Credit: Kirsten Moy, DLNR – DAR.

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CONTENTS

EXECUTIVE SUMMARY

Japanese Tsunami Marine Debris Aerial Imagery Analysis and GIS Support in the Main Hawaiian Islands - The Department of Land and Natural Resources (DLNR) and the Hawaii Coral Reef Initiative of the University of Hawaii at Manoa collaborated on a large-scale aerial surveillance project of shoreline marine debris in the Main Hawaiian Islands (MHIs) in autumn of 2015. The analysis of the high-resolution imagery identified 20,658 marine debris items in total. Areas of the highest concentration of debris were found primarily on northern and eastern facing shores. The island of Niihau had the highest concentration of debris (38%), and all other islands accounted for less than 14% each with Oahu having the lowest (5%). Debris was categorized by type; plastics were the most prevalent, accounting for 47% of all shoreline debris statewide. The study's findings may assists regulatory agencies and local community partners to plan further management actions, to identify marine debris from the 2011 Tohoku Earthquake and tsunami, and to evaluate accumulation patterns in the MHIs over time.

SECTION 1: BACKGROUND

Marine Debris and the Japanese Tsunami

Marine debris is defined 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 or the Great Lakes."[1] On March 11, 2011, the Tohoku Earthquake and resulting tsunami devastated Japan, claiming human lives and damaging coastal infrastructure, which in turn created millions of tons of debris. Much of this debris was swept back into the ocean, and items buoyant enough to float can travel thousands of miles driven by wind and current.[2] Hawai'i is one destination for this debris.

Marine Debris Accumulation in Hawaii

Several oceanographic processes, including gyres, eddies, and meanders, drive the movement and accumulation of marine debris. Hawai'i is located in the center of the North Pacific Subtropical Convergence Zone, largely affected by the Central Pacific Gyre.[3] This gyre is powered by four major ocean currents that stretch across the north Central Pacific Ocean from Japan to California.[4] Because a circulating body of water collects debris in its center, the coastlines of Hawai'i receive significant quantities of debris each year. The first confirmed item of Japanese tsunami-linked marine debris in Hawai'i, a blue plastic fishing container, was recovered on September 18, 2012 off Makapu'u, O'ahu.[5] Since 2012, a number of debris items have been intercepted by the state of Hawai'i, including 21 vessels and an assortment of buoys, fishing containers, signs, and other items.[6]

[1] PIFSC. 2010. 2008 Main Hawaiian Islands Derelict Fishing Gear Survey. NOAA Fisheries Pacific Islands Fisheries Science Center, PIFSC Special Publication, SP-10-003.
[2] Ghaderi, Z., & Henderson, J. 2013. Japanese tsunami debris and the threat to sustainable tourism in the Hawaiian Islands. *Tourism Management Perspectives*, 98-105.
[3] NOAA Office of Response and Restoration – Marine Debris Program. 2015. How Debris Accumulates. Accessed 12/3/2015. http://marinedebris.noaa.gov/movement/how-debris-accumulates.
[4] Ribic, C., Sheavly, S., Rugg, D., & Erdmann, E. 2012. Trends in marine debris along the U.S. Pacific Coast and Hawai'i 1998-2007. *Marine Pollution Bulletin*, 994-1004.
[5] Department of Land and Natural Resources. 2013. Marine Debris. Accessed 12/3/2015. http://dlnr.hawaii.gov/marine-debris/.
[6] Department of Land and Natural Resources. 2015. Division of Aquatic Resources Marine Debris Coordinator. Personal Communication.

Marine Debris Impact

Marine debris can have numerous impacts on natural environments, many of them detrimental to the overall health of the ecosystem. Wildlife are known to become entangled in debris such as net and line, or mistakenly ingest other debris items that they confuse for food, and incidents such as these can lead to various complications that may ultimately be fatal.[7] Marine debris also damages crucial habitat through its movement and accumulation in coastal areas, which can be particularly harmful to reef habitats through breakage of corals and substrate as wind and wave action forces it across reef structures.[8] Less understood is the potential for marine debris to act as a vector in the transport of aquatic invasive species (AIS) through a process known as rafting. As an example, a 188-ton dock arrived on Oregon shores in 2012 carrying over 100 different species from Japan.[2] These AIS can become established and outcompete and overwhelm the native ecosystem. Impacts of marine debris affect humans as well, with debris presenting a hazard to personal and boating safety, and marring beaches that attract economic income through tourism.[2] The unique environment and tourism-based economy of the Hawaiian Islands could suffer greatly from the effects of marine debris.

Previous Aerial Marine Debris Mapping of the Main Hawaiian Islands

In 2006 and 2008, the NOAA Pacific Islands Fisheries Science Center (PIFSC) Coral Reef Ecosystem Division (CRED) conducted oblique-angle aerial surveys of derelict fishing gear (DFG) in the Main Hawaiian Islands.[1] The surveys were performed from Hughes 500 helicopters flying at 20-60 knots at altitudes of 31-92m. Observers recorded data while in-flight when DFG was identified, noting its color, size class, and type of material.

The 2006 NOAA aerial survey identified 711 individual DFG sites throughout the Main Hawaiian Islands (surveyed islands included Kauaʻi, Oʻahu, Lānaʻi, Maui, Molokaʻi, and Hawaiʻi Island). This project also included the removal of 225 piles of DFG from Oʻahu and 156 piles of DFG from Lānaʻi, a total of 16 and 17.4 metric tons respectively.

Aerial survey methodology was repeated in 2008, and identified 1086 individual DFG sites. The increase from the 2006 study is thought to be reflective of refined flying methods, rather than a result of higher accumulation rates. It was also noted that on islands where removal efforts had not taken place, the size class of DFG was generally larger. This was attributed to smaller debris piles becoming tangled together over time, leading to massive accumulations of net and rope.

[7] Sheavly, S., & Register, K. (2007). Marine Debris & Plastics: Environmental Concerns, Sources, Impacts and Solutions. *Journal of Polymers and the Environment*, 301-305.

[8] Donohue, M., Boland, R., Sramek, C., & Antonelis, G. (2001). Derelict Fishing Gear in the Northwestern Hawaiian Islands: Diving Surveys and Debris Removal in 1999 Confirm Threat to Coral Reef Ecosystems. Marine Pollution Bulletin, 1301-1312.

SECTION 2: PROJECT OVERVIEW

Project Purpose

In order to characterize the potential ecological consequence of tsunami debris, it is important to characterize the debris itself. Understanding the type, size, and location of debris accumulating on Hawaiian coastlines is crucial in developing plans to streamline the removal process and mitigate any negative impacts this debris may have on the islands and their inhabitants. Given the vast extent and remoteness of coastlines in the Hawaiian Islands, large scale surveillance efforts are necessary to identify and describe these accumulations. Capture and analysis of high-resolution aerial imagery allows for rapid qualitative and quantitative assessments at this scale, providing data that can be used to plan further management actions and evaluate marine debris accumulation patterns in Hawai‘i.

Project Objective

The objective is to document and describe marine debris on coastlines of the Main Hawaiian Islands by using high-resolution aerial imagery paired with ArcGIS mapping software to locate, quantify, and categorize debris accumulations.

Deliverables/Outcomes

- ArcGIS point shapefiles showing marine debris locations, with supporting attribute tables
- ArcGIS coastline shapefiles showing overall debris density and distribution, with supporting attribute tables
- Additional maps, figures, and tables displaying debris density, type, and size data
- Summary report of findings

SECTION 3: METHODS

The project was carried out in multiple phases, beginning with the collection and processing of high-resolution aerial imagery of coastlines of the Main Hawaiian Islands to create ArcGIS image files. The second phase was to analyze this imagery using ArcGIS software to identify, quantify, and categorize marine debris accumulations along coastlines of the Main Hawaiian Islands. The final phase involved using the collected data to generate maps and figures displaying marine debris composition, density, and distribution for each island, as well as statewide.

Aerial Imagery Collection and Processing

Resource Mapping Hawai'i (RMH) was contracted by PICES and Hawai'i Department of Land and Natural Resources (DLNR) to produce high resolution ortho-imagery of the coastlines of the main eight islands. Aerial surveys were conducted from a Cessna 206 between August and November 2015. Using an array of three DSLR cameras, multiple photos were captured every 0.7 seconds while flying at an average ground speed of 85 knots per hour. The cameras were mounted on a three-axis stabilizer gimbal to ensure that photos were taken within 4 degrees of crab, roll and pitch angles. The mapping system also includes differential GPS to collect latitude, longitude and altitude data. The surveys had a target altitude of 2,000 feet above ground level to achieve a ground resolution of two centimeters per pixel and a swath width between 200-300 meters. Areas where flight restrictions apply, such as military bases and airports, were excluded from the imagery collection process. Using custom photogrammetry software, the aerial photos were mosaicked and ortho-rectified to an accuracy of five meters RMS, then divided into GeoTIFF raster tiles for use in ArcGIS.

Marine Debris Classifications and Categories

Marine debris type was classified into seven categories (Table 1) prior to GIS analysis. These categories were designed to characterize debris found on shorelines, as different debris types can pose different threats to the marine environment. For example, net and line pose a serious entanglement hazard, while small plastics and foam are more likely to be mistakenly ingested by wildlife. While there are limitations on the ability to determine debris types at this scale, categorization of identifiable debris is useful to determine trends in debris accumulation. If a piece of debris was made up of more than one type of material, the main material was listed and the additional materials were included as a comment.

Debris was also categorized by size class (Table 2). Size was measured as the approximate area of the object in meters squared, and four size classes were delineated ranging from less than 0.5 square meters to over 2 square meters. Object size was estimated using the measurement tool within ArcGIS.

Table 1. Seven categories of marine debris material observed in the aerial imagery. See Appendix B for image examples of each category.

Type	Code	Description
Buoys and Floats	B	Any float used for mooring, as a buffer for boats, marking a channel, or fishing. Can be plastic, glass, rubber, foam or metal and can range in size.
Foam	F	Large blocks used as floats, insulation and packaging material. Foam will often vary in shape and size. Color typically ranges from white to yellow-orange.
Derelict Fishing Gear	N	Derelict fishing gear includes nets and line (single pieces of rope, fishing line, tangled rope, string, twine, and any other type of rope that is not woven into netting).
Plastic	P	All drums, jugs, tubs, buckets, bins, plastic chairs, plastic pallets, tables, gardening items, outdoor equipment like fins and masks, vehicle parts like bumpers and seats, as well as unidentifiable or broken pieces of plastic. Variable colors, shapes, and sizes with a majority of objects being white.
Tires	T	This category includes full tires and tire treads that have been repurposed as boat bumpers.
Other	O	Other includes the categories of processed wood, metal, cloth, and vessels: Wood is any wood-based product such as lumber, furniture, crates, pallets, wooden docks, and ply board. This category does not include fallen logs, tree branches, or any wood material that has not been altered by humans. Metal can include sheet metal, metal drums, tanks, machinery, appliances, and metal piping. Cloth includes sheets, sails and canvas, upholstered furniture, and carpet. Vessels are abandoned boats and boat fragments.
Inconclusive	I	If an item was clearly marine debris but it was not possible to determine the material category, the item was marked as 'inconclusive.'

Table 2. Size classes used to classify items of marine debris.

Size Class	Area Measurement
Very small	< 0.5 m^2
Small	0.5 – 1 m^2
Medium	1 – 2.0 m^2
Large	> 2 m^2

GIS Analysis

Line shapefiles were created to divide each island's coastline into one-mile-long segments, and tile outlines of polygon shapefiles were created for each of the imagery raster tiles, thus matching the aerial imagery files to the segment of coastline they depict (Figure 1). Analysis was conducted on a segment-by-segment basis to ensure that each area of shoreline was systematically surveyed. Following completed analysis of each one-mile segment of shoreline, the segment was given a rating between 0 and 5, based on density and distribution of debris (Table 3). Total item count, dates completed, observer(s), and additional comments were recorded for each segment in addition to the density rating.

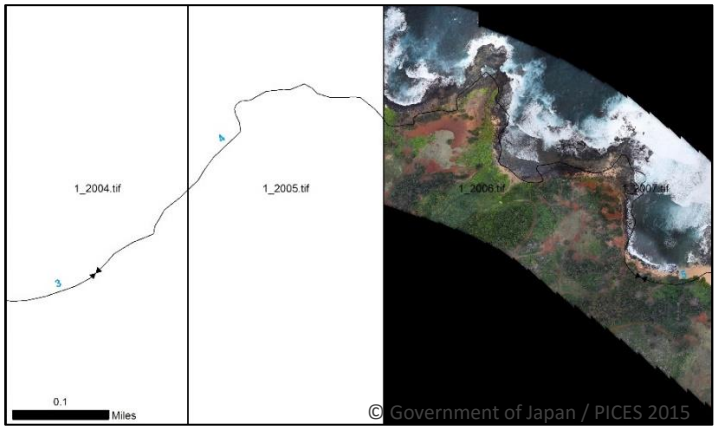


Figure 1. ArcGIS shapefiles depicting the Kaua'i coastline segments and tile polygons, with example image tiles.

Table 3. Definitions of debris density ratings given to each 1-mile segment of coastline.

Rating	Definition
0	No debris found
1	1-5 pieces of debris
2	6-15 pieces of debris
3	16-30 pieces of debris
4	30+ pieces of debris (in pockets or aggregations)
5	30+ pieces of debris (evenly distributed)

Marine Debris Identification

Point shapefiles were created by the analyst to mark each item of marine debris found (Figure 2). A unique, sequential identification number was attributed to each item, starting at 1 within each one-mile segment of coastline. Descriptive data was then collected for each item, including location (latitude and longitude), type of debris, size class, any comments about the item, and the initials of the observer identifying the debris.

Figure 2. Screenshot of identified marine debris on the Ni'ihau coast displaying the identification number, line segment, and image tile file name.

Quality Control

Quality control was performed for each coastline after analysis was completed, to assess the accuracy and precision of the data collection, identify potential errors, improve standardization of data collection between observers throughout the course of the project, and enhance confidence in the data. For each island, 20% of the segments were chosen at random to be re-analyzed by a different observer from the one who originally completed the segment. The result of the quality control process was the creation of standardized rules (Table 4), which were subsequently used to guide the marine debris identification process. See *Appendix C* for more information on quality control, and examples of results from Lāna'i.

Table 4. Standardized rules for marine debris identification that were used to ensure quality control.

Question	**Answer**
What counts as "debris" vs "natural material"?	Any object that is a 'natural' color (white, beige, brown) has the potential to be a natural feature (coconut, driftwood, rock). Marine debris should be identified based on its shape (jagged edges, spherical, large objects), color (bright or 'unnatural' colors), and size (can range, but very large objects are likely to be debris).
What is the minimum qualifying size for marine debris?	If you can make out clear features of the target debris, then count it. If the object is < 0.2m^2 and ambiguous, disregard the item.
How far inland should I count debris?	On most sand beaches, there is a line of small items washed up by the tide. If there is debris seaward of the high tide line, count it. If it is clear that the waves have washed the debris past the high tide line (you can see water marks and a line of debris past the high tide line), then count it. If the debris is landward of the high tide line, disregard the item.
What counts as "evenly distributed"?	When classifying the segments according to the density rating, "evenly distributed" means there are not clear gaps between debris accumulations, or there is equal spacing between debris throughout the segment. If there are clear areas of debris and no debris, the segment is aggregated rather than evenly distributed.
What if there is a concentrated spot of debris?	If there is a clump or pile of debris, label each individual item as best you can. Marking each item is important for the final debris density statistics.
What if I can't tell if an item is processed wood or driftwood?	If it has rounded edges, it is most likely driftwood. If it has square edges, it is probably processed.

SECTION 4: RESULTS

Lānaʻi

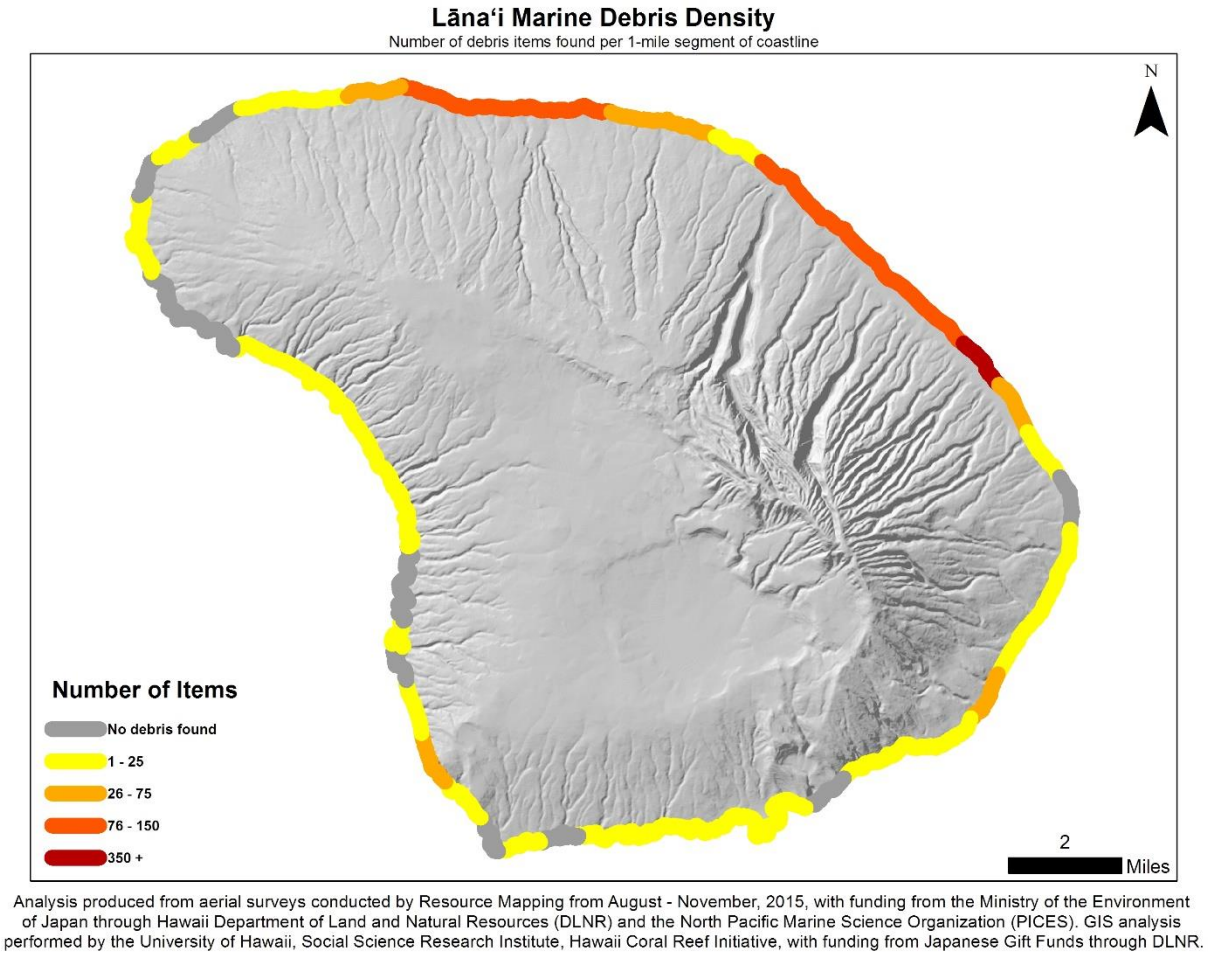


Figure 3. Relative density of marine debris identified around the island of Lānaʻi.

Distribution of Debris

Marine debris was heavily concentrated on the northeast coast of the island (Figure 3). The highest density of debris was found in a segment on the eastern coast, which contained 386 items. Most of the segments on the south and west shores had fewer than 50 pieces of marine debris, with the exception of one segment, which contained 56 items.

Type of Debris

Imagery analysis identified a total of 1,829 pieces of marine debris around the coastline of Lānaʻi (Table 5). The most common type of the debris was plastic (53%) followed by items in the "other" category (includes processed wood, metal, cloth, and vessels) (14%), and derelict fishing gear (13%) (Figure 4). The remaining categories each contributed 8% or less to the total debris count.

Table 5. Number of items of each type of marine debris found around Lānaʻi.

Material	Count
Plastic	969
Other	256
Derelict Fishing Gear	241
Buoys and Floats	150
Foam	130
Tires	71
Inconclusive	12
Total	**1829**

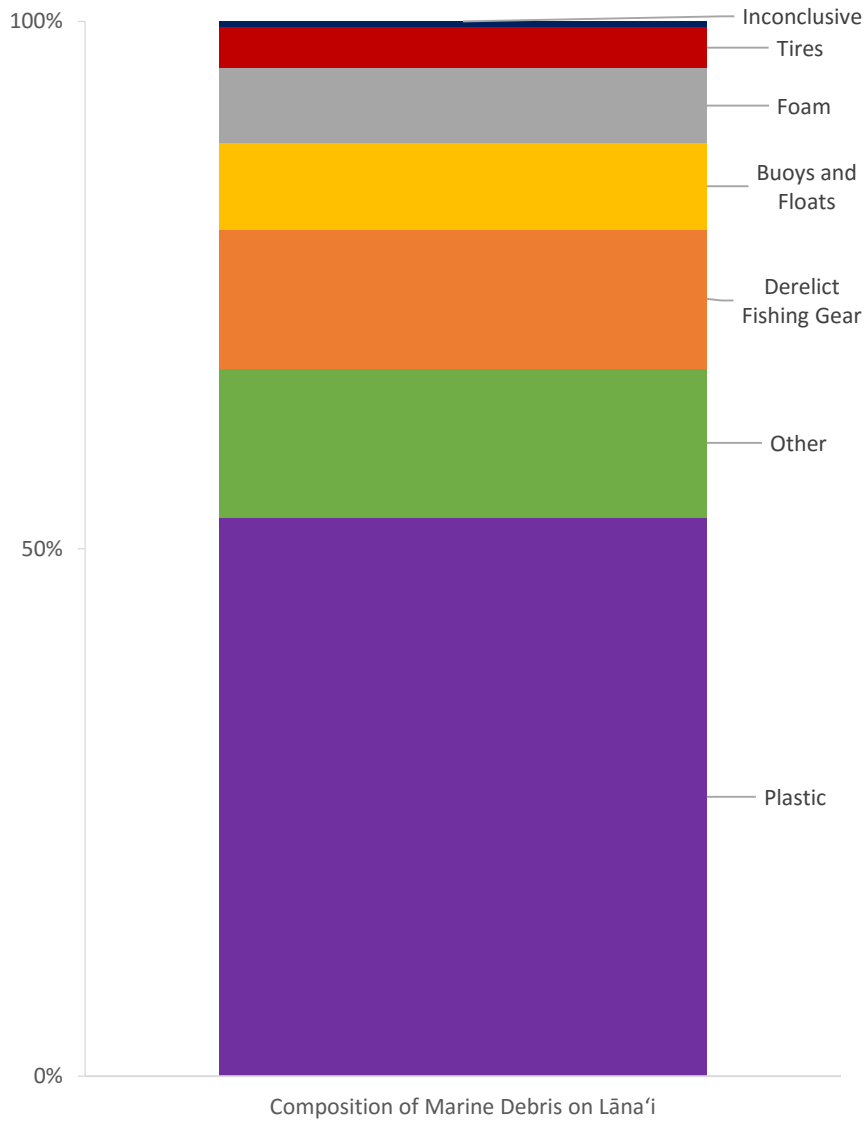


Figure 4. Composition of marine debris around Lāna‘i. Derelict Fishing Gear: nets and line; Other: processed wood, metal, cloth, and vessels.

Size of Debris

The majority (86%) of marine debris around Lāna‘i fell into the smallest size classification of less than 0.5m^2 (Figure 5). The remaining size classes each contained 5% or less of the debris (Table 6).

Table 6. Number of items of each size class found around Lāna‘i

Classification	Size Class (m^2)	Count
Very small	< 0.5	1574
Small	0.5 - 1	97
Medium	1 - 2	79
Large	> 2	79

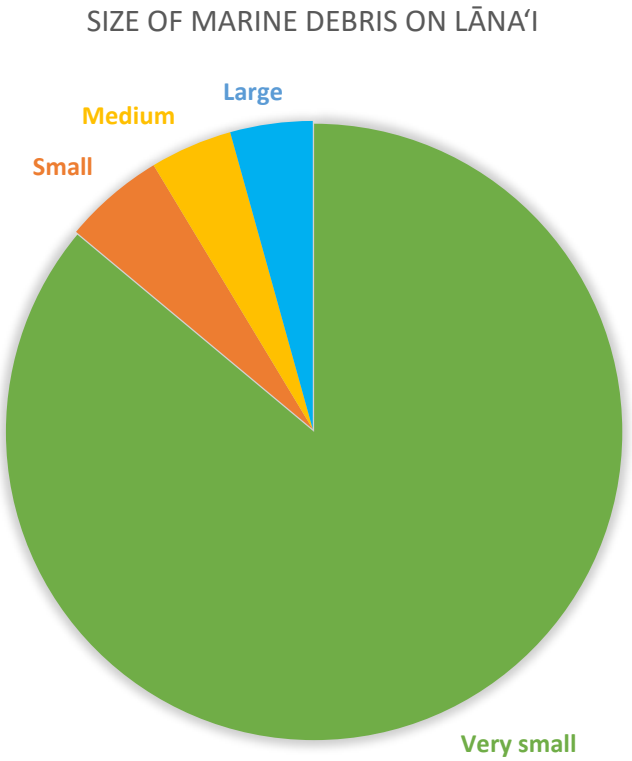


Figure 5. Debris size distribution on Lāna‘i. Very Small: < 0.5 m^2, Small: 0.5 – 1 m^2, Medium: 1 – 2 m^2, Large: >2 m^2.

Niʻihau

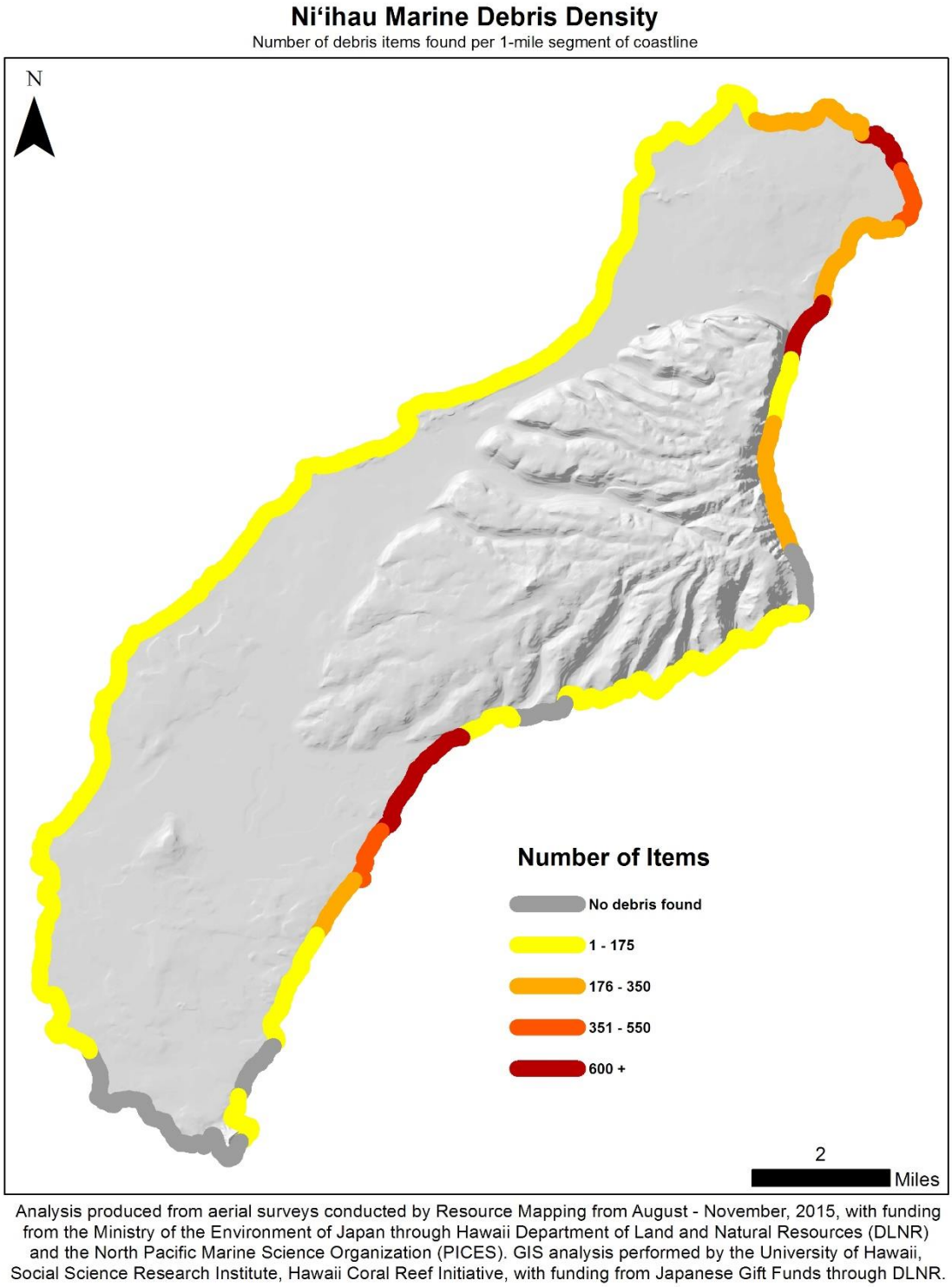


Figure 6. Relative density of marine debris identified around the island of Niʻihau.

Distribution of Debris

Ni‘ihau had the greatest debris densities on its east-facing shores, particularly on the northeastern corner and a portion of the coast further to the south (Figure 6). All segments on the western coast of the island had 175 or fewer items per one mile. The highest density of debris found was 1,137 items within a one-mile segment, which occurred along the southeastern coast. Three additional segments had a density greater than 600 items per one mile of coastline.

Type of Debris

A total of 7,871 debris items were identified around the coastline of Ni‘ihau (Table 7). The most common type of the debris was plastic (46%) followed by buoys and floats (25%), and derelict fishing gear (12%) (Figure 7). The remaining categories each made up 6% or less of the identified debris.

Table 7. Number of items of each type of marine debris found around Ni‘ihau.

Material	Count
Plastic	3665
Buoys and Floats	2000
Derelict Fishing Gear	975
Inconclusive	472
Tires	306
Other	239
Foam	214
Total	**7871**

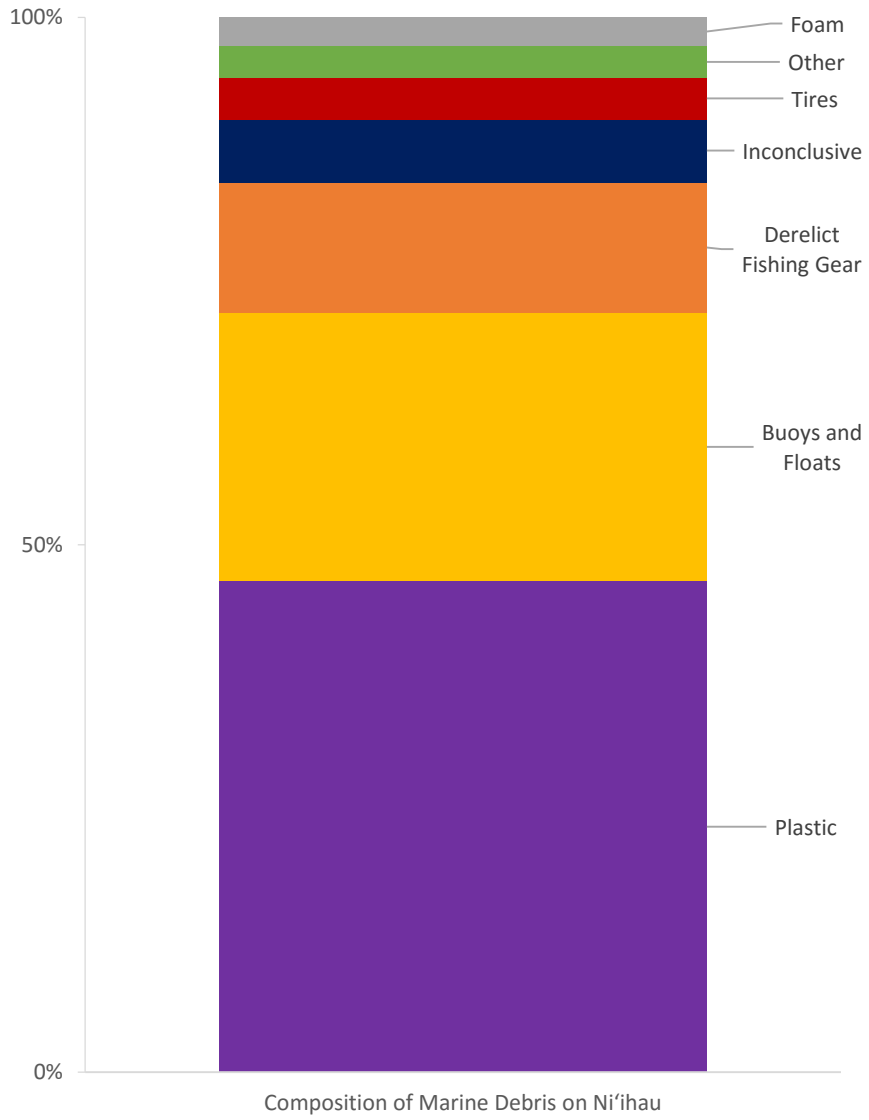


Figure 7. Composition of marine debris identified around Ni‘ihau. Derelict Fishing Gear: nets and line; Other: processed wood, metal, cloth, and vessels.

Size of Debris

The smallest category (less than 0.5m^2) made up the majority (87%) of marine debris around Ni'ihau (Figure 8). The remaining size classes contributed 6% or less to the total debris count (Table 8).

Table 8. Number of items of each size class found around Ni'ihau.

Classification	Size Class (m^2)	Count
Very small	< 0.5	6825
Small	0.5 - 1	490
Medium	1 - 2	249
Large	> 2	307

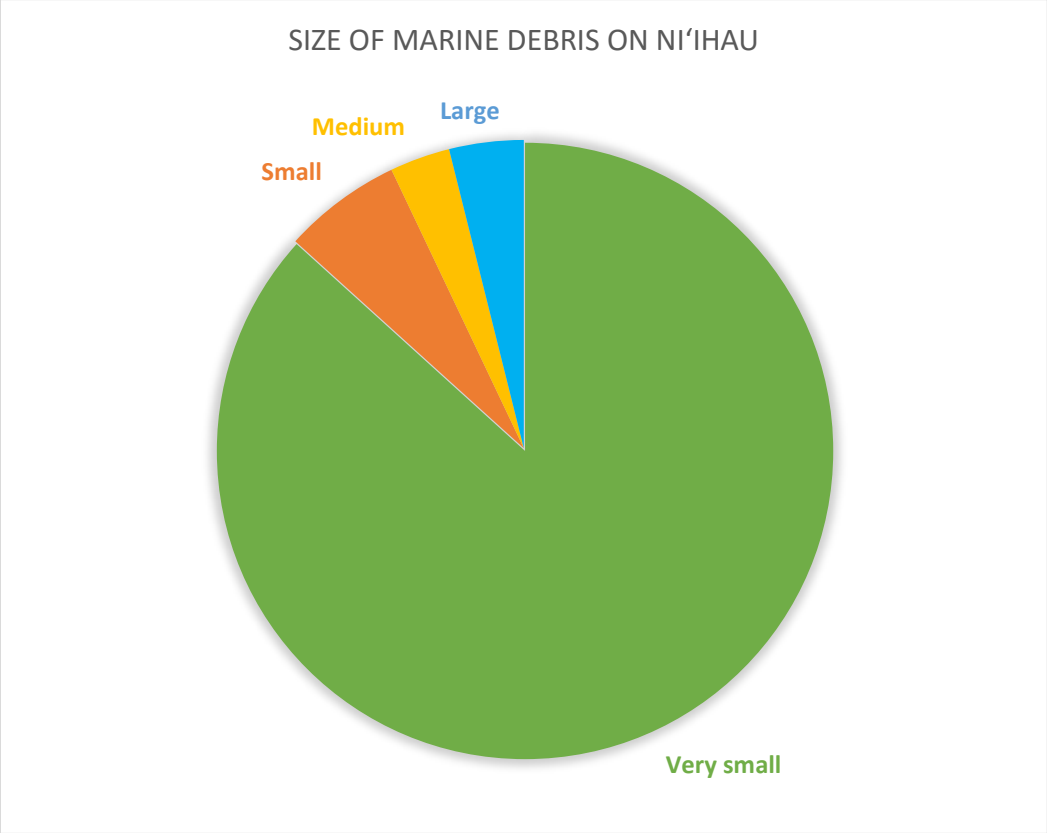


Figure 8. Debris size distribution on Ni'ihau. Very Small: < 0.5 m^2, Small: 0.5 – 1 m^2, Medium: 1 – 2 m^2, Large: >2 m^2.

Kaua‘i

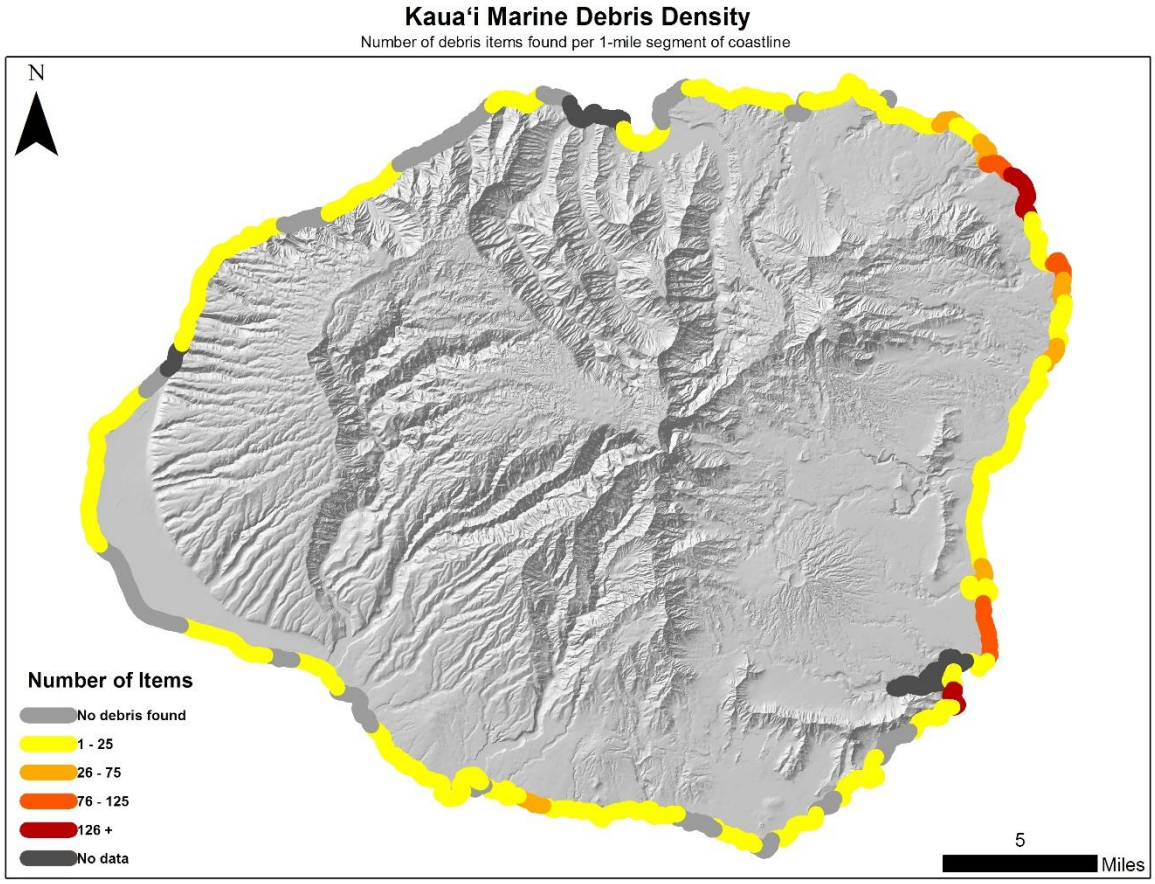


Figure 9. Relative density of marine debris identified around the island of Kaua‘i.

Distribution of Debris

On Kaua‘i, marine debris was most concentrated on eastern shores, particularly at the northern and southern extents (Figure 9). The highest density of debris was found in a segment on the northeast corner, which contained 276 pieces of debris per one mile of shoreline. Almost all segments on the north, west, and southern shores contained 25 or fewer pieces of debris per mile, with the exception of one segment along the south shore, which had a total of 35 pieces of debris.

Type of Debris

A total of 1,849 pieces of marine debris were identified around the coastline of Kaua‘i (Table 9). The most common type of the debris was plastic (49%) followed by buoys and floats (27%), and derelict fishing gear (13%) (Figure 10). All other categories each equaled 9% or less to the total debris count.

Table 9. Number of items of each type of marine debris found around Kaua‘i.

Material	Count
Plastic	905
Buoys and Floats	310
Derelict Fishing Gear	239
Tires	172
Other	122
Inconclusive	55
Foam	46
Total	**1849**

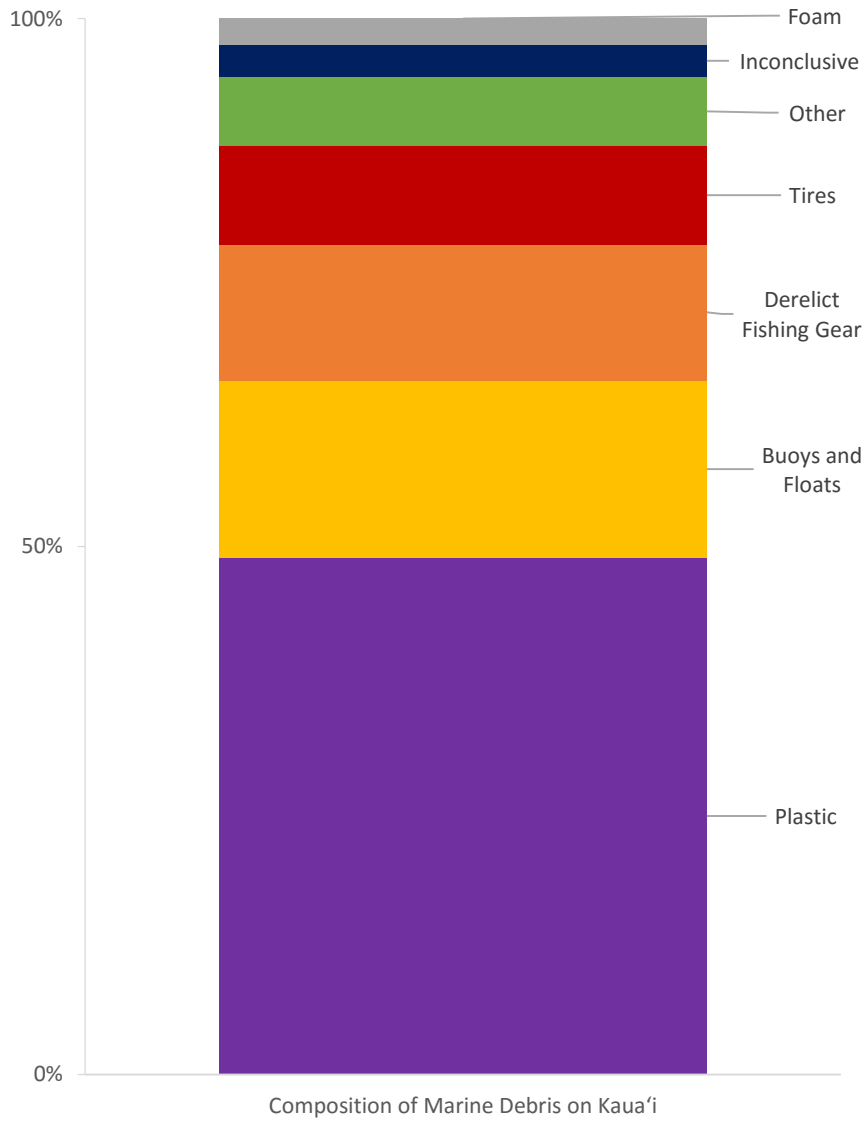


Figure 10. Composition of marine debris identified around Kaua‘i. Derelict Fishing Gear: nets and line; Other: processed wood, metal, cloth, and vessels.

Size of Debris

The majority (84%) of marine debris around Kaua'i fell into the smallest size classification of less than 0.5m^2 (Figure 11). The next most common was 0.5 - 1m^2 (7%). The remaining size classes each contained 4% and 3% of the debris, respectively (Table 10).

Table 10. Number of items of each size class found around Kaua'i.

Classification	Size Class (m^2)	Count
Very small	< 0.5	1569
Small	0.5 - 1	135
Medium	1 - 2	84
Large	> 2	61

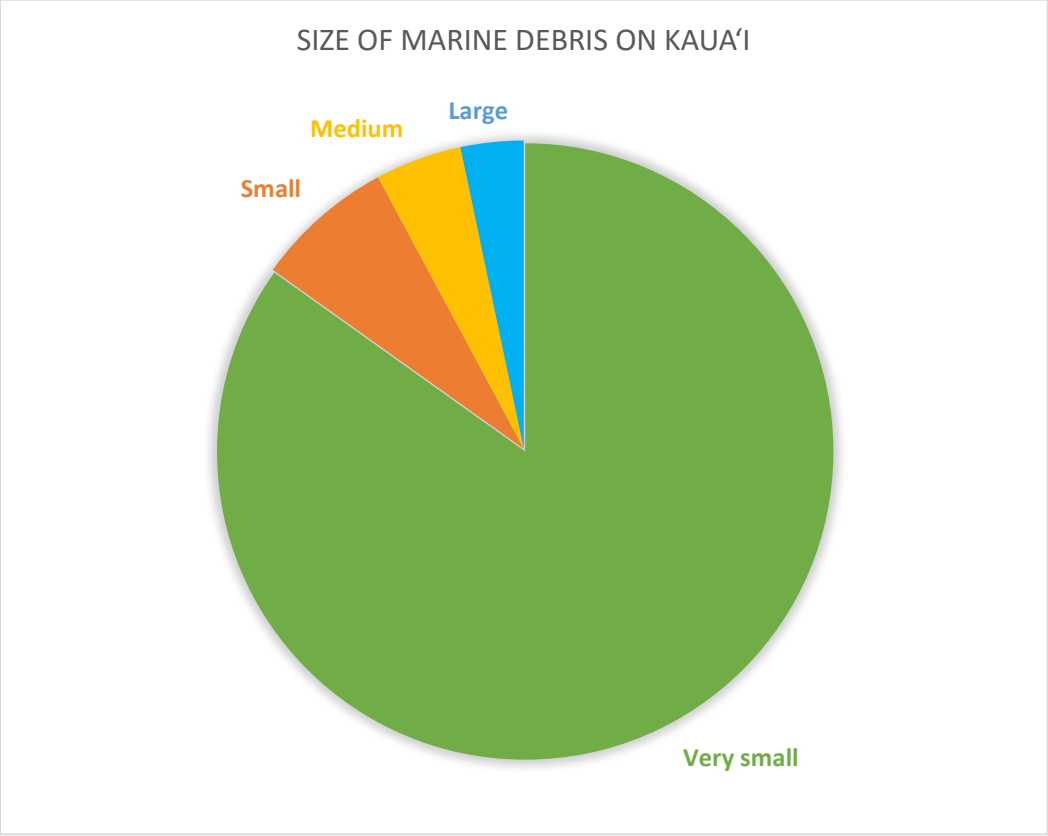


Figure 11. Debris size distribution on Kaua'i. Very Small: < 0.5 m^2, Small: 0.5 – 1 m^2, Medium: 1 – 2 m^2, Large: >2 m^2.

Hawai‘i Island

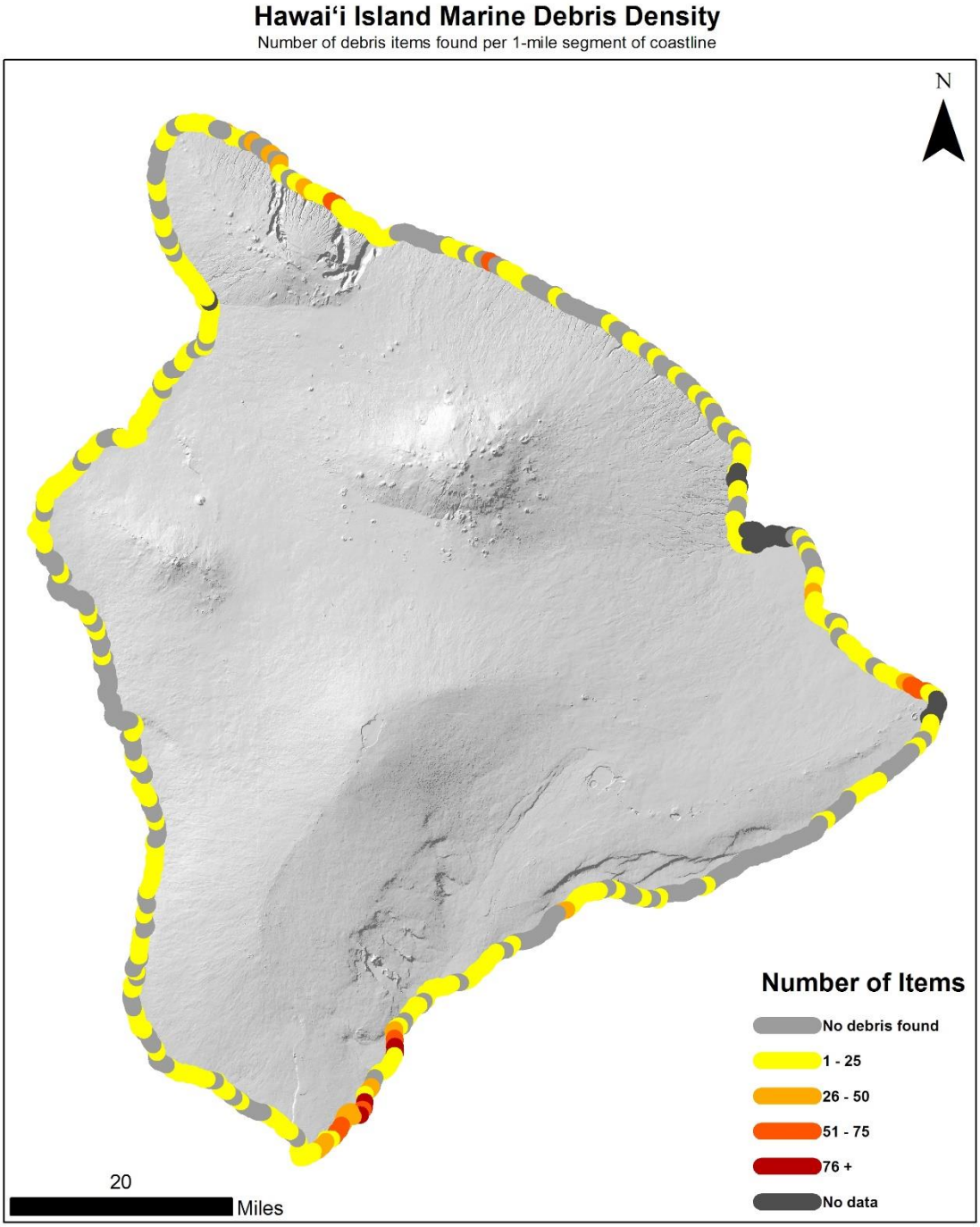


Figure 12. Relative density of marine debris identified around the island of Hawai‘i.

Distribution of Debris

Hawai‘i Island had the greatest debris densities near the Kamilo Point area, which is located on the southeastern tip of the island (Figure 12). Highest density of debris items identified was 129 pieces of debris per one-mile segment. All west-facing shores had 25 or fewer pieces of debris per one-mile segment of coast. Small portions of the eastern coast, particularly to the north, had relatively higher densities, but no density higher than 75 items per mile was found anywhere except for the Kamilo Point area on the southeastern tip.

Type of Debris

Imagery analysis identified a total of 2,200 pieces of marine debris around the coastline of Hawai‘i Island (Table 11). The most common type of the debris was plastic (52%) followed by buoys and floats (12%) (Figure 13). Inconclusive items and “other” category items, which includes processed wood, metal, cloth, and vessels, each contributed 9%, with the remaining categories each contributing 8% or less.

Table 11. Number of items of each type of marine debris found around Hawai‘i Island.

Material	Count
Plastic	1138
Buoys and Floats	271
Other	206
Inconclusive	194
Derelict Fishing Gear	180
Tires	134
Foam	77
Total	**2200**

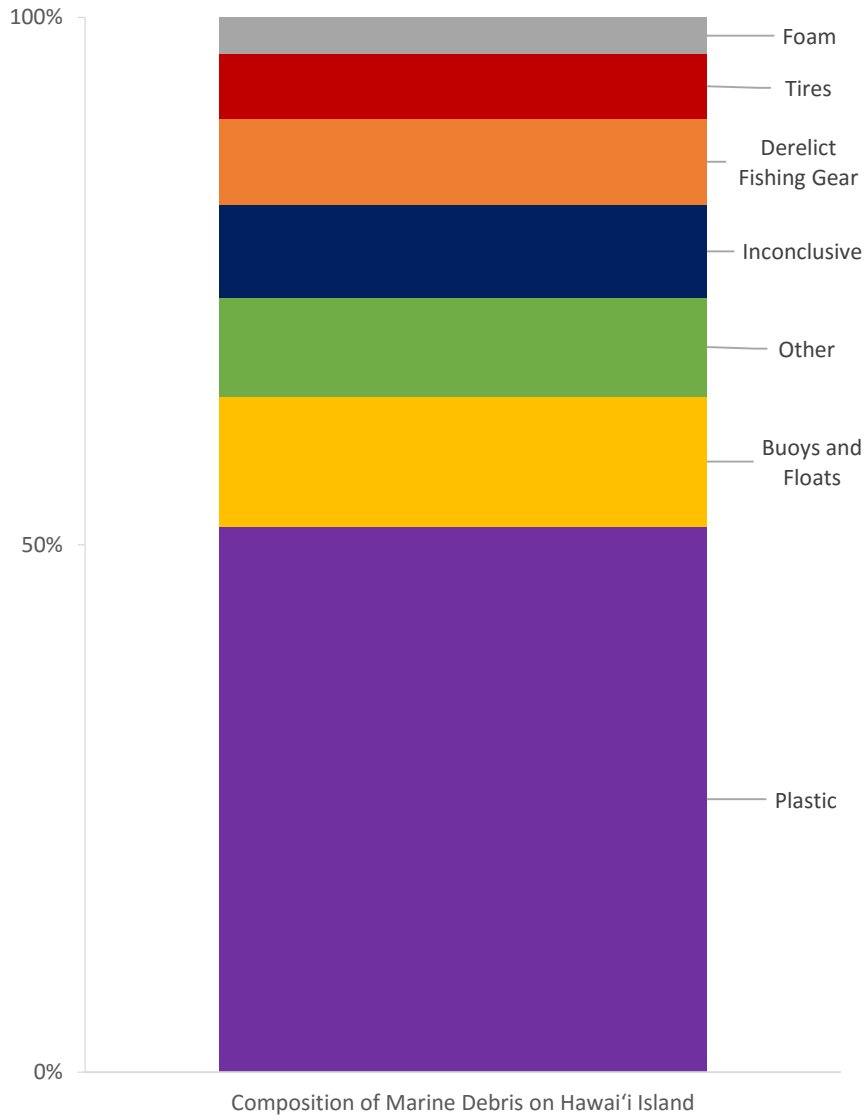


Figure 13. Composition of marine debris around Hawai'i Island. Derelict Fishing Gear: nets and line; Other: processed wood, metal, cloth, and vessels.

Size of Debris

85% of the debris found on Hawai'i Island fell into the smallest size classification of less than 0.5m^2 (Figure 14). All other size classes each contained 6% or less of the debris (Table 12).

Table 12. Number of items of each size class found around Hawai'i Island.

Classification	Size Class (m^2)	Count
Very small	< 0.5	1880
Small	0.5 - 1	115
Medium	1 - 2	127
Large	> 2	78

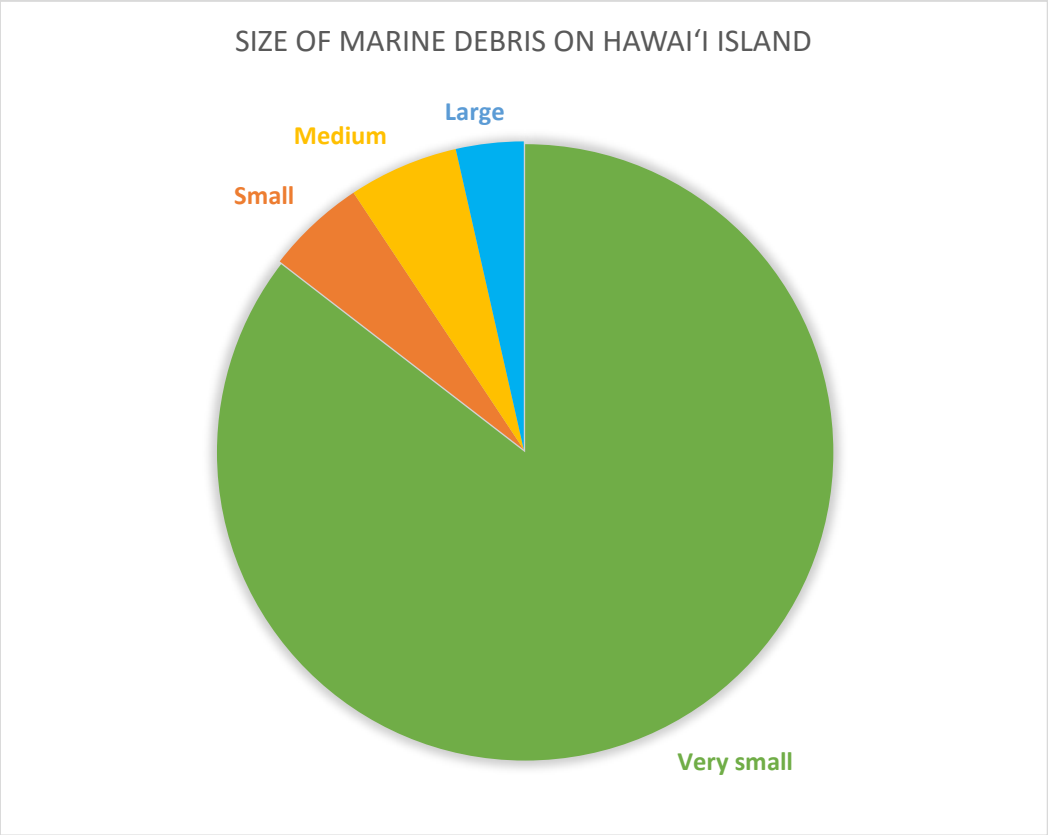


Figure 14. Debris size distribution on Hawai'i Island. Very Small: < 0.5 m^2, Small: 0.5 – 1 m^2, Medium: 1 – 2 m^2, Large: >2 m^2.

Maui

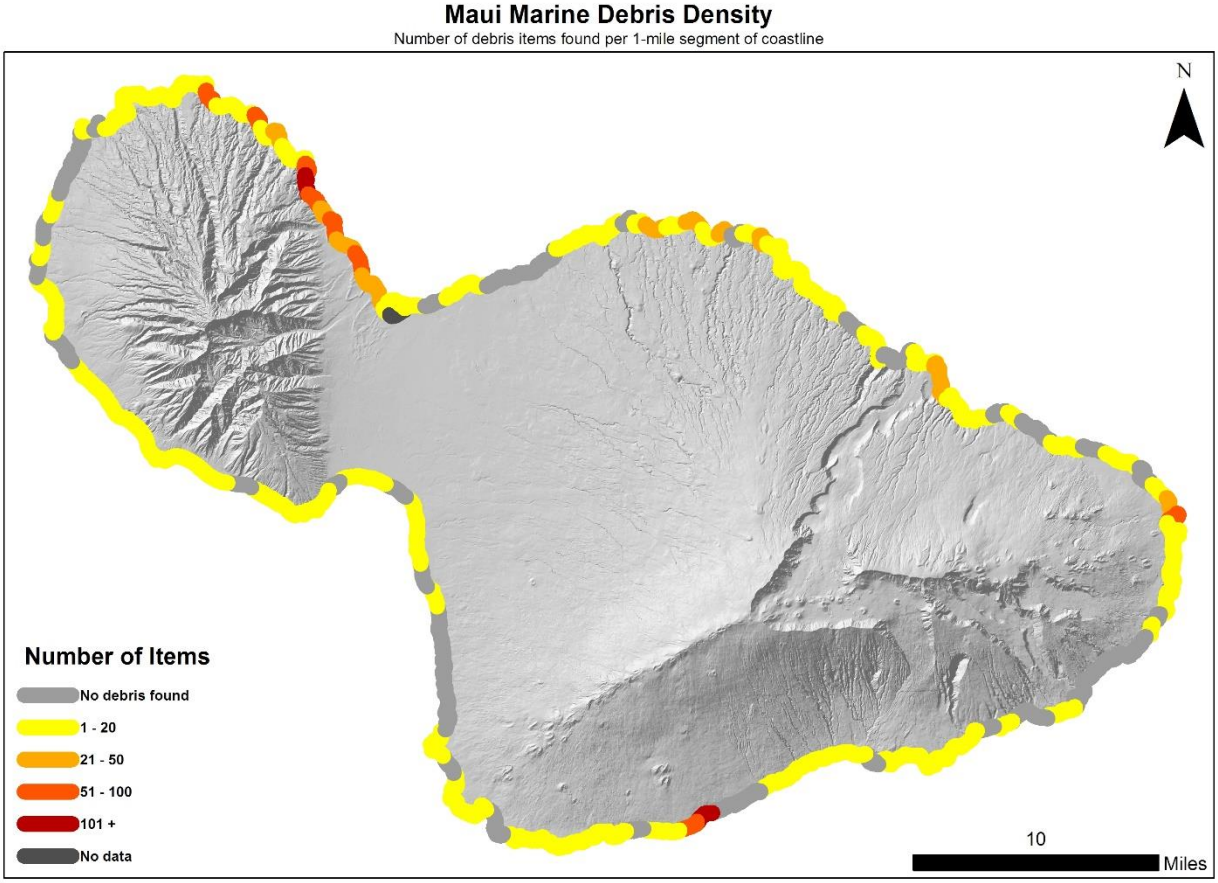


Figure 15. Relative density of marine debris identified around the island of Maui.

Density and Distribution of Debris

Maui had the greatest debris density on the northern coast, particularly to the west where the coastline slopes south toward Kahului Bay (Figure 15). The segment with the highest density was also located in this area, with a total of 116 debris items within one mile. Only one other segment, located along the southern coast, contained a density greater than 100 pieces of debris per mile. All but two segments on the southern and western coasts of the island contained 20 or fewer pieces of debris per mile.

Type of Debris

A total of 1,749 marine debris items were found around the Maui coastline (Table 13). The most common type of debris was plastic (40%) followed by buoys and floats (25%), and inconclusive items (10%) (Figure 16). The remaining categories each made up 8% or less of the debris composition.

Table 13. Number of items of each type of marine debris found around Maui.

Material	Count
Plastic	702
Buoys and Floats	445
Inconclusive	167
Other	145
Foam	124
Derelict Fishing Gear	86
Tires	80
Total	**1749**

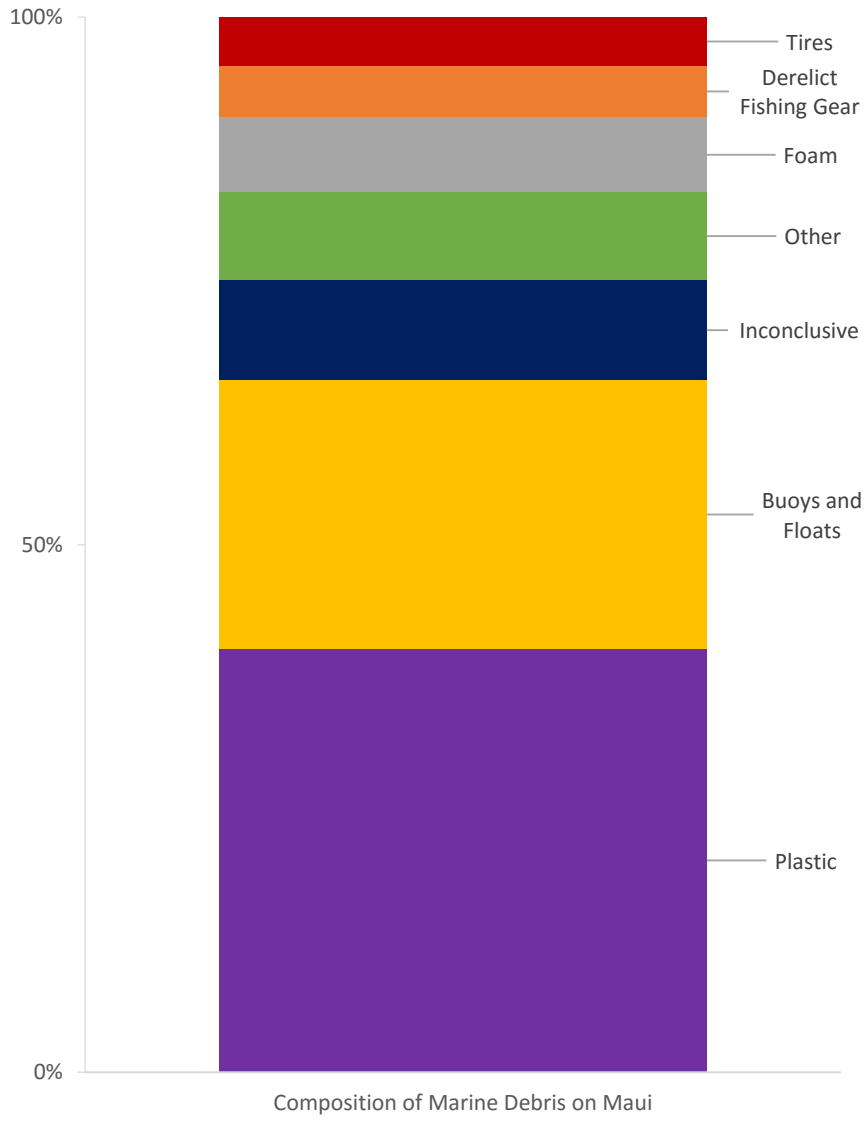


Figure 16. Composition of marine debris identified around Maui. Derelict Fishing Gear: nets and line; Other: processed wood, metal, cloth, and vessels.

Size of Debris

Most (87%) of the marine debris around Maui fell into the smallest size classification of less than 0.5m^2 (Figure 17). The remaining size classes each contributed 6% or less to the total debris count (Table 14).

Table 14. Number of items of each size class found around Maui.

Classification	Size Class (m^2)	Count
Very small	< 0.5	1514
Small	0.5 - 1	108
Medium	1 - 2	84
Large	> 2	43

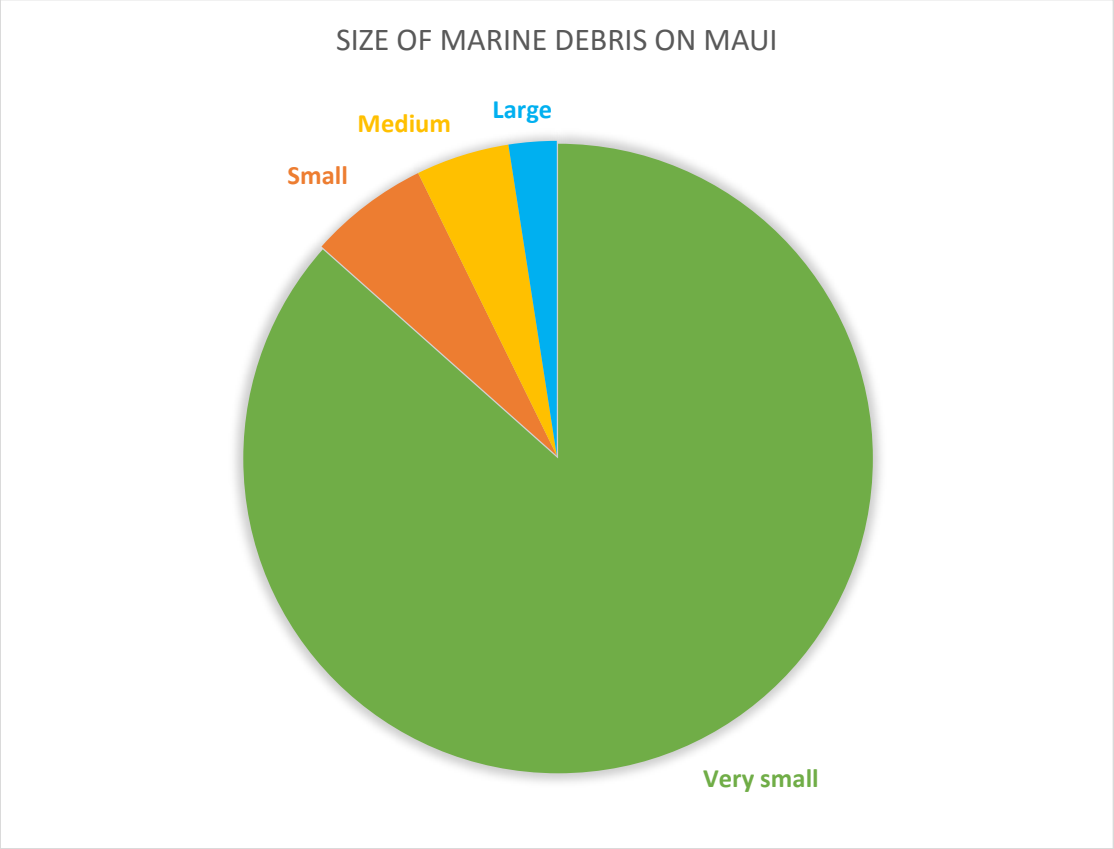


Figure 17. Debris size distribution on Maui. Very Small: < 0.5 m^2, Small: 0.5 – 1 m^2, Medium: 1 – 2 m^2, Large: >2 m^2.

Molokaʻi

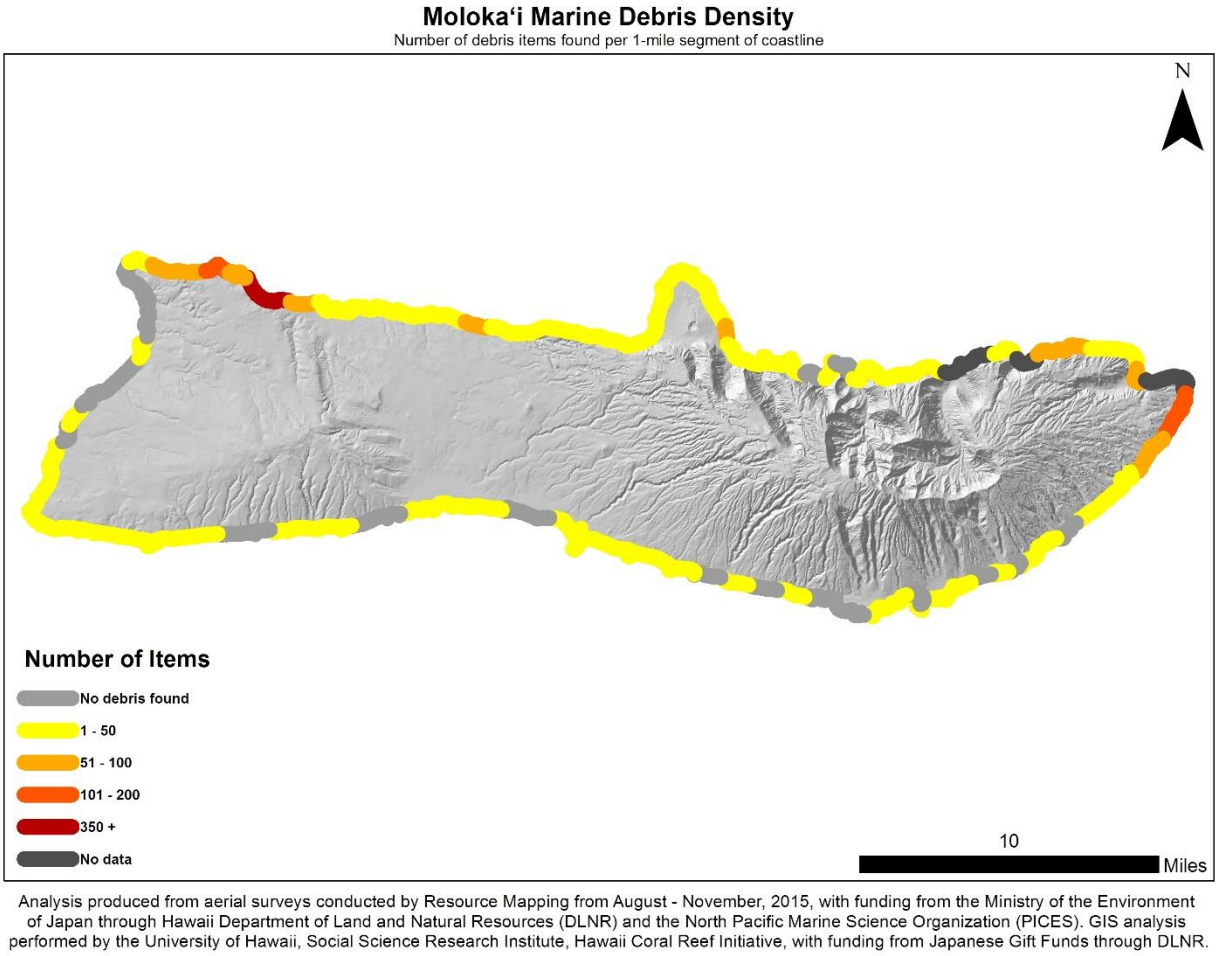


Figure 18. Relative density of marine debris identified around the island of Molokaʻi.

Density and Distribution of Debris

On Molokaʻi, marine debris was concentrated on northwestern shores, and a small area on the north-eastern corner (Figure 18). Highest debris density found was 612 items within a one-mile segment, with the next highest being 360 items per mile. These segments were adjacent to each other, and both were located on the northwest coast of the island. All remaining segments had fewer than 200 items per mile, with all segments on south-facing shores having 50 or fewer items per mile.

Type of Debris

Imagery analysis identified a total of 2,878 pieces of marine debris around the coastline of Molokaʻi (Table 15). The most common types of debris were plastic and buoys and floats, which had similar densities of 37% and 35%, respectively (Figure 19). Inconclusive items made up 14% of the debris composition, with all remaining categories contributing 5% or less.

Table 15. Number of items of each type of marine debris found around Moloka'i.

Material	Count
Plastic	1069
Buoys and Floats	1012
Inconclusive	410
Derelict Fishing Gear	153
Tires	92
Other	90
Foam	52
Total	**2878**

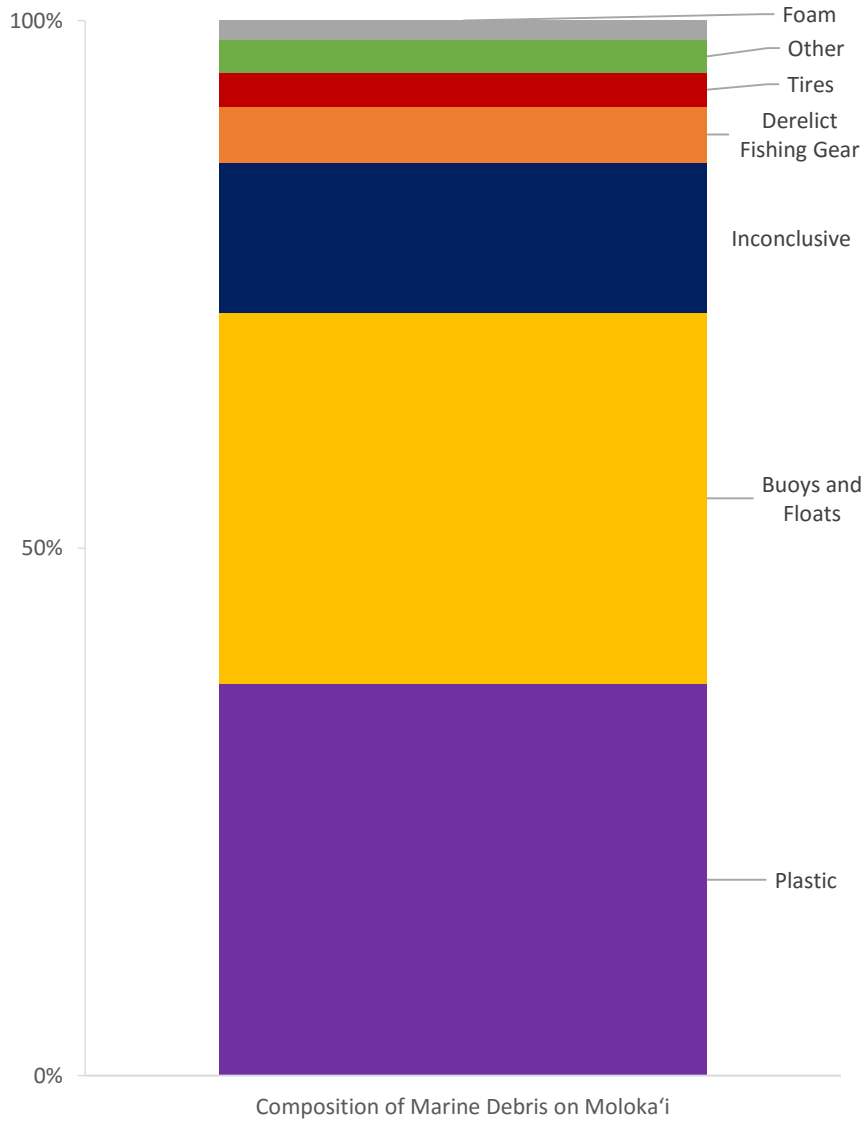


Figure 19. Composition of marine debris identified around Moloka'i. Derelict Fishing Gear: nets and line; Other: processed wood, metal, cloth, and vessels.

Size of Debris

89% of the marine debris on Moloka'i fell into the smallest size classification of less than 0.5m^2 (Figure 20). The next size class, 0.5 - 1m^2, contained 6% of the debris, with the remaining size classes each containing approximately 3% of the debris (Table 16).

Table 16. *Number of debris items of each size class found around Moloka'i.*

Classification	Size Class (m^2)	Count
Very small	< 0.5	2556
Small	0.5 - 1	162
Medium	1 - 2	85
Large	> 2	75

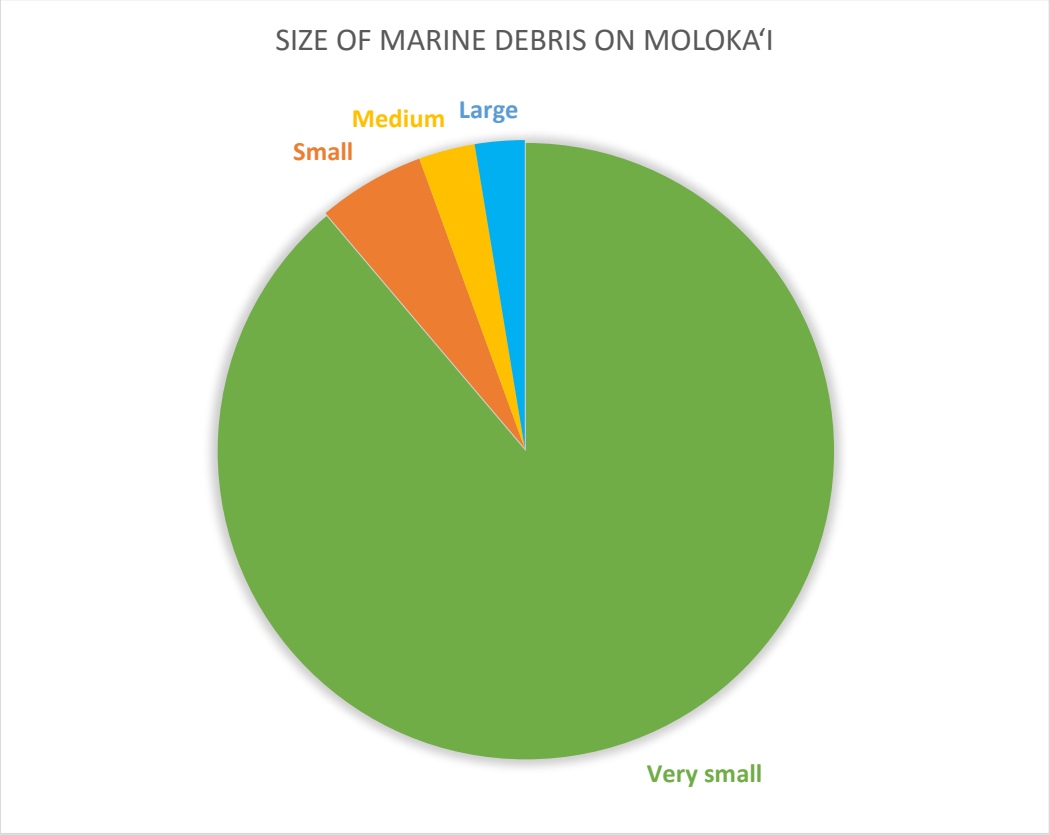


Figure 20. Debris size distribution on Moloka'i. Very Small: < 0.5 m^2, Small: 0.5 – 1 m^2, Medium: 1 – 2 m^2, Large: >2 m^2.

Kahoʻolawe

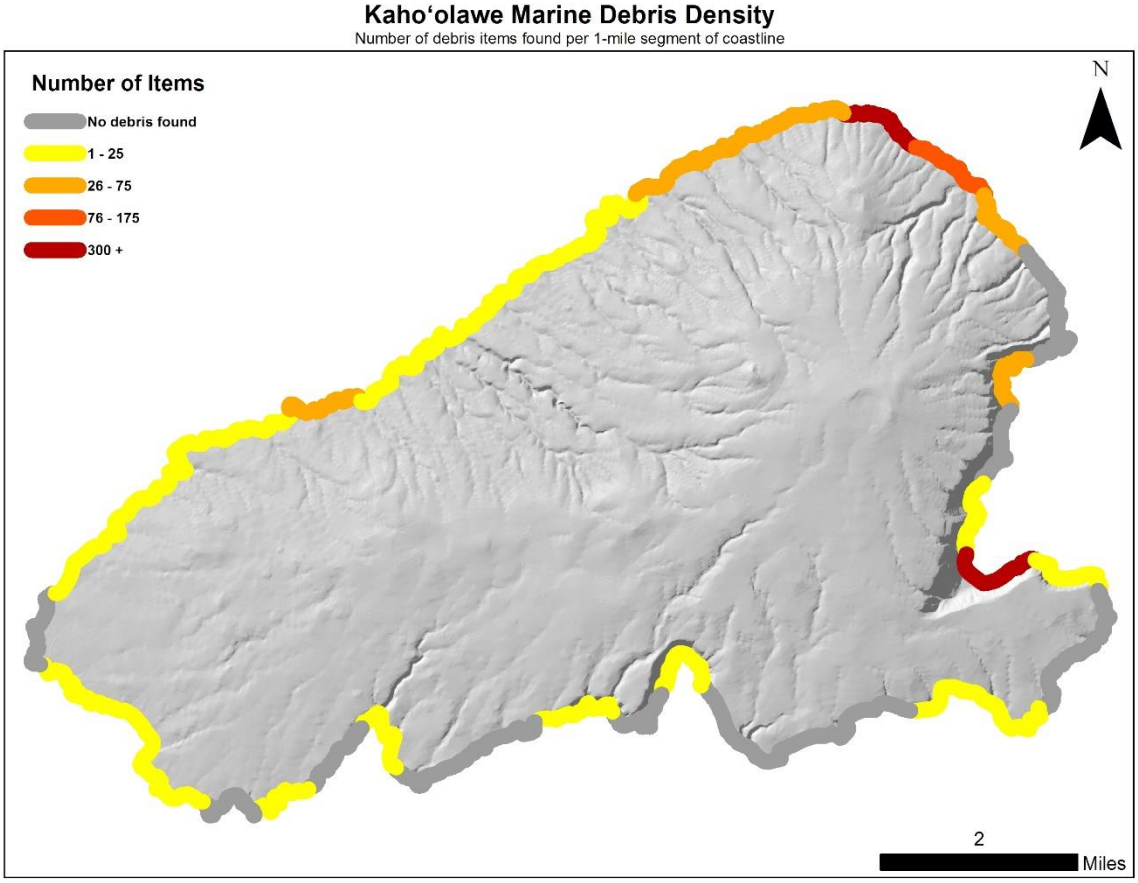


Figure 21. Relative density of marine debris identified around the island of Kahoʻolawe.

Distribution of Debris

Marine debris on Kahoʻolawe was concentrated in two locations along the coast, both on the northern tip of the island and in the Keoneuli area along the eastern coast, where the shoreline curves inward (Figure 21). The Keoneuli area contained the highest debris density, with 342 debris items found in a one-mile segment. The segment at the northern most point of the island contained 304 items per mile. All south-facing shores contained 25 or fewer items per mile.

Type of Debris

A total of 1,298 pieces of marine debris were identified around the Kahoʻolawe coastline (Table 17). The most common type of debris was plastic (47%), followed by buoys and floats and derelict fishing gear, which each made up 21% of the debris composition (Figure 22). All other categories made up 5% or less of the total debris count.

Table 17. Number of items of each type of marine debris found around Kaho‘olawe.

Material	Count
Plastic	607
Buoys and Floats	274
Derelict Fishing Gear	272
Other	61
Tires	34
Foam	27
Inconclusive	23
Total	**1298**

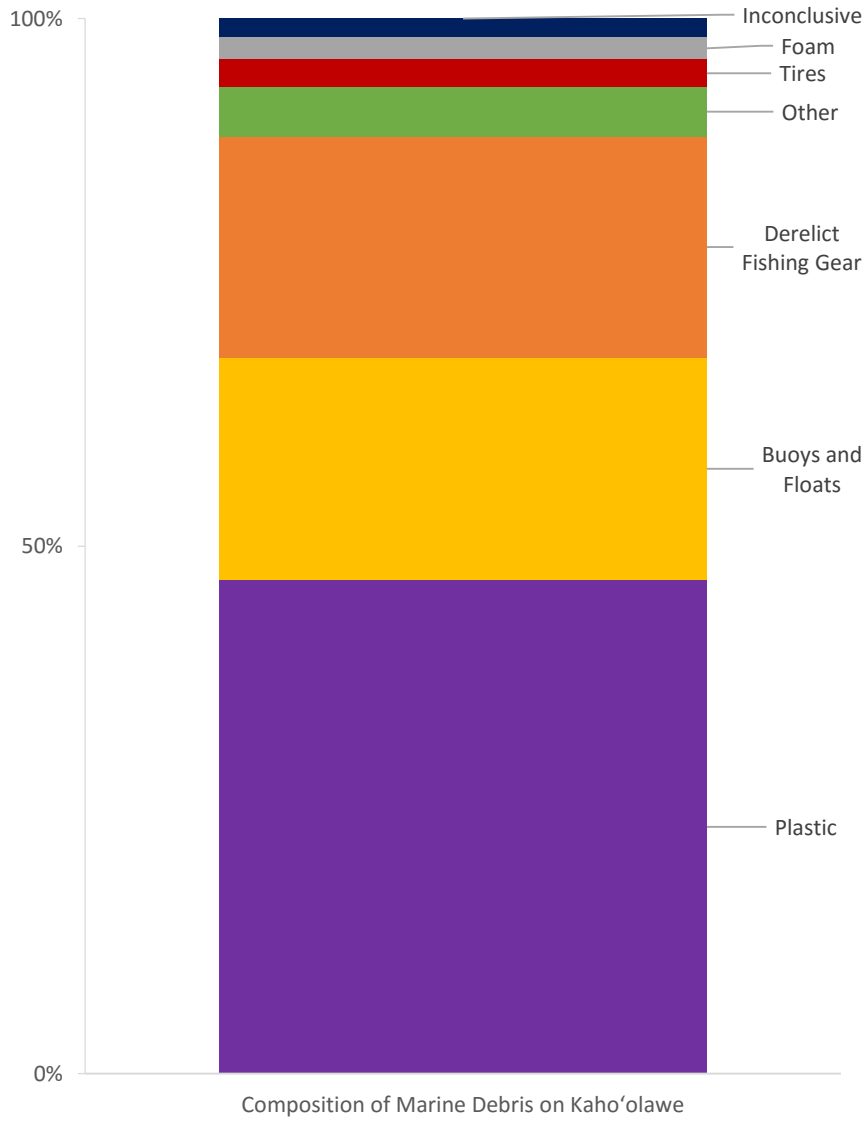


Figure 22. Composition of marine debris around Kaho‘olawe. Derelict Fishing Gear: nets and line; Other: processed wood, metal, cloth, and vessels.

Size of Debris

The majority (84%) of marine debris around Kaho'olawe fell into the smallest size classification of less than 0.5m^2 (Figure 23). The next size class of 0.5 - 1m^2 contained 7% of the debris, while the remaining size classes each contained around 5% of the debris (Table 18).

Table 18. Number of items of each size class found around Kaho'olawe.

Classification	Size Class (m^2)	Count
Very small	< 0.5	1084
Small	0.5 - 1	85
Medium	1 - 2	69
Large	> 2	60

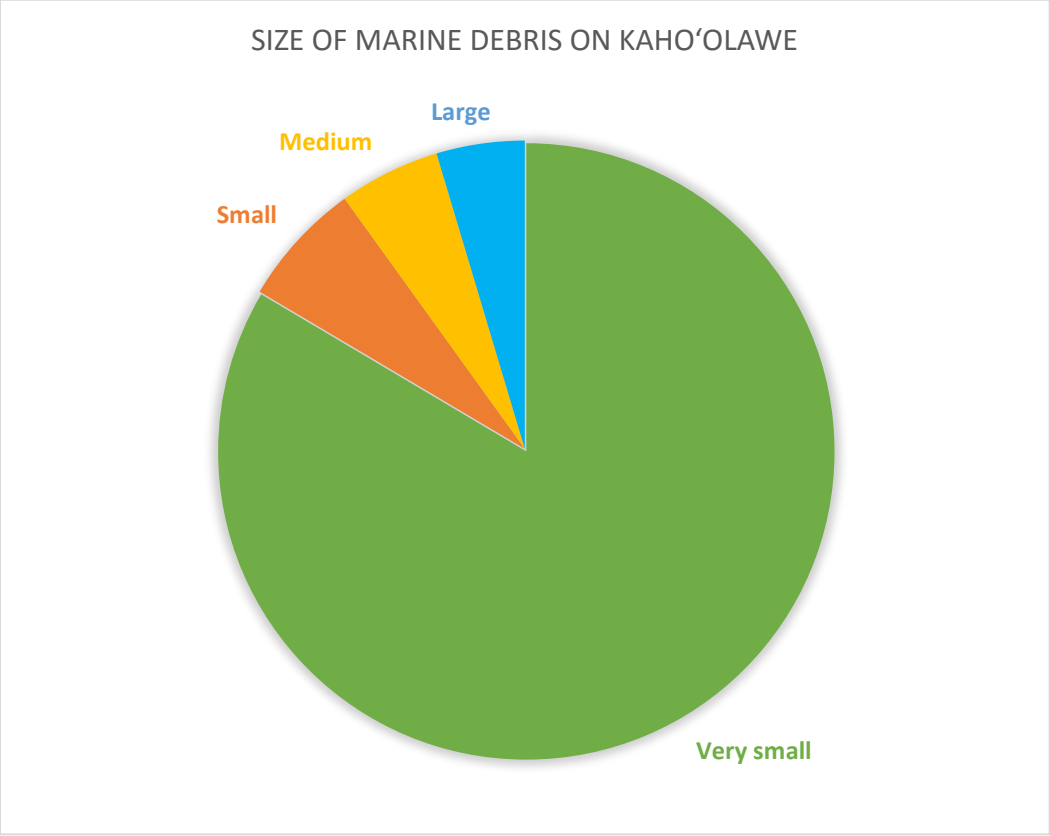


Figure 23. Debris size distribution on Kaho'olawe. Very Small: < 0.5 m^2, Small: 0.5 – 1 m^2, Medium: 1 – 2 m^2, Large: >2 m^2.

O‘ahu

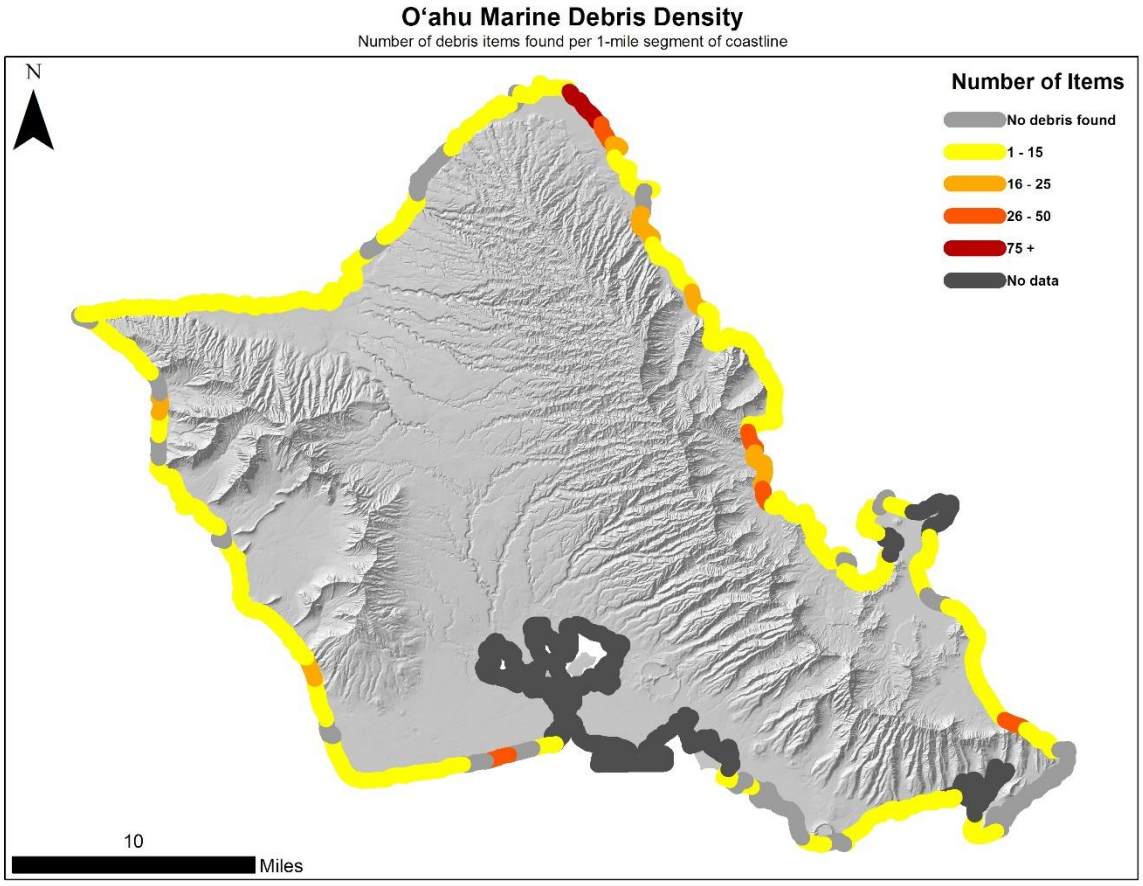


Figure 24. Relative density of marine debris identified around the island of O‘ahu.

Distribution of Debris

O‘ahu marine debris was concentrated on the northern tip of the island, on the east-facing shore between the northern most point and the Kahuku area (Figure 24). Only two segments contained 75 or greater debris items per mile, with the densest segment containing 108 debris items in one mile. All remaining segments contained 50 or fewer debris items per mile, with the majority of segments having a density of 15 or fewer items per mile.

Type of Debris

Imagery analysis identified a total of 984 pieces of marine debris around the O‘ahu coastline (Table 19). The most common debris type was plastic (63%) followed by debris in the category “other” (11%), which is a compilation of debris identified as either processed wood, metal, cloth, or vessels (Figure 25). All remaining debris categories each made up less than 10% of the total debris count.

Table 19. Number of items of each type of marine debris found around O‘ahu.

Material	Count
Plastic	618
Other	106
Buoys and Floats	82
Tires	73
Derelict Fishing Gear	57
Inconclusive	32
Foam	16
Total	**984**

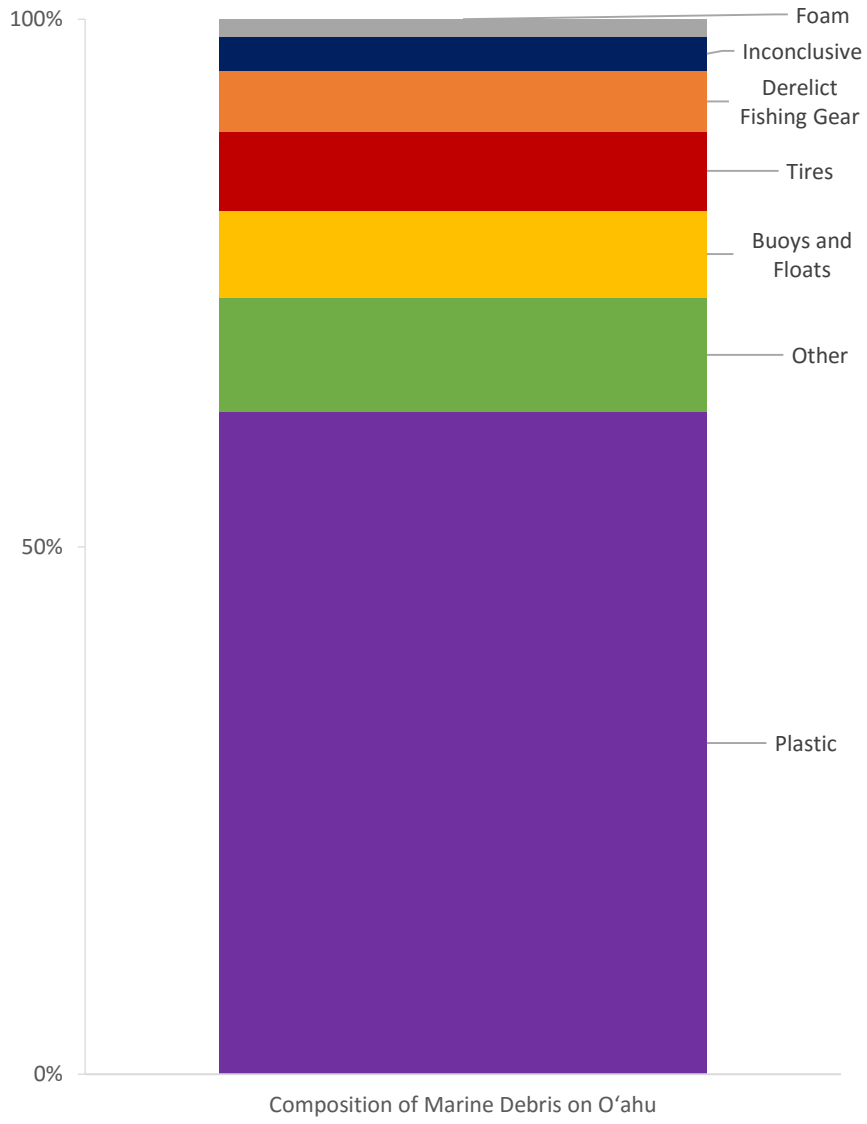


Figure 25. Composition of marine debris around O‘ahu. Derelict Fishing Gear: nets and line; Other: processed wood, metal, cloth, and vessels.

Size of Debris

The smallest size category of less than 0.5m^2 contained the majority (86%) of marine debris on O'ahu (Figure 26). The small size class (0.5 - 1m^2) contained 7% of the debris, and the remaining size classes contained 3% and 4% of the debris, respectively (Table 20).

Table 20. Number of items of each size class found around O'ahu.

Classification	Size Class (m^2)	Count
Very small	< 0.5	850
Small	0.5 - 1	64
Medium	1 - 2	34
Large	> 2	36

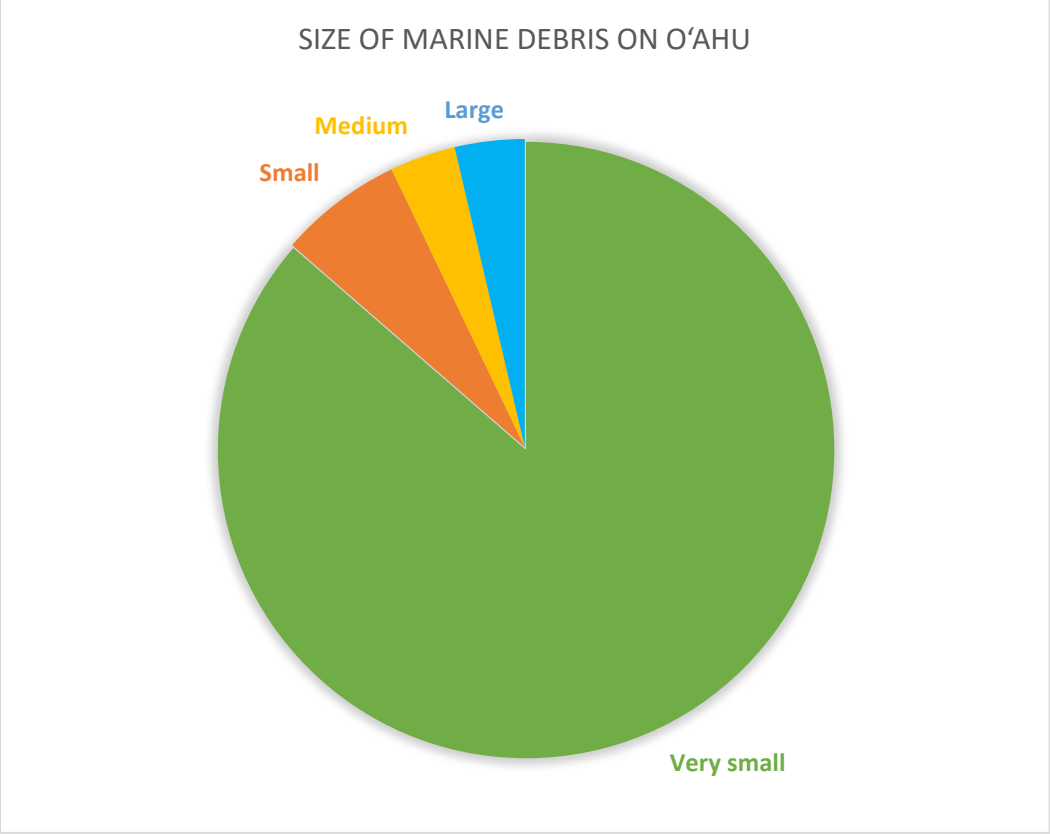


Figure 26. Debris size distribution on O'ahu. Very Small: < 0.5 m^2, Small: 0.5 – 1 m^2, Medium: 1 – 2 m^2, Large: >2 m^2.

Main Hawaiian Islands

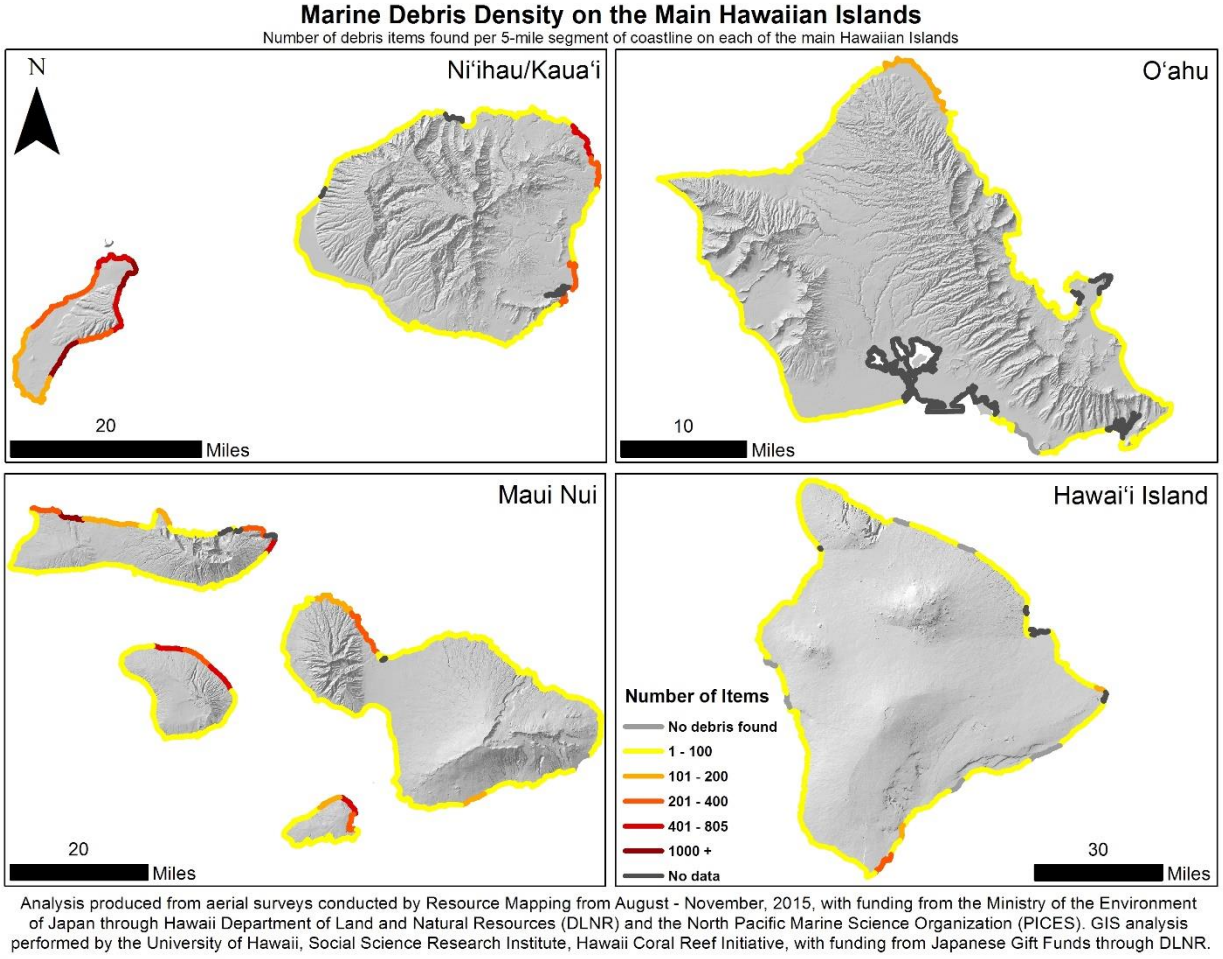


Figure 27. Marine debris density across the Main Hawaiian Islands, described as the number of items identified within a 5-mile segment of coastline.

Distribution of Debris

Marine debris on the Main Hawaiian Islands was heavily concentrated on the island of Ni'ihau (Figure 27). Ni'ihau contained 38% of the total debris identified across all of the islands surveyed. All other islands contained 14% or less of the total debris identified, with O'ahu being the least dense, containing only 5% of the total debris. Debris density was not reflective of total coastline length or number of segments (Figure 28). On all islands, marine debris was primarily concentrated on north and east-facing shores, with west-facing shores containing the least amount of debris.

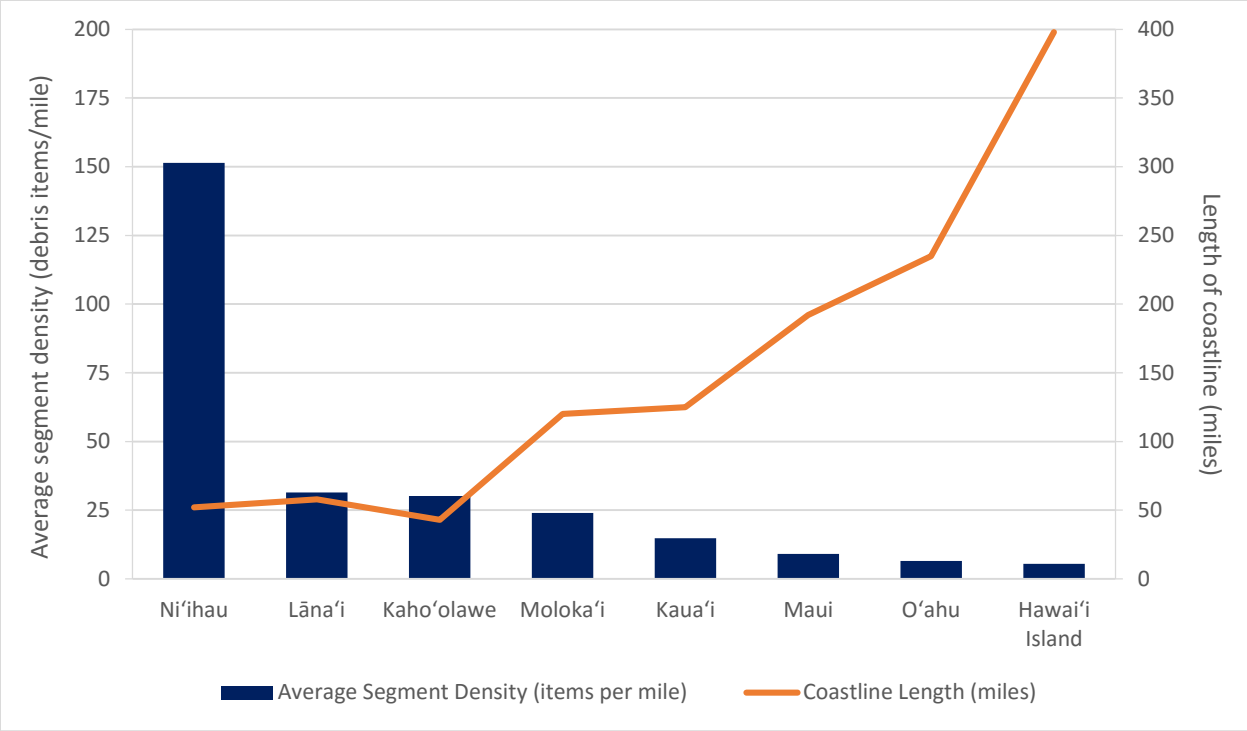


Figure 28. Average number of debris items found per 1-mile segment of coastline for the Main Hawaiian Islands, in relation to total coastline length in miles.

Type of Debris

Imagery analysis identified a total of 20,658 pieces of marine debris on coastlines of the Main Hawaiian Islands. Composition of debris varied between islands (Figure 29), but the most common type of debris on all islands was plastic, making up 47% of the overall composition of debris identified (Figure 30) and at least 37% on any individual island. Buoys and floats and derelict fishing gear were the next largest categories when comparing total debris counts, at 22% and 11%, respectively. Between islands, however, the amount of debris in these categories varied from 8% to 35% (average of 19%) for buoys and floats, and 5% to 21% (average 11%) for derelict fishing gear. Both tires and foam each made up less than 10% of the composition on any island, and 5% and 3% across all islands, respectively. "Other" category items (items identified as processed wood, metal, cloth, or vessels) contributed 6% to the overall debris count, and inconclusive items contributed 7%, with varying degrees of density across islands.

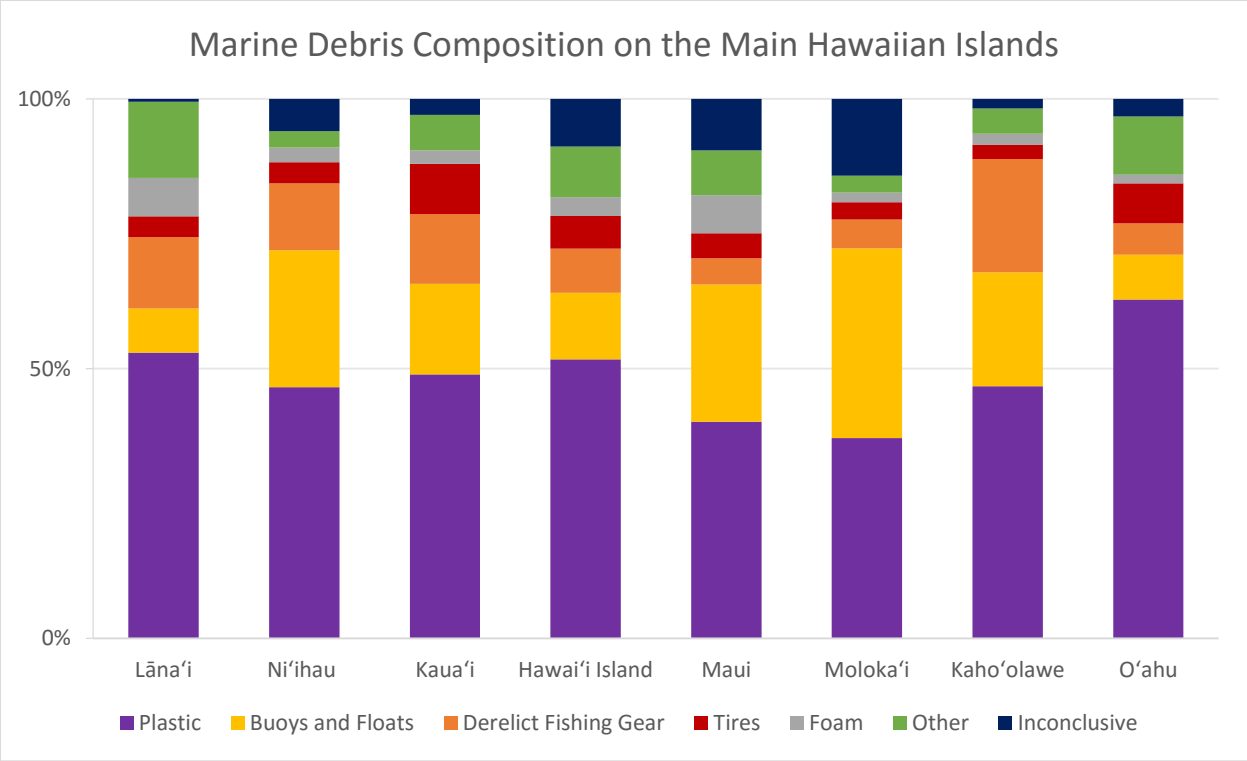


Figure 29. Composition of marine debris compared between the Main Hawaiian Islands. Derelict Fishing Gear: nets and line; Other: processed wood, metal, cloth, and vessels.

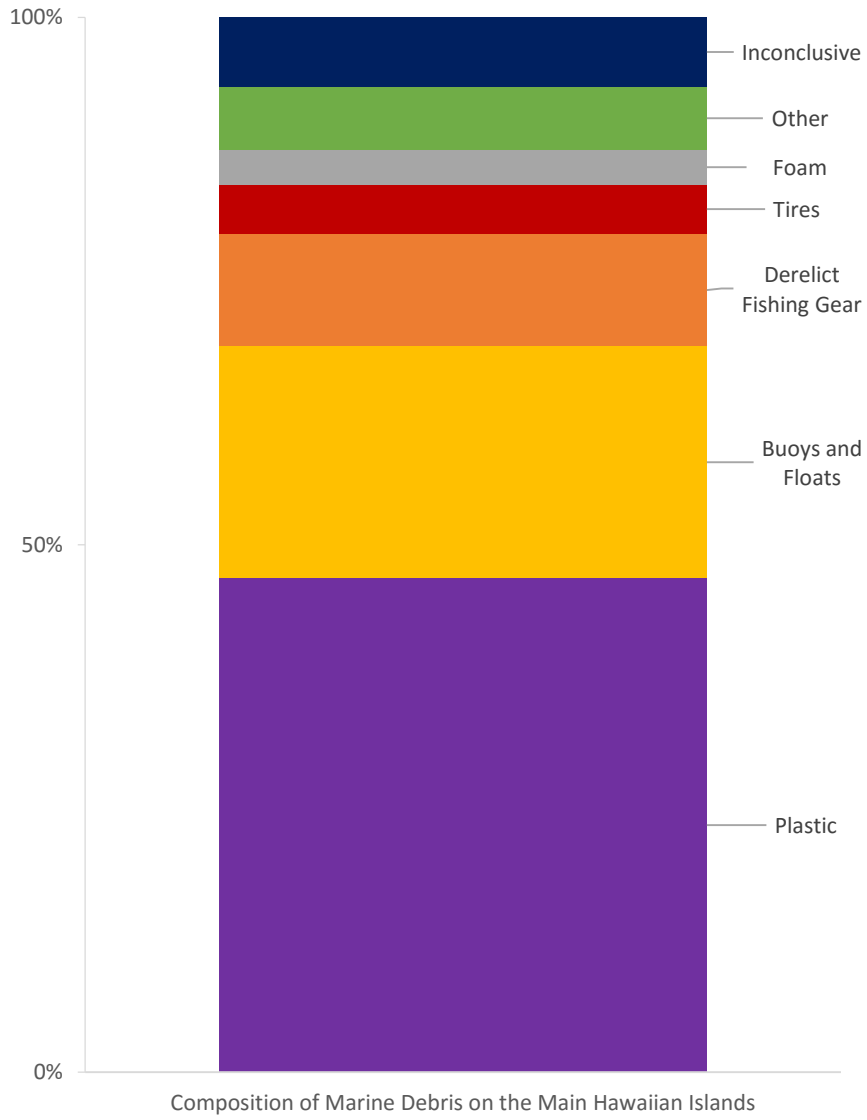


Figure 30. Composition of marine debris found on all of the Main Hawaiian Islands. Derelict Fishing Gear: nets and line; Other: processed wood, metal, cloth, and vessels.

Size of Debris

Size distribution of marine debris identified on the Main Hawaiian Islands was less variable than type composition (Figure 31). The smallest category (< 0.5m^2) made up 86% of the total debris found on all islands (Figure 32), and contributed between 84% to 89% on individual islands. The remaining categories each made up less than 10% on any island, with the total contribution statewide from the small category (0.5 – 1m^2) being 6% and the total contribution from the remaining size classes (1 – 2m^2 and > 2m^2) being 4% each.

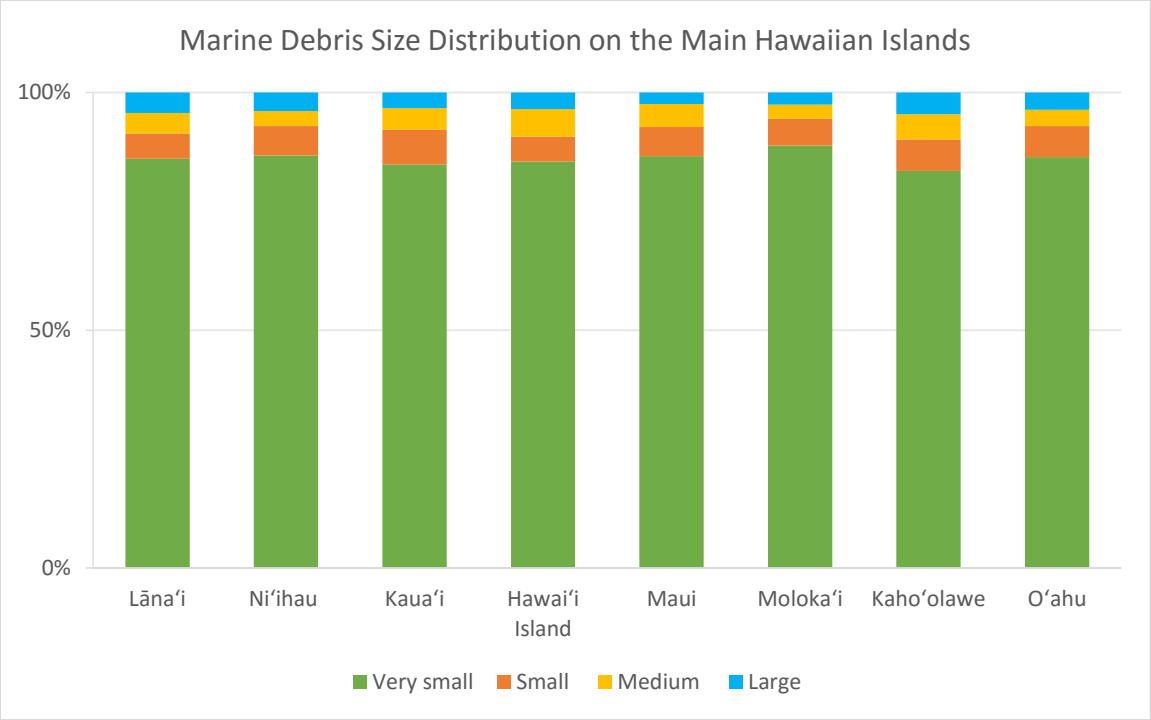


Figure 31. Size distribution of marine debris compared between the Main Hawaiian Islands. Very Small: < 0.5 m^2, Small: 0.5 – 1 m^2, Medium: 1 – 2 m^2, Large: >2 m^2.

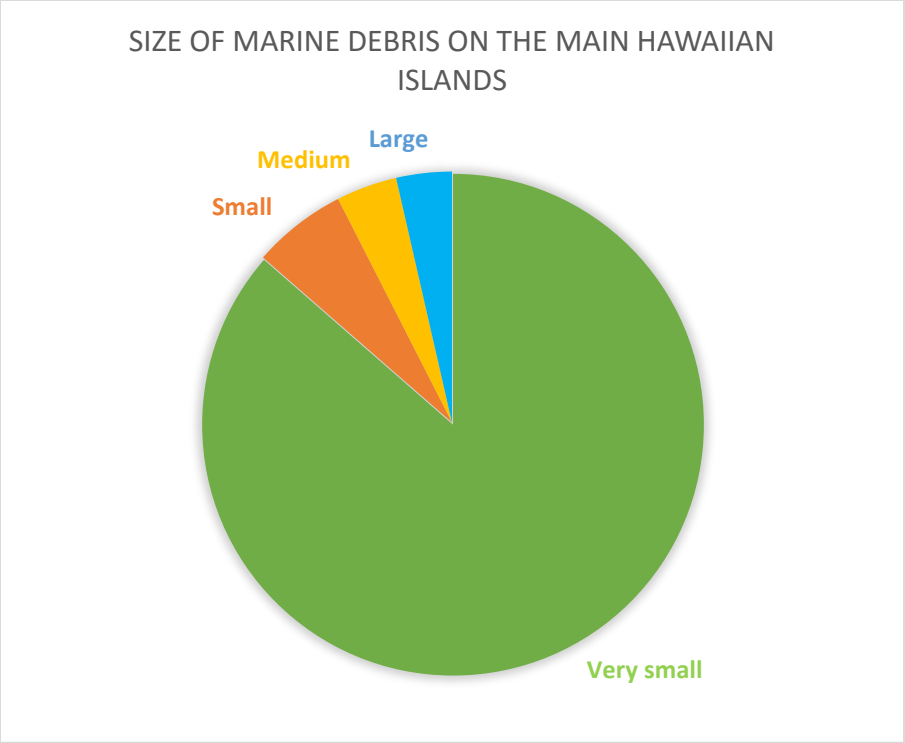


Figure 32. Debris size distribution across all of the Main Hawaiian Islands. Very Small: < 0.5 m^2, Small: 0.5 – 1 m^2, Medium: 1 – 2 m^2, Large: >2 m^2.

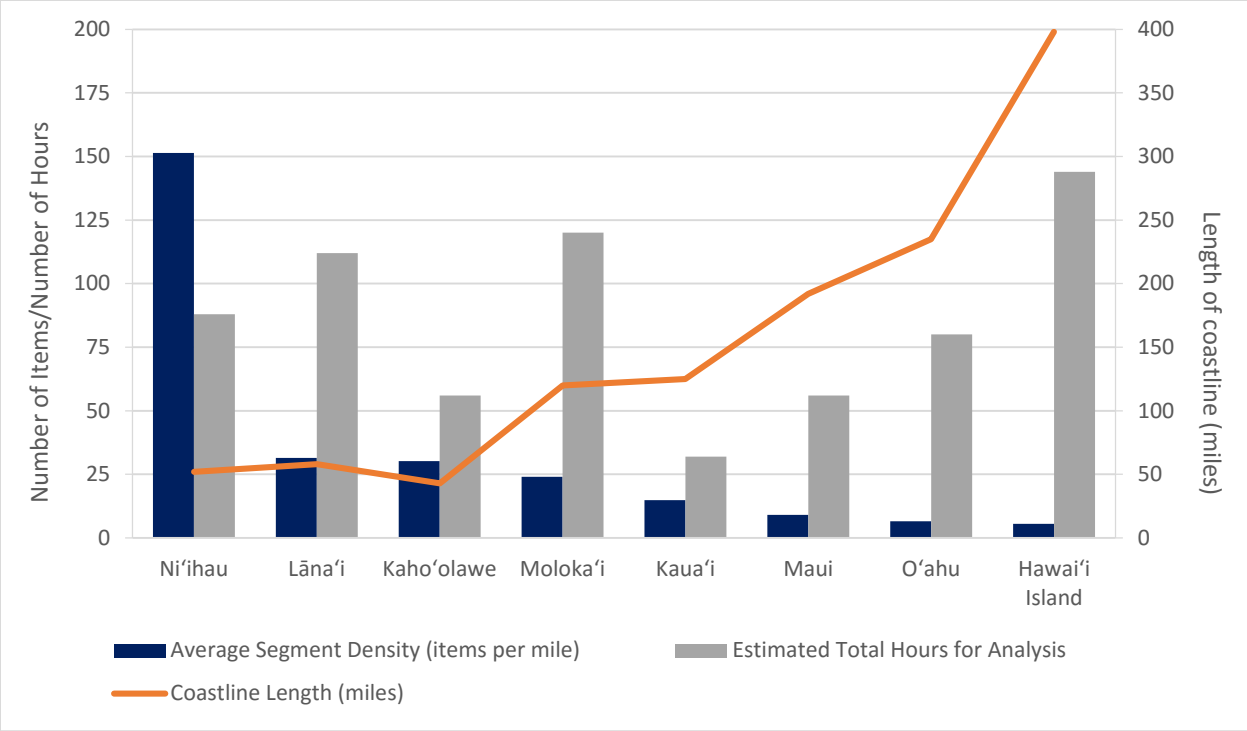


Figure 33. Amount of hours for analysis, compared to average segment density (1-mile segments) and length of coastline in miles.

Analysis Effort

Aerial imagery analysis was conducted between October 2015 and February 2016, with analysts working a varied number of hours per week. The amount of time required to analyze an island's coastline was dependent on multiple factors. The main factors determining analysis time were 1) average segment density; 2) total coastline length; and 3) analyst experience. Since the analysis for this project was completed by students learning the GIS process, the increase in experience using the program over time was shown to impact the total analysis time, with analysis progressing faster further along into the project. For example, Lāna‘i and Kaho‘olawe had similar average segment densities, however Lāna‘i was the first island surveyed, while Kaho‘olawe was one of the last islands surveyed, resulting in a faster analysis time for Kaho‘olawe (Figure 33). Islands were analyzed in the following order: Lāna‘i, Ni‘ihau, Hawai‘i Island, Kaua‘i, Maui, Moloka‘i, Kaho‘olawe, and O‘ahu.

NEXT STEPS

This project focused on the collection and processing of data to provide a comprehensive assessment of the distribution and composition of marine debris on Hawaiian coastlines; however, the ultimate goal is to mitigate possible negative effects this debris may have on coastal areas. The next steps toward achievement of this goal would be to use the data provided from this project to organize and plan cleanup efforts, and develop a community-accessible database to distribute debris data and track removal efforts throughout the islands. Accomplishment of these tasks involves additional efforts to prepare, such as the ground-truthing of reported debris and preparation of this data for online access and publication.

Additional possibilities for future directions include analysis of changes over time with repeated imagery datasets, and investigating patterns in debris movement and accumulation in relation to oceanographic features such as currents and wind, or coastal features such as coral reef or wildlife habitat. The image collection and analysis techniques used here could also be applied to other areas of research and conservation as a method for collecting data on a large scale. For example, similar approaches could be used in projects that seek to characterize distribution of other natural resources, such as native or invasive species, or to survey coral bleaching on nearshore reefs (Figure 34, 35). There are numerous other possibilities for using aerial imagery data to identify and analyze features important to the understanding of biological, ecological, and geographical processes.

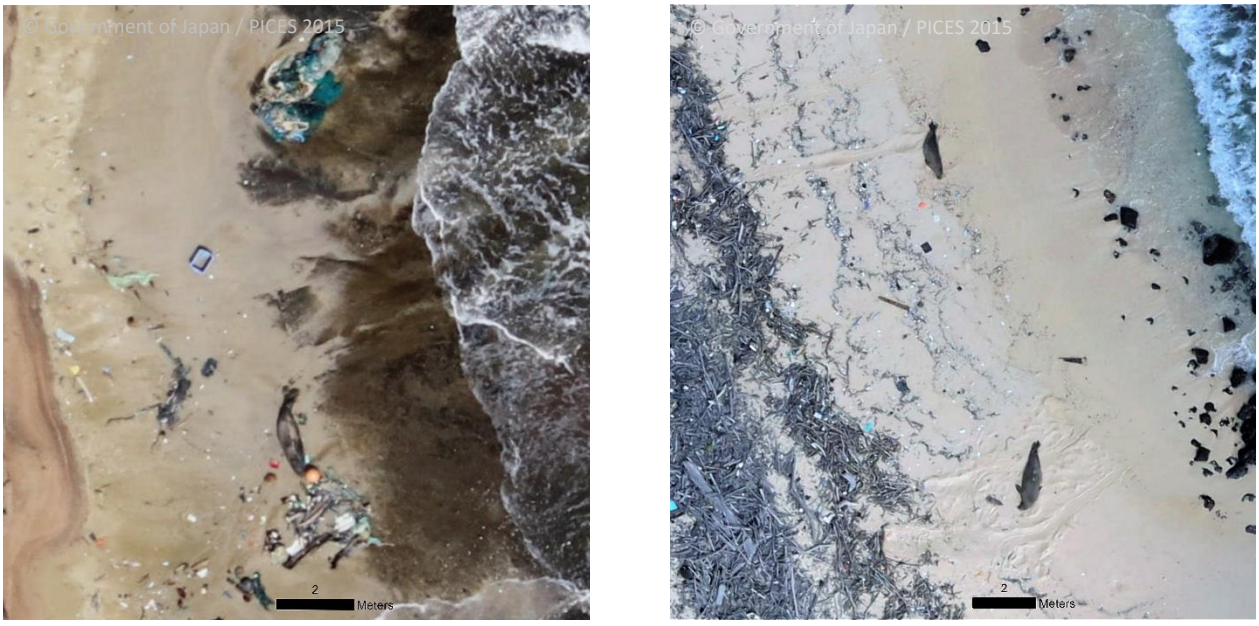


Figure 34. Imagery analyzed for this project shows endangered Hawaiian Monk Seals resting on Ni'ihau beaches that are littered with marine debris, including plastic and derelict fishing gear, which present ingestion and entanglement hazards.

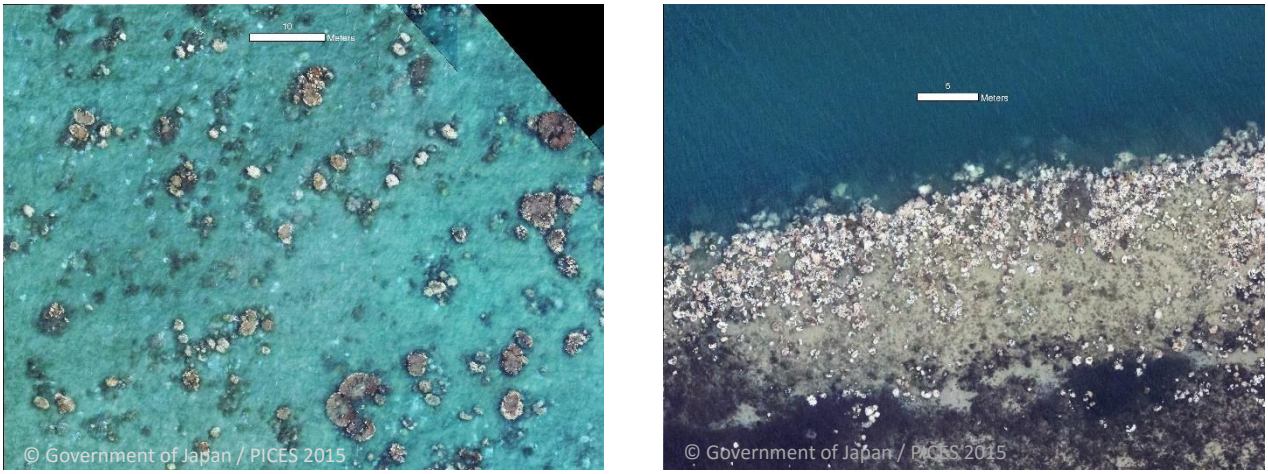
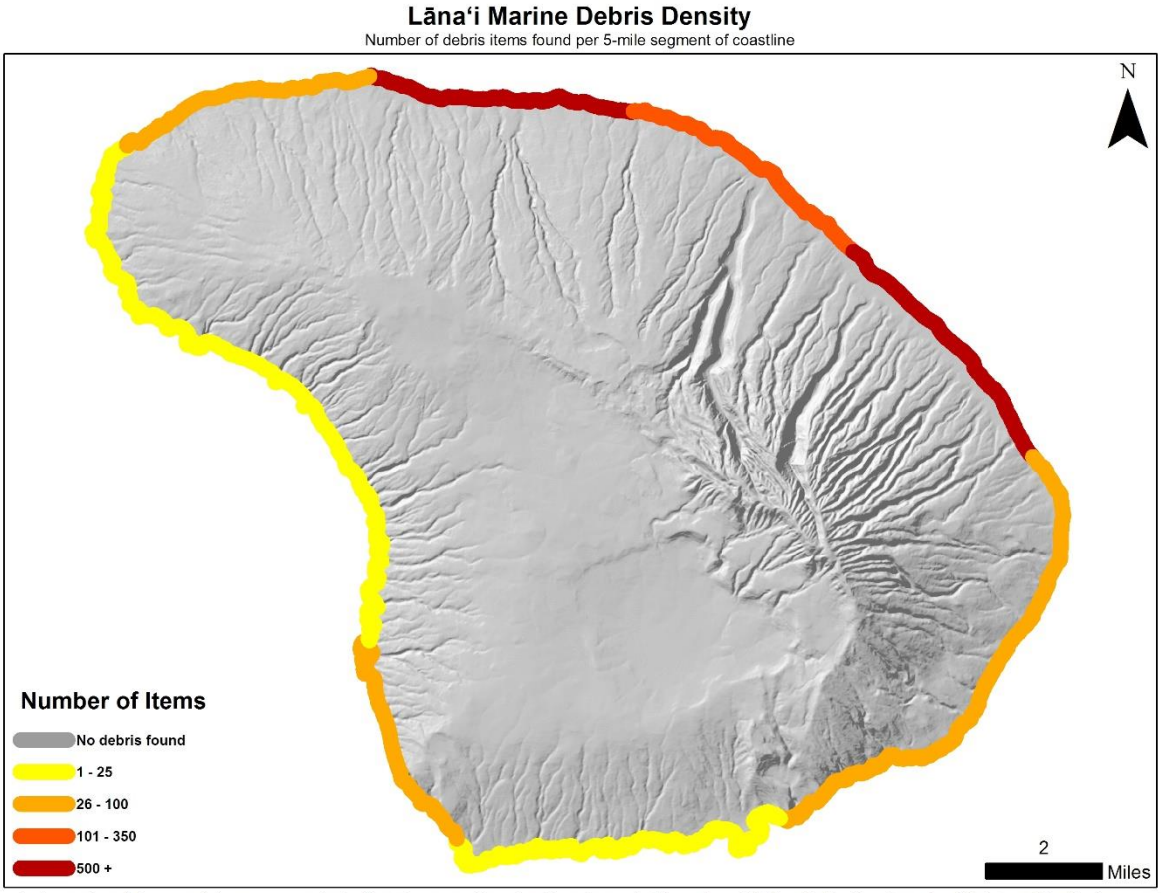


Figure 35. Imagery analyzed for this project shows bleached coral in Lanikai (left) and Kāne‘ohe Bay (right) on the island of O‘ahu.

APPENDIX

Appendix A. Additional Maps

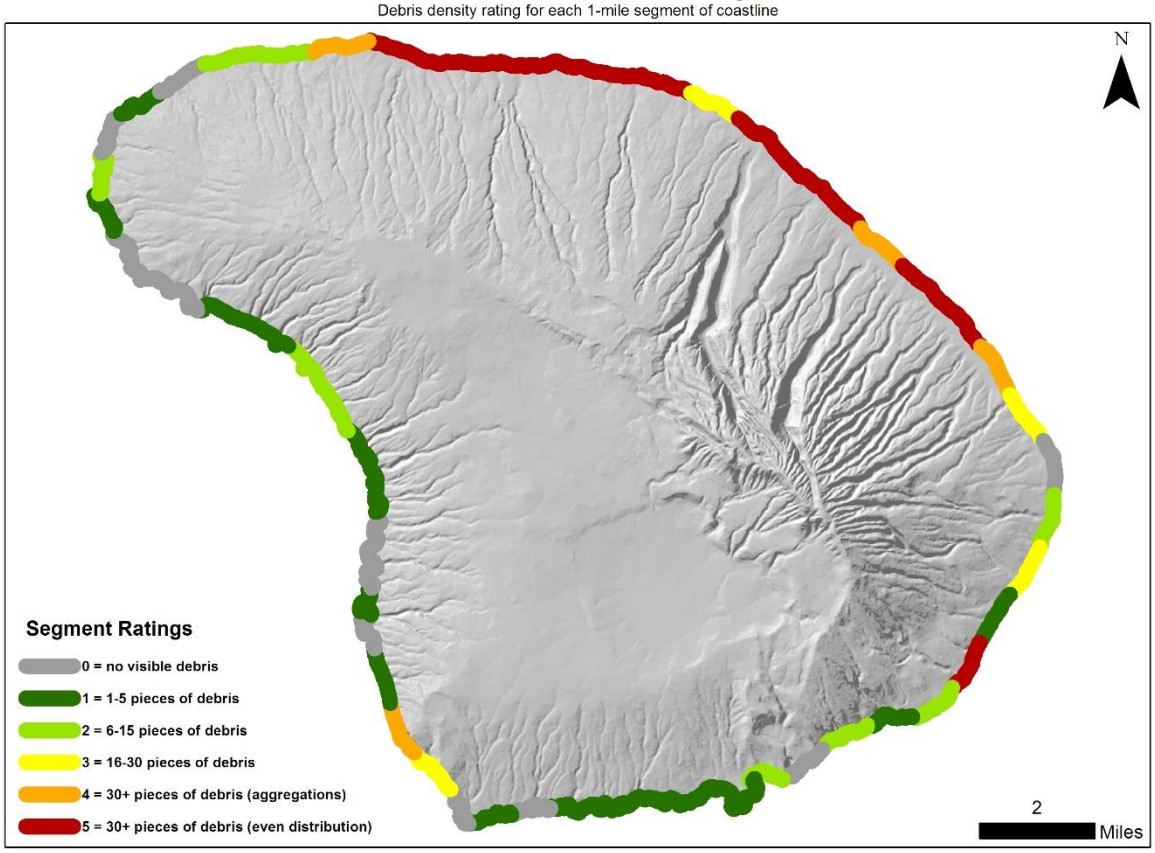
Lānaʻi



Analysis produced from aerial surveys conducted by Resource Mapping from August - November, 2015, with funding from the Ministry of the Environment of Japan through Hawaii Department of Land and Natural Resources (DLNR) and the North Pacific Marine Science Organization (PICES). GIS analysis performed by the University of Hawaii, Social Science Research Institute, Hawaii Coral Reef Initiative, with funding from Japanese Gift Funds through DLNR.

Lānaʻi Marine Debris Density

Debris density rating for each 1-mile segment of coastline



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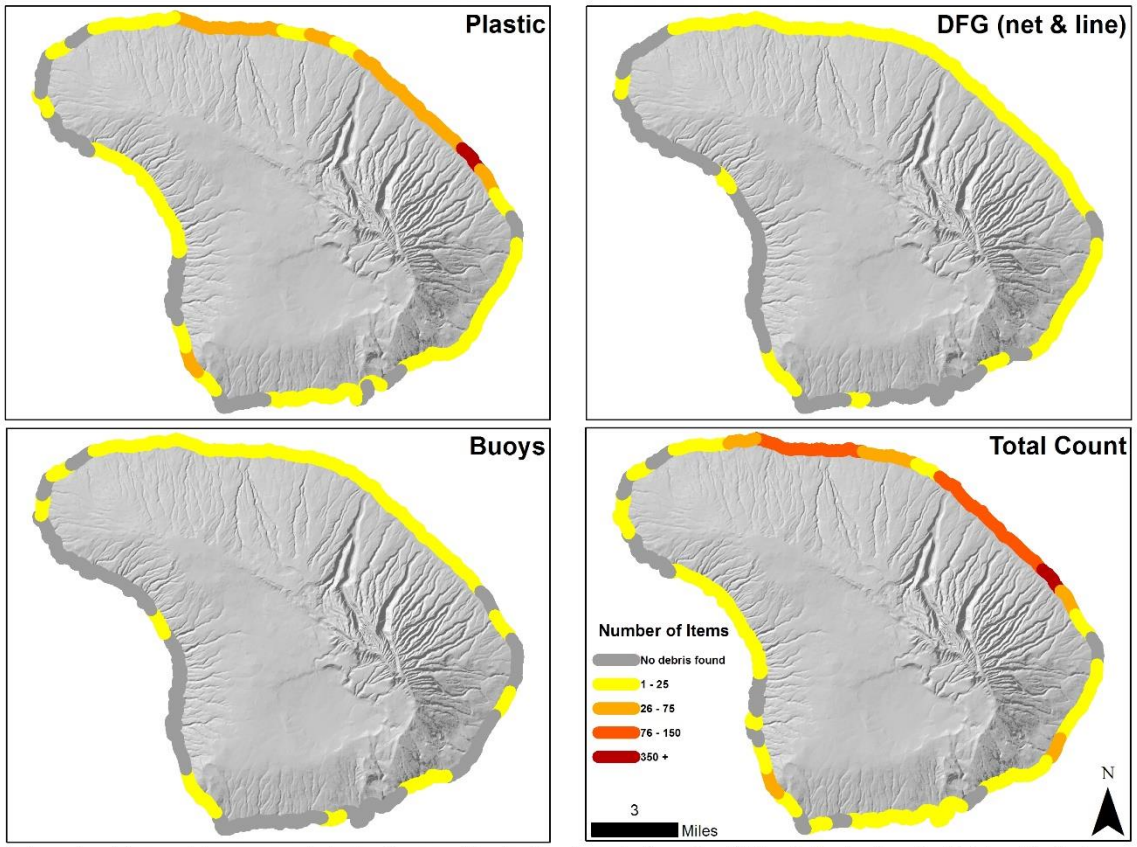
Lānaʻi Marine Debris Density by Item Type

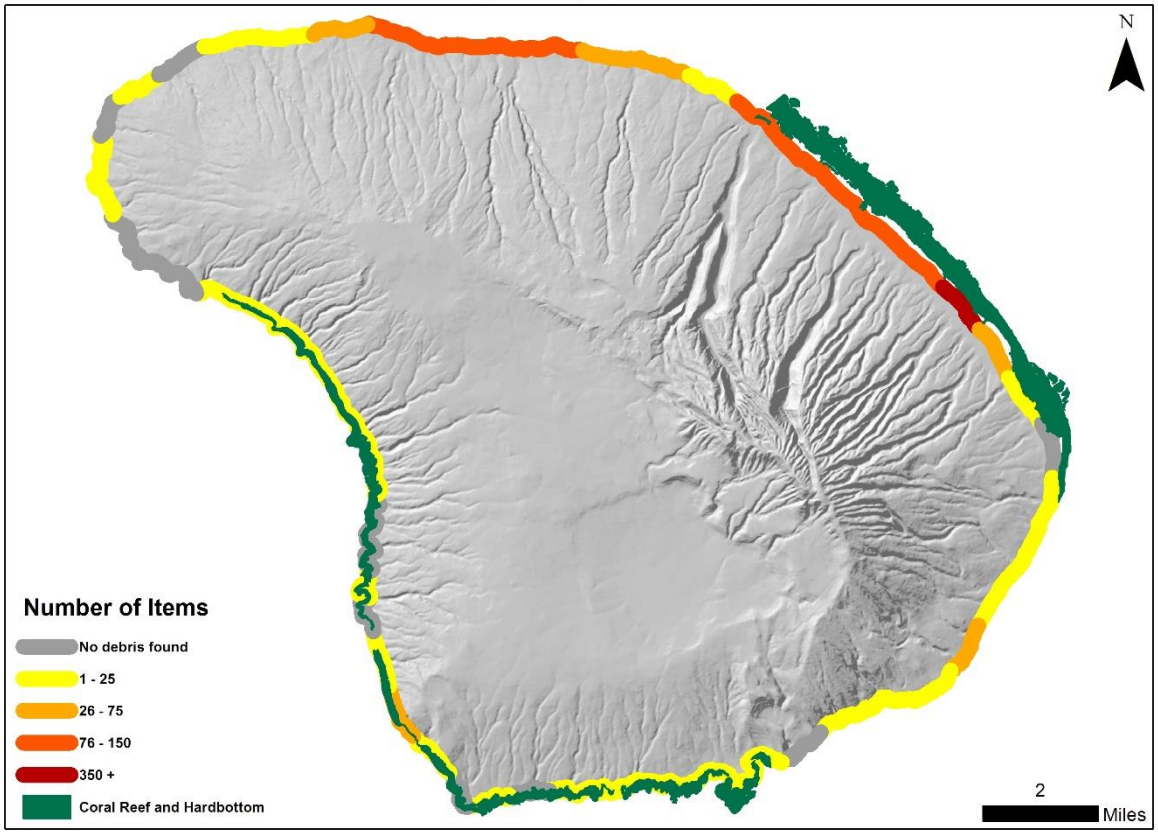
Number of debris items per 1-mile segment of coastline for three main debris types



Analysis produced from aerial surveys conducted by Resource Mapping from August - November, 2015, with funding from the Ministry of the Environment of Japan through Hawaii Department of Land and Natural Resources (DLNR) and the North Pacific Marine Science Organization (PICES). GIS analysis performed by the University of Hawaii, Social Science Research Institute, Hawaii Coral Reef Initiative, with funding from Japanese Gift Funds through DLNR.

Lānaʻi Marine Debris Density in Relation to Reef Habitat

Number of debris items found per 1-mile segment of coastline, shown with reef habitats



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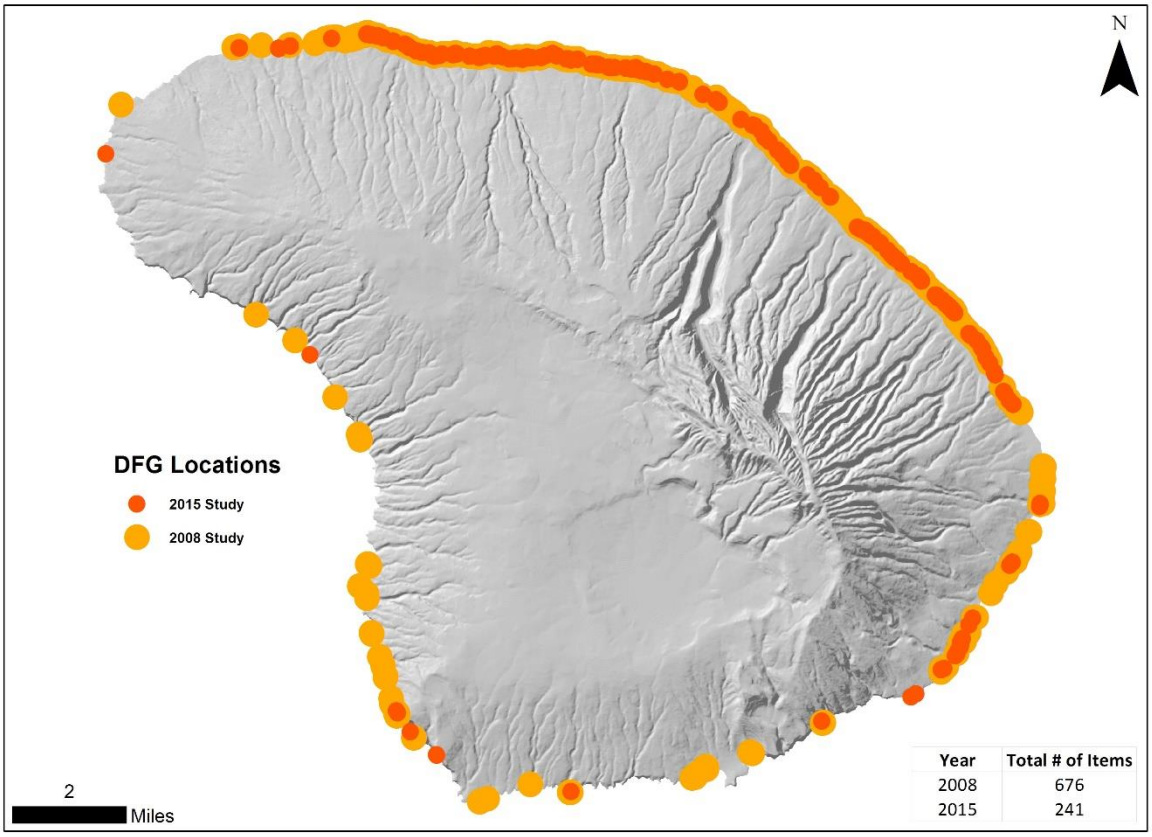
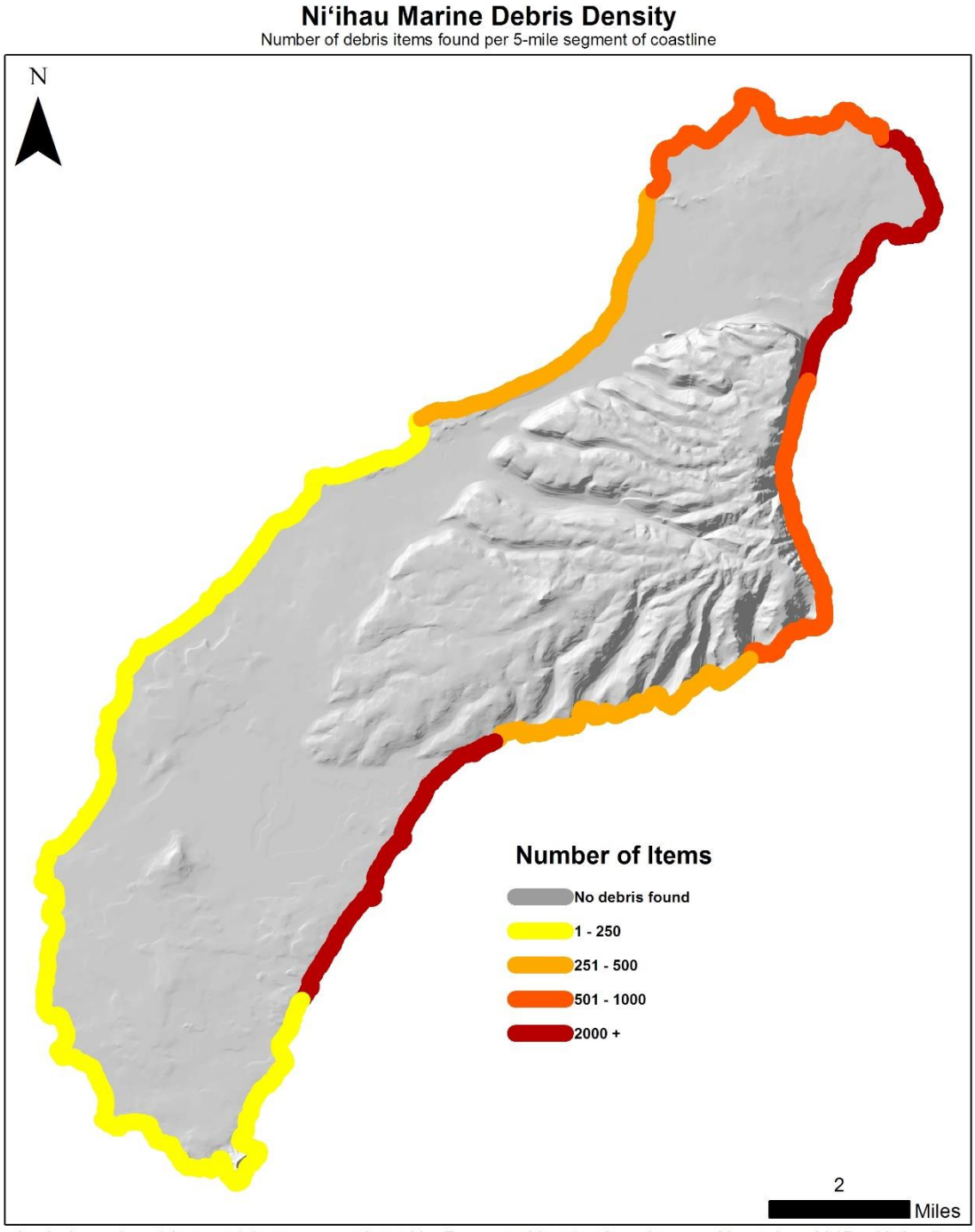
Lānaʻi Derelict Fishing Gear

Comparing the 2008 NOAA study to current findings



Analysis produced from aerial surveys conducted by Resource Mapping from August - November, 2015, with funding from the Ministry of the Environment of Japan through Hawaii Department of Land and Natural Resources (DLNR) and the North Pacific Marine Science Organization (PICES). GIS analysis performed by the University of Hawaii, Social Science Research Institute, Hawaii Coral Reef Initiative, with funding from Japanese Gift Funds through DLNR.

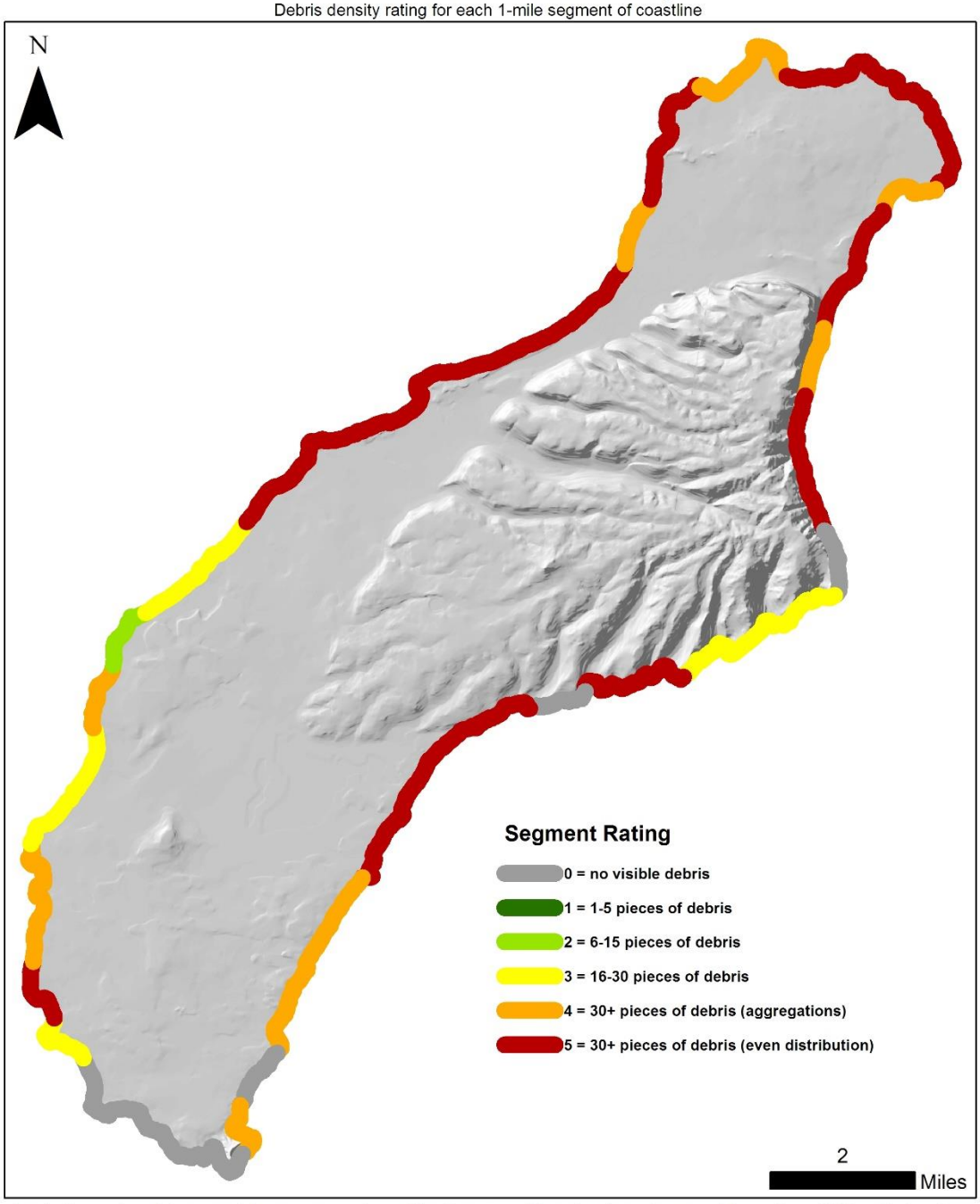
Ni‘ihau



Analysis produced from aerial surveys conducted by Resource Mapping from August - November, 2015, with funding from the Ministry of the Environment of Japan through Hawaii Department of Land and Natural Resources (DLNR) and the North Pacific Marine Science Organization (PICES). GIS analysis performed by the University of Hawaii, Social Science Research Institute, Hawaii Coral Reef Initiative, with funding from Japanese Gift Funds through DLNR.

Ni‘ihau Marine Debris Density

Debris density rating for each 1-mile segment of coastline



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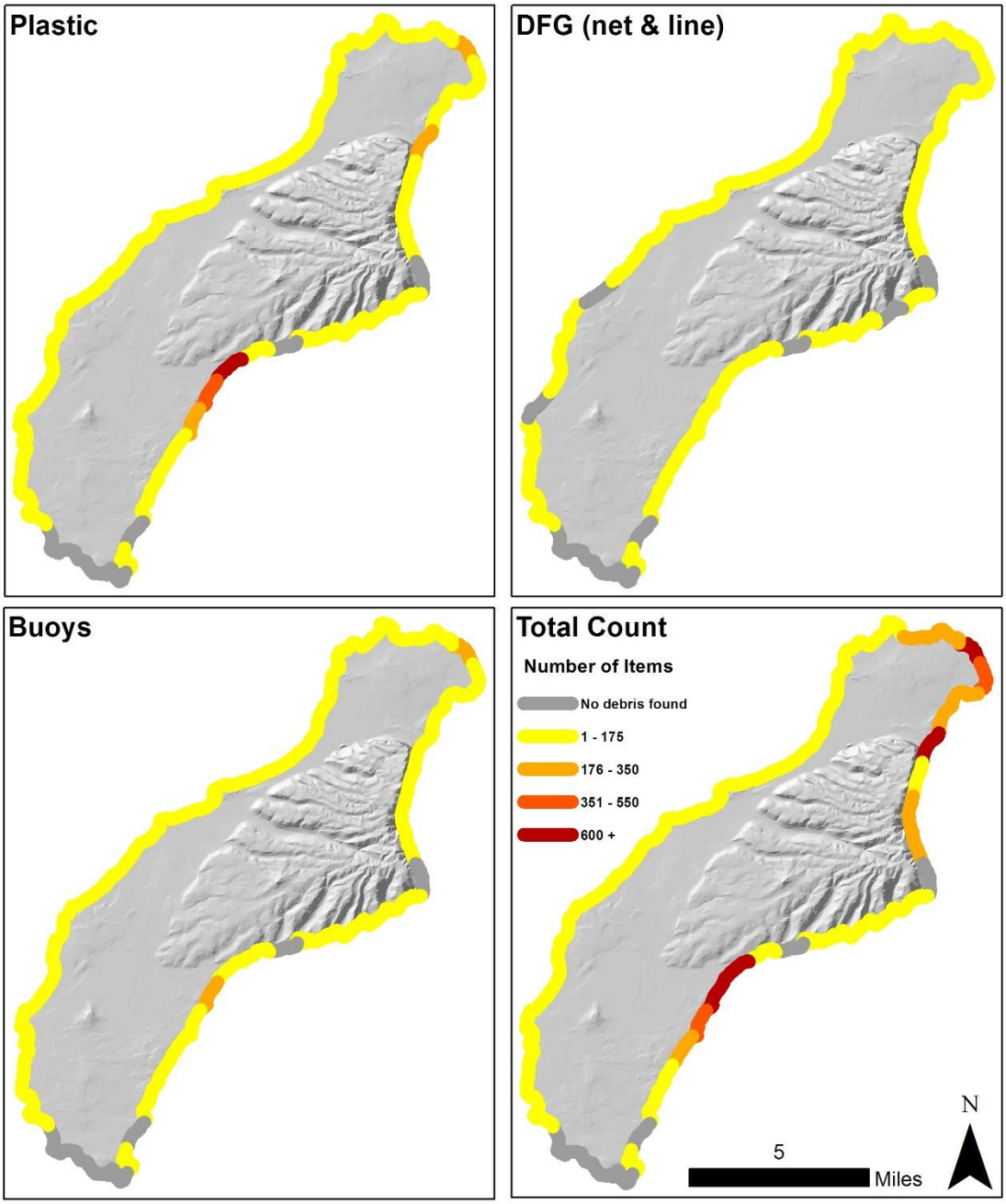
Ni‘ihau Marine Debris Density by Item Type

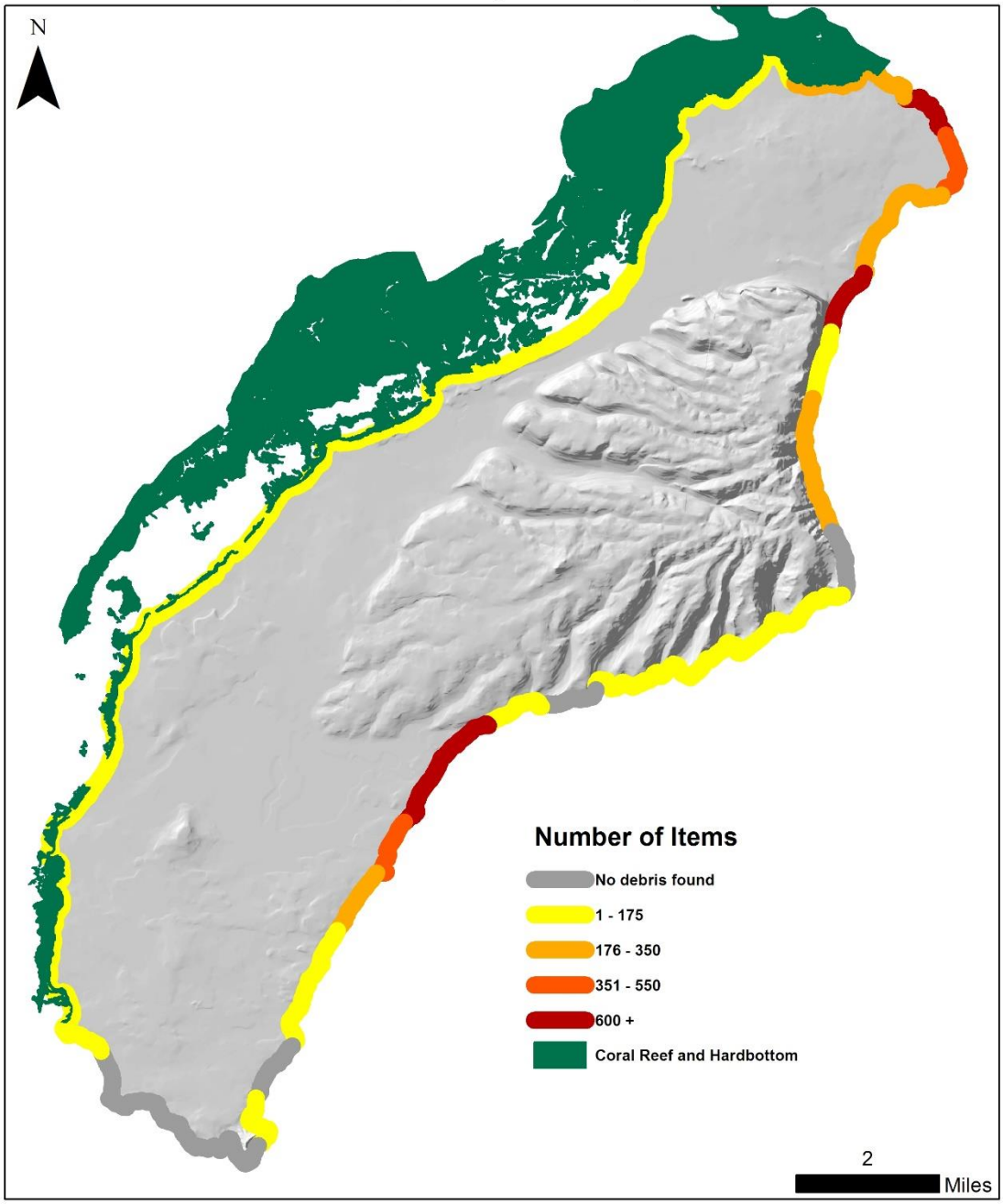
Number of debris items per 1-mile segment of coastline for three main debris types



Analysis produced from aerial surveys conducted by Resource Mapping from August - November, 2015, with funding from the Ministry of the Environment of Japan through Hawaii Department of Land and Natural Resources (DLNR) and the North Pacific Marine Science Organization (PICES). GIS analysis performed by the University of Hawaii, Social Science Research Institute, Hawaii Coral Reef Initiative, with funding from Japanese Gift Funds through DLNR.

Ni‘ihau Marine Debris Density in Relation to Reef Habitat

Number of debris items found per 1-mile segment of coastline, shown with reef habitats



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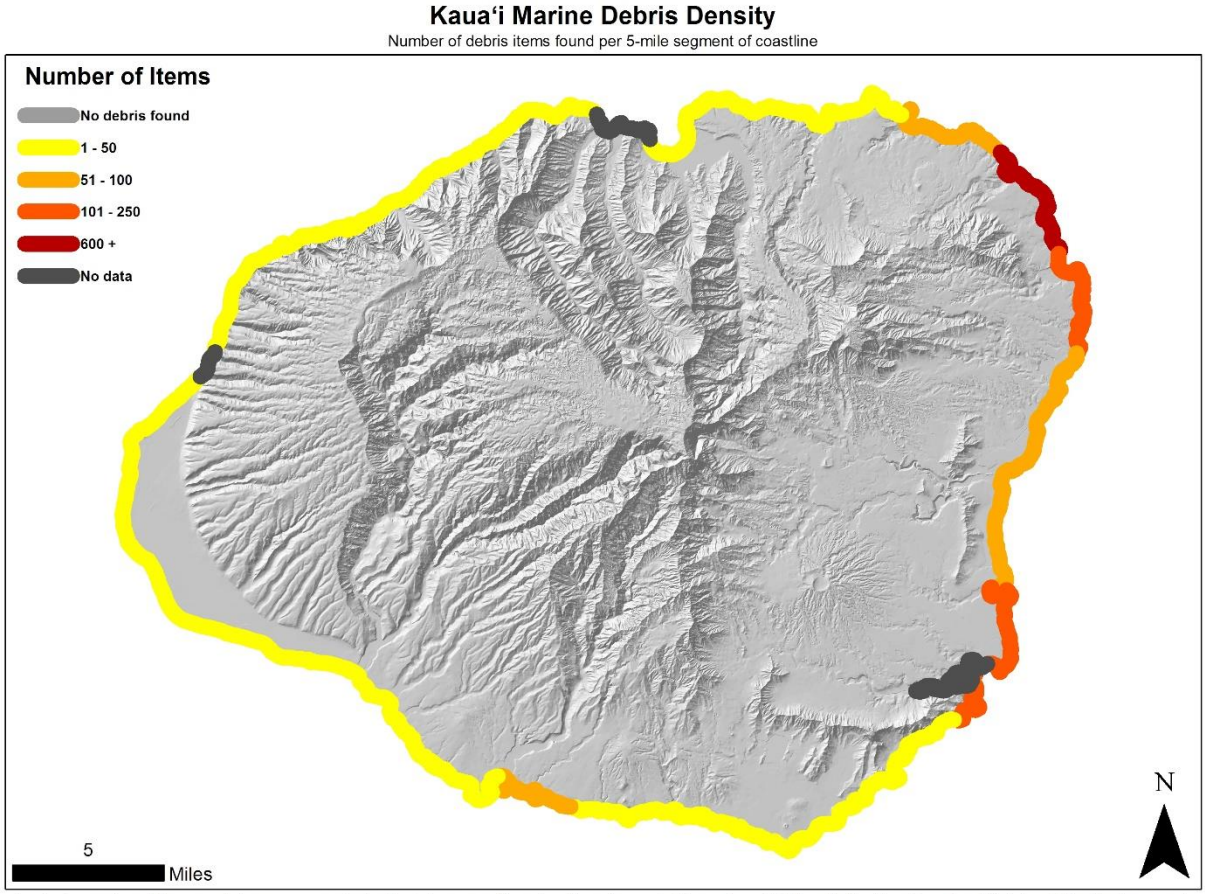
Kaua‘i



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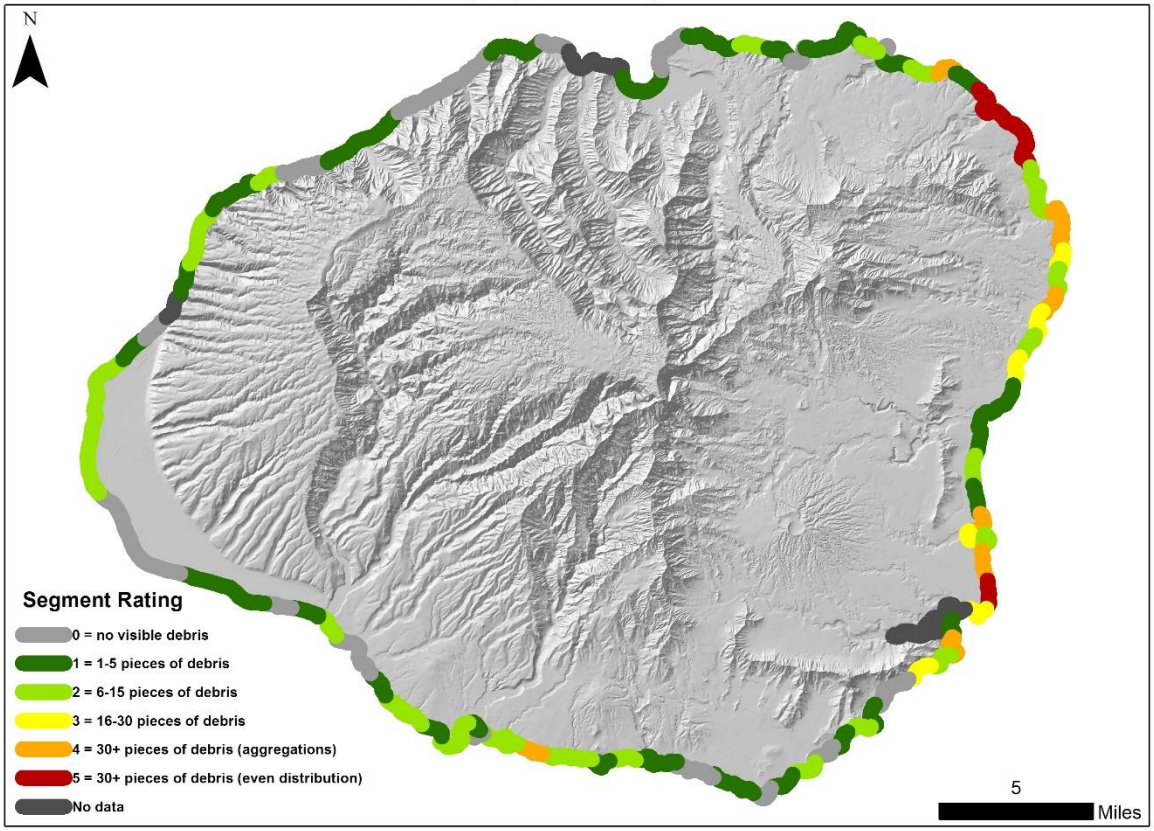
Kaua‘i Marine Debris Density

Debris density rating for each 1-mile segment of coastline



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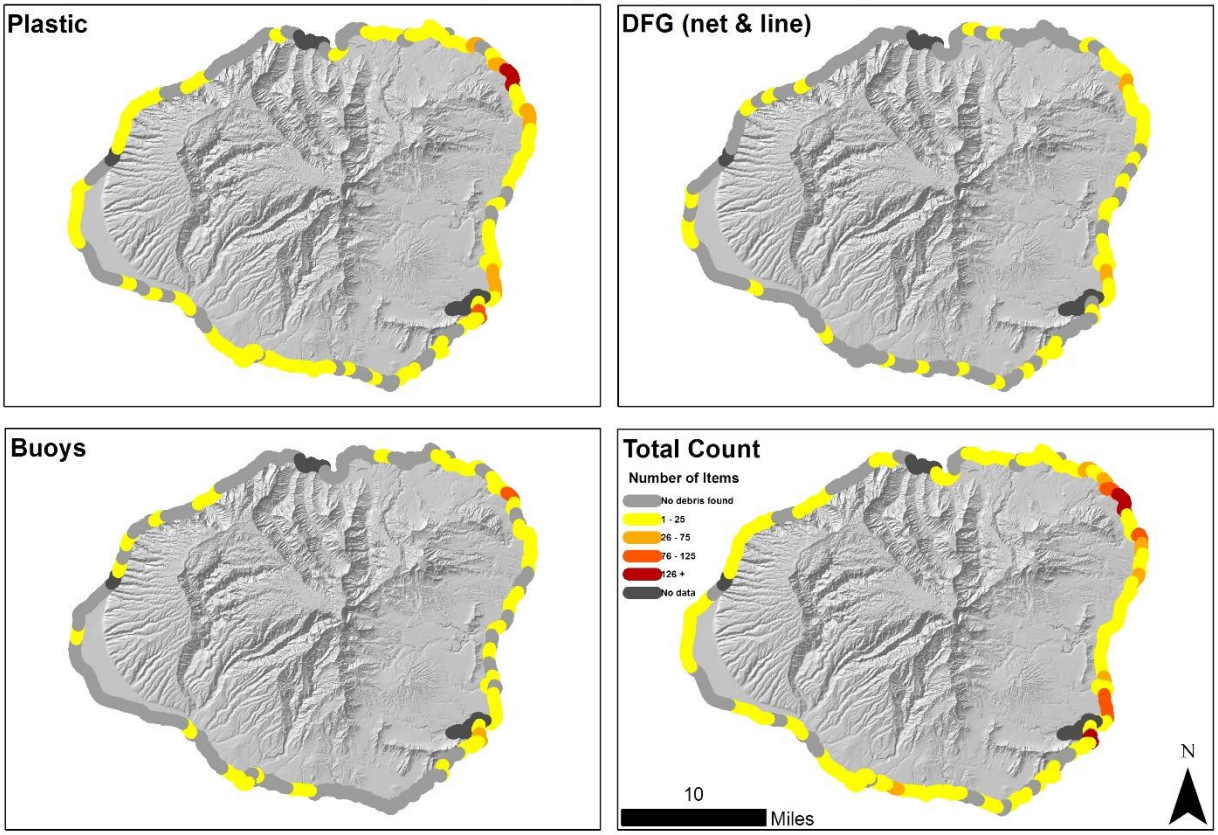
Kaua‘i Marine Debris Density by Item Type

Number of debris items per 1-mile segment of coastline for three main debris types



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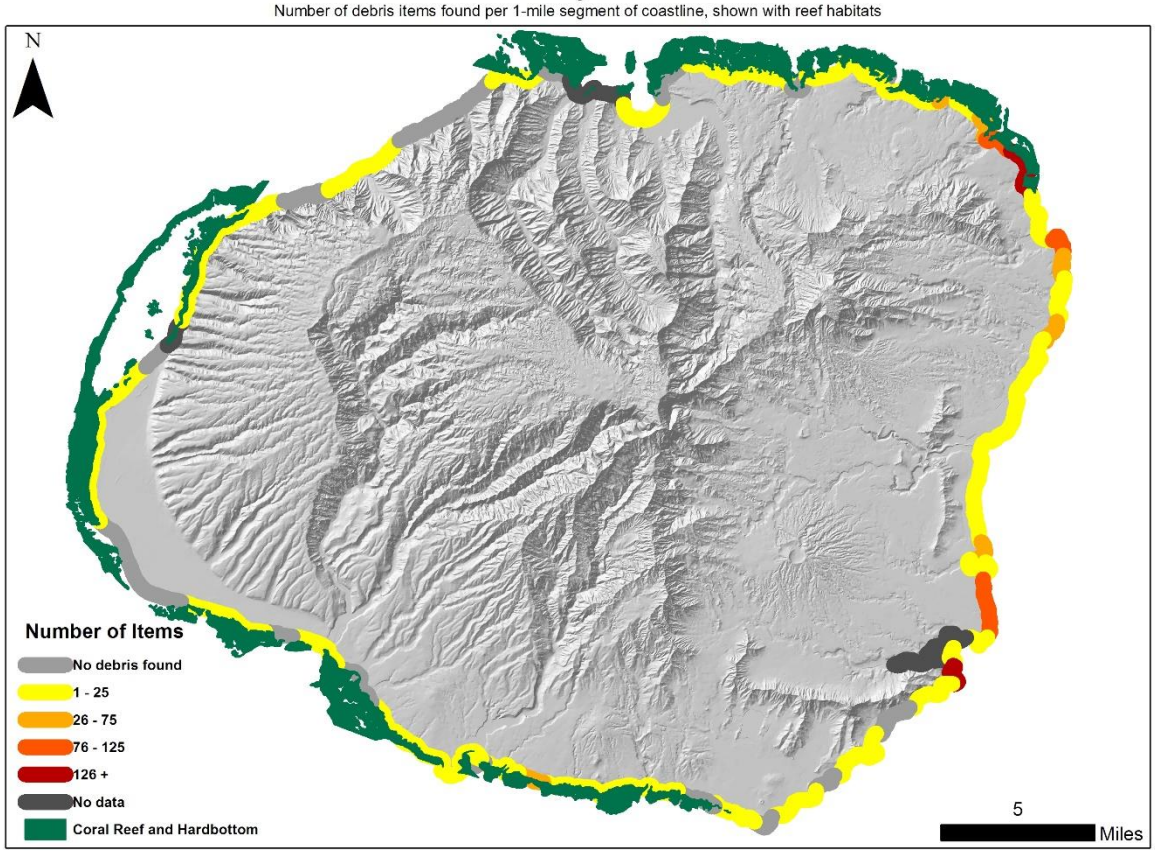
Kaua'i Marine Debris Density in Relation to Reef Habitat

Number of debris items found per 1-mile segment of coastline, shown with reef habitats



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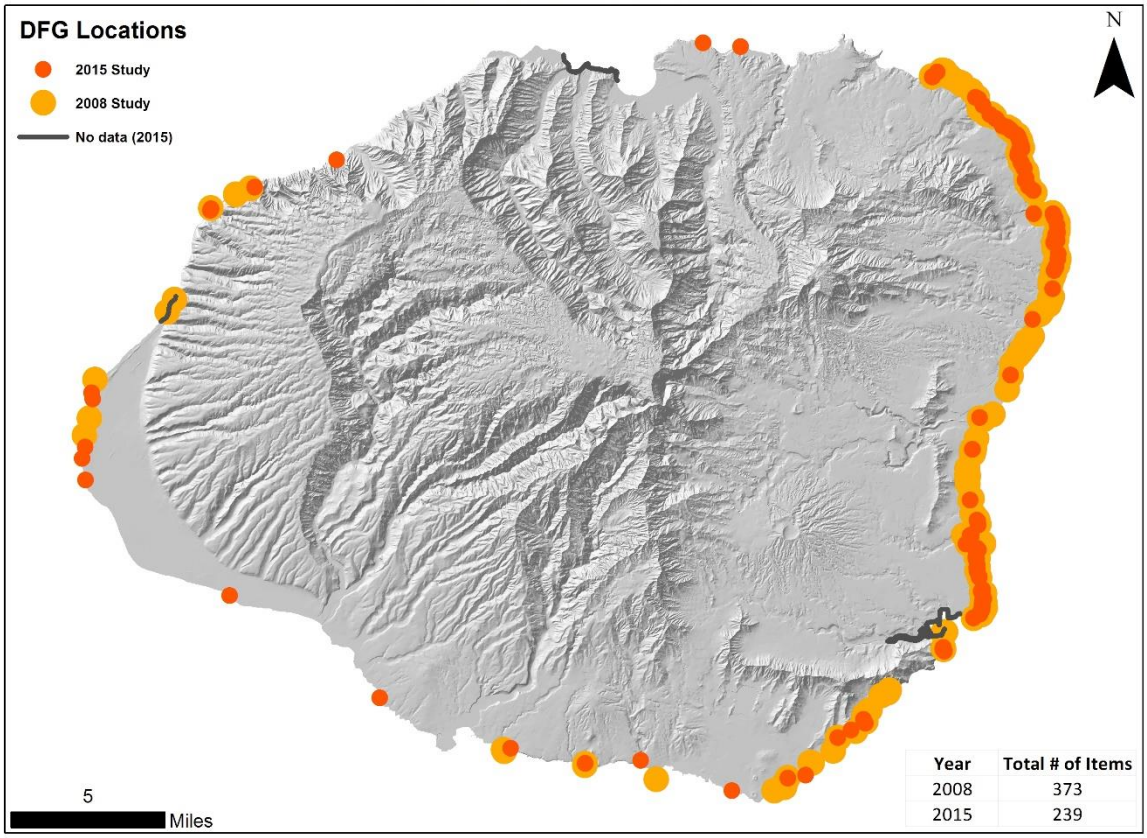
Kaua'i Derelict Fishing Gear

Comparing the 2008 NOAA study to current findings



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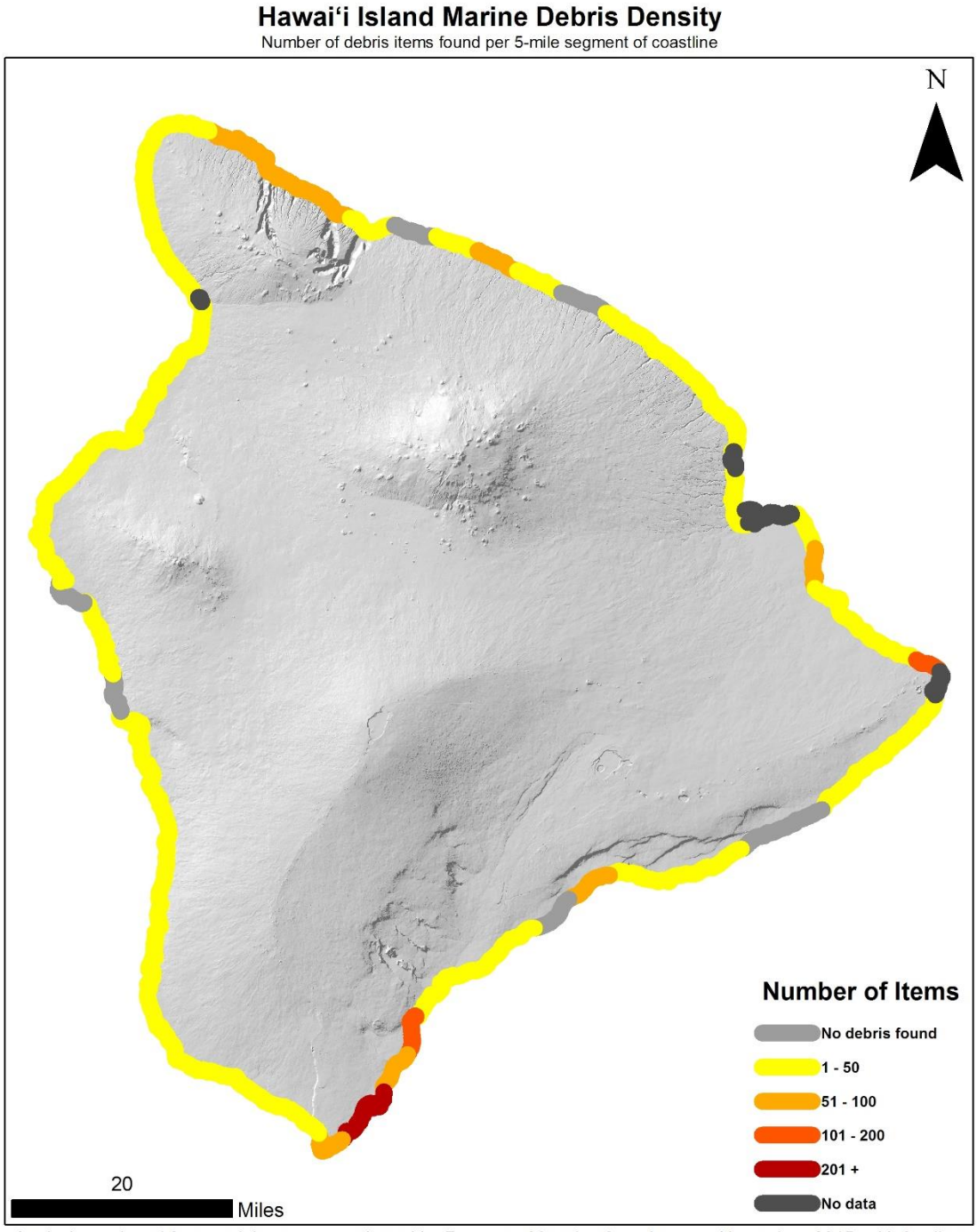
Hawai‘i Island



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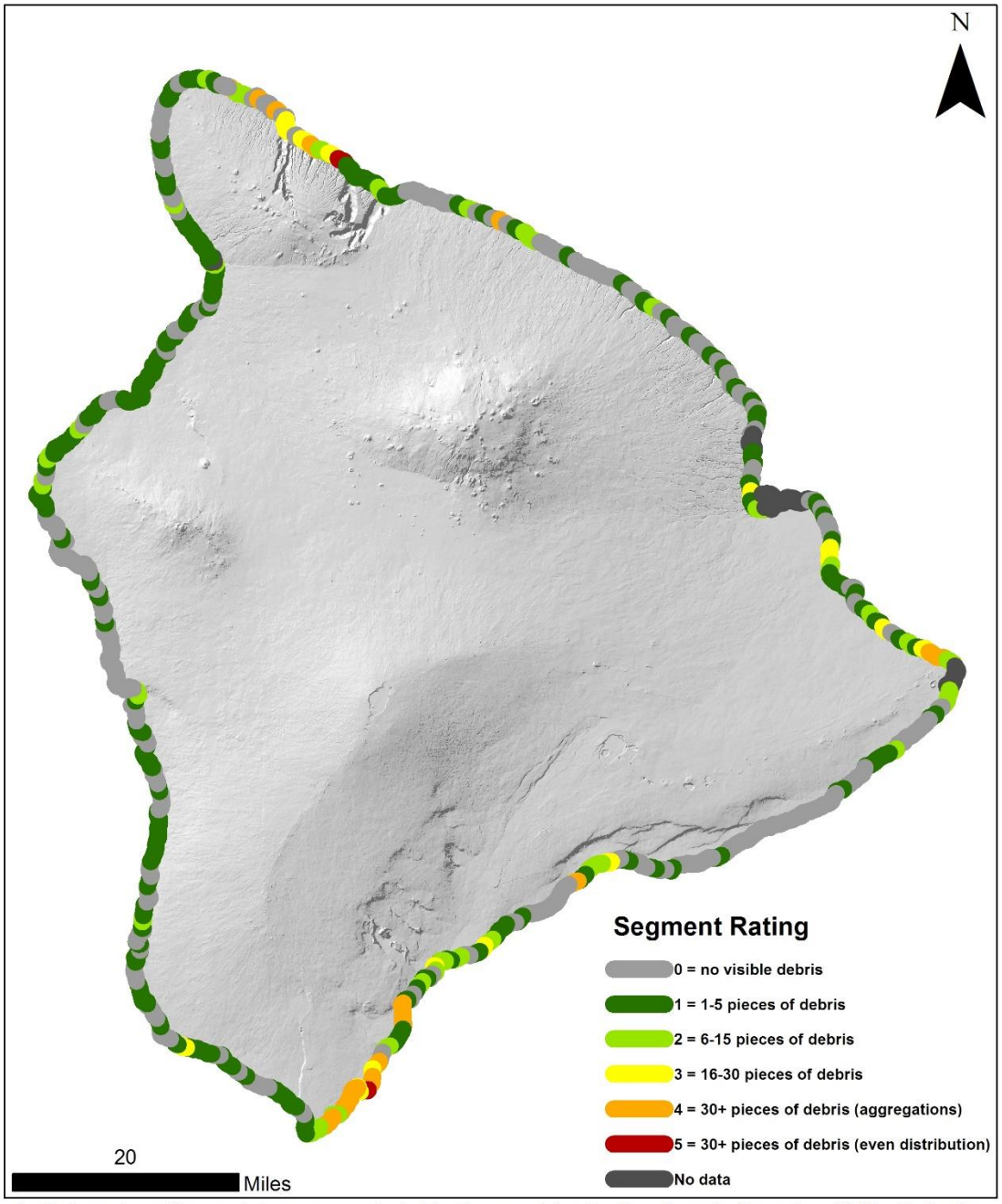
Hawai‘i Island Marine Debris Density

Debris density rating for each 1-mile segment of coastline



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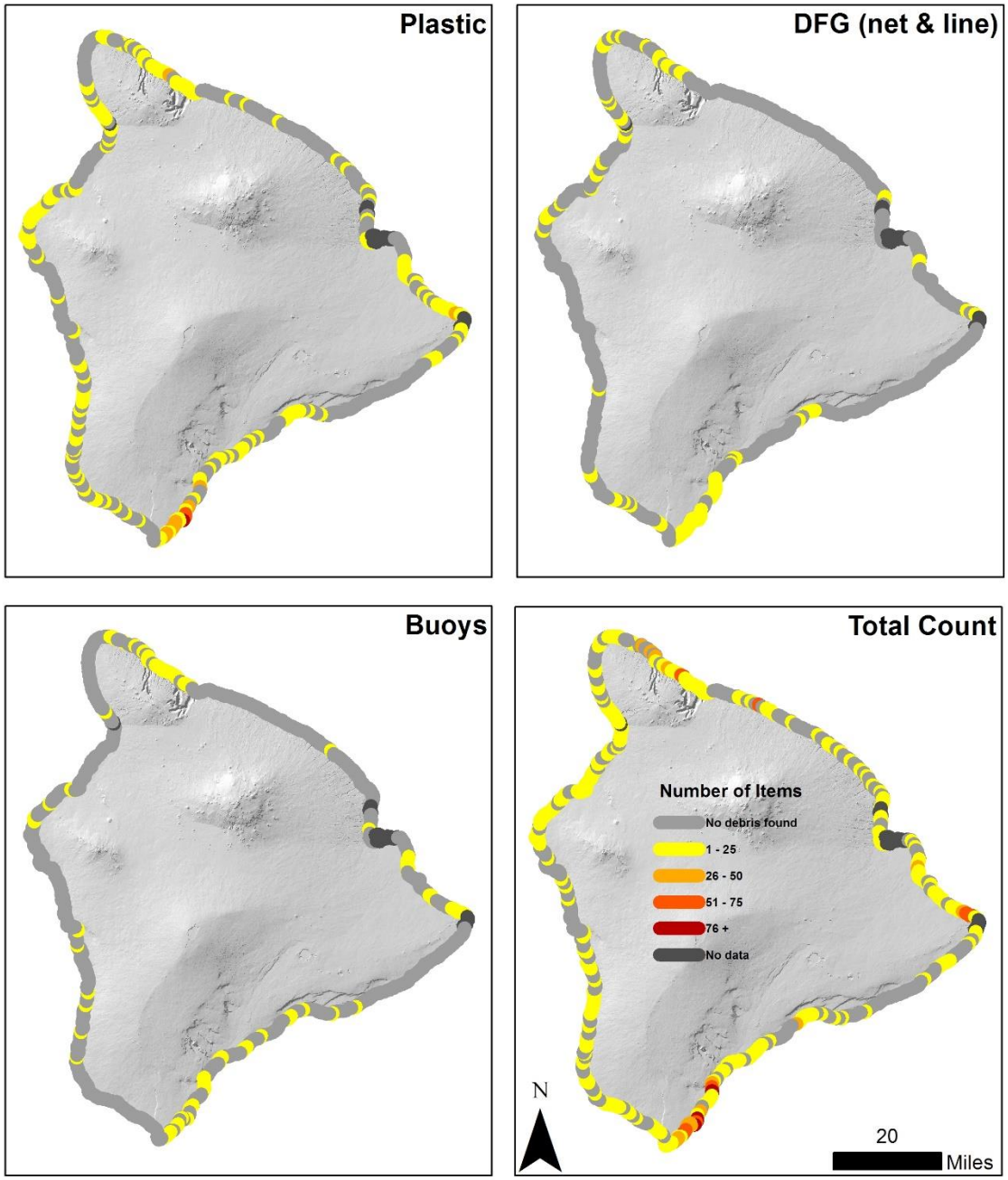
Hawai‘i Island Marine Debris Density by Item Type

Number of debris items per 1-mile segment of coastline for three main debris types



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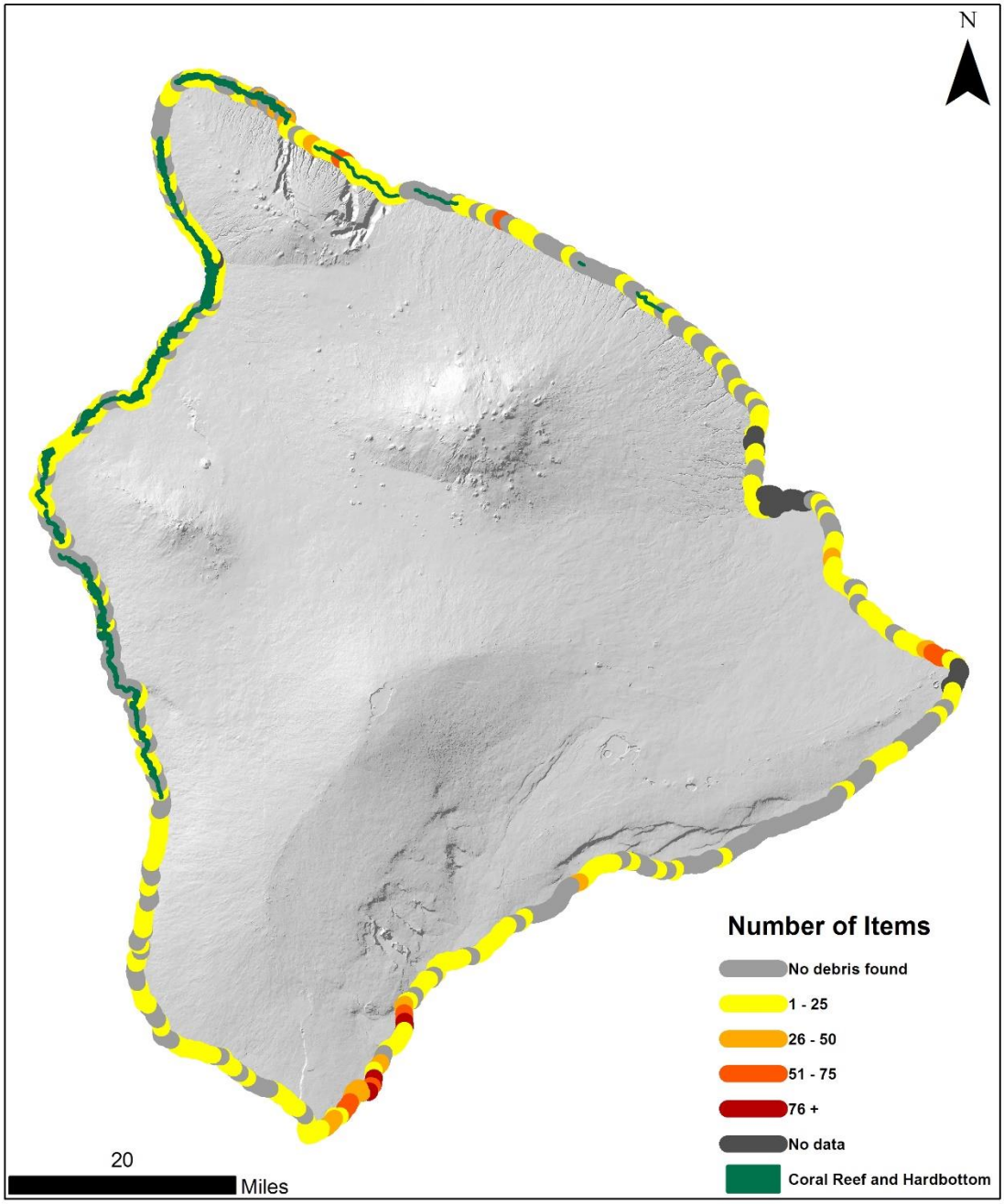
Hawai‘i Island Marine Debris Density in Relation to Reef Habitat

Number of debris items found per 1-mile segment of coastline, shown with reef habitats



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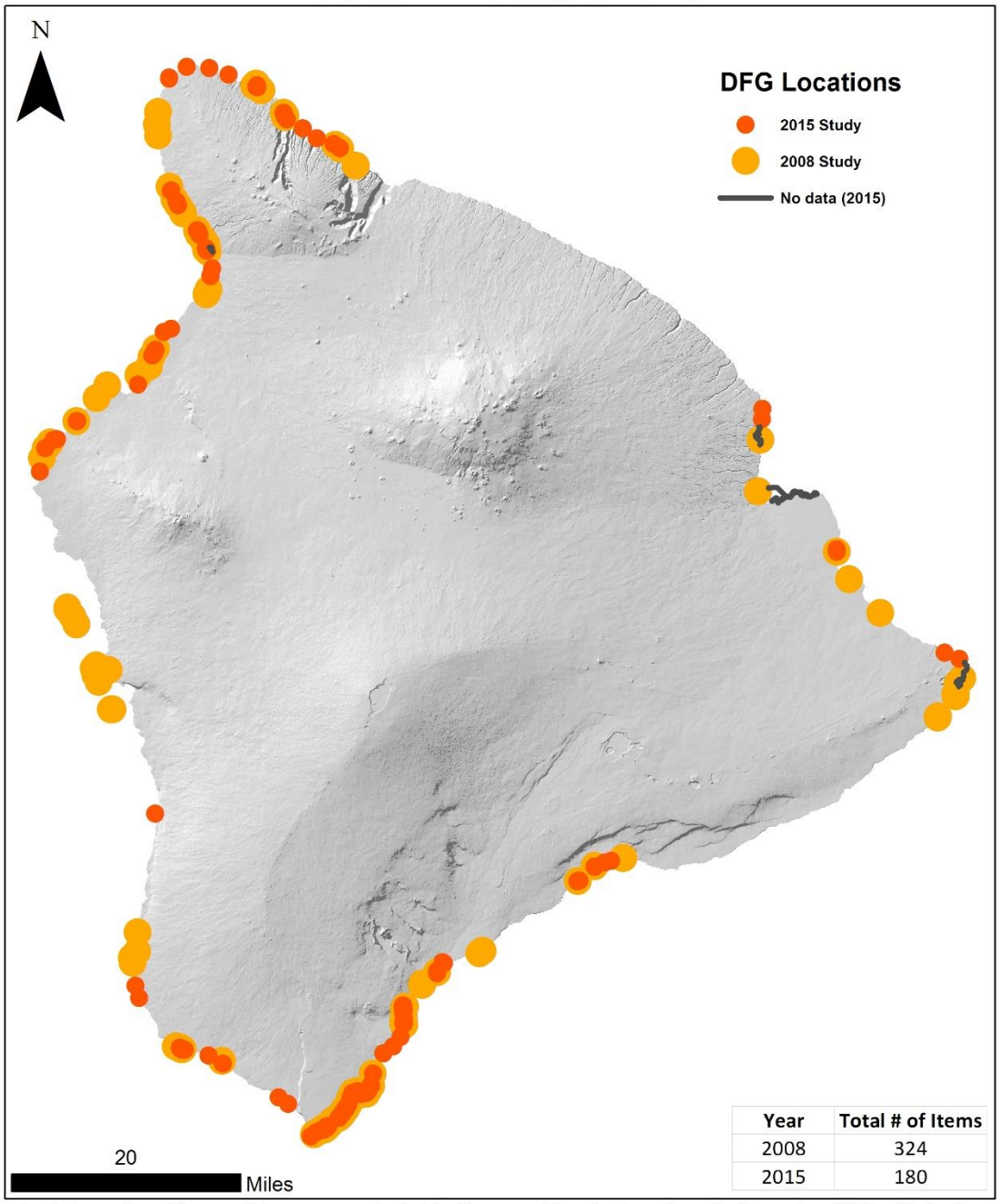
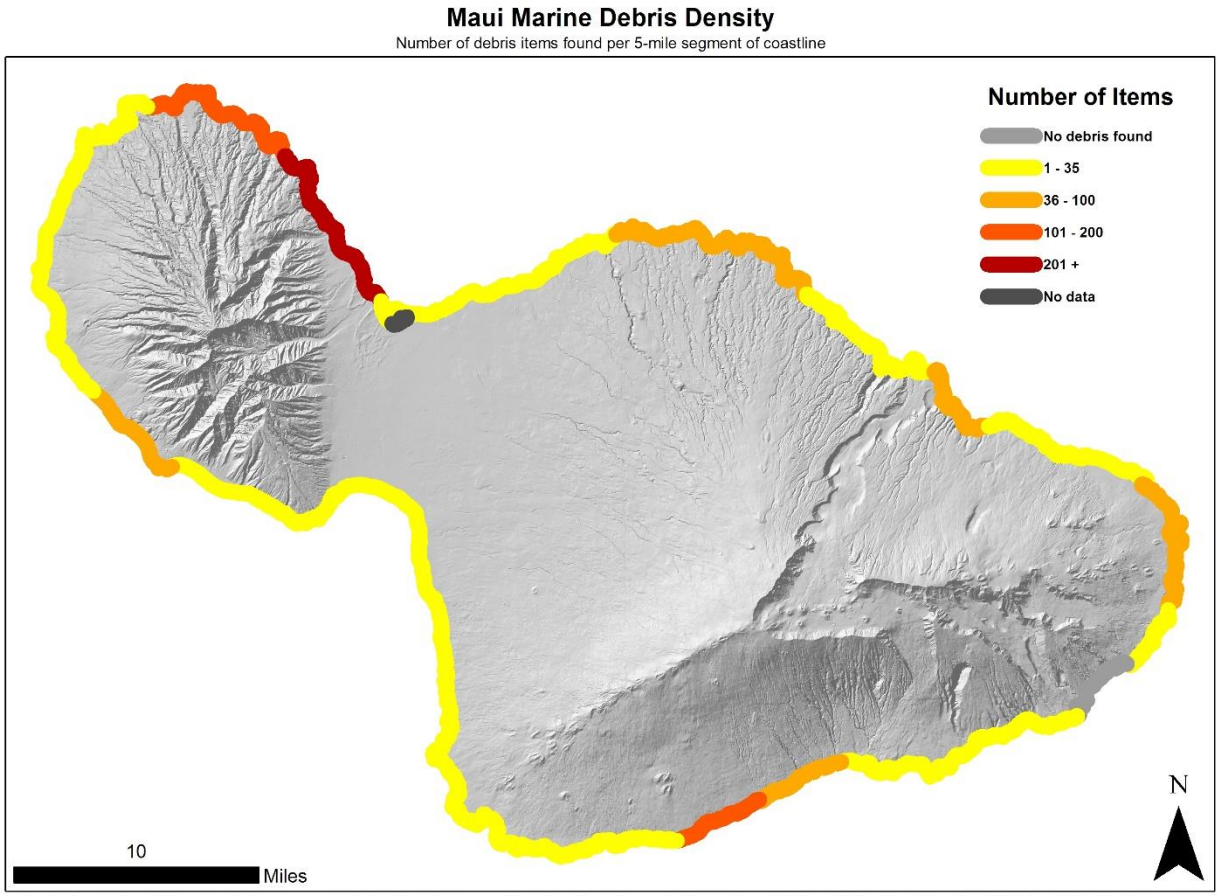
Hawai‘i Island Derelict Fishing Gear

Comparing the 2008 NOAA study to current findings



Year	Total # of Items
2008	324
2015	180

Analysis produced from aerial surveys conducted by Resource Mapping from August - November, 2015, with funding from the Ministry of the Environment of Japan through Hawaii Department of Land and Natural Resources (DLNR) and the North Pacific Marine Science Organization (PICES). GIS analysis performed by the University of Hawaii, Social Science Research Institute, Hawaii Coral Reef Initiative, with funding from Japanese Gift Funds through DLNR.



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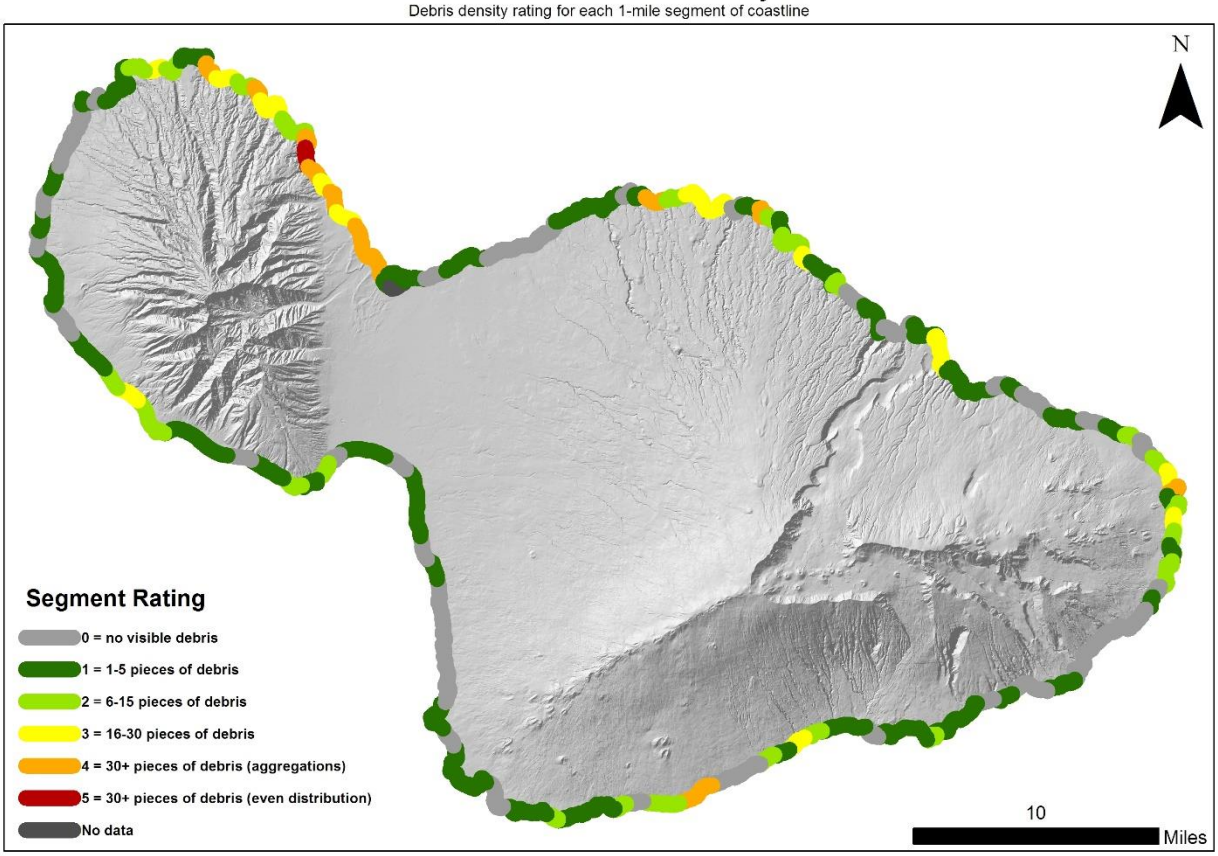
Maui

Maui Marine Debris Density

Debris density rating for each 1-mile segment of coastline



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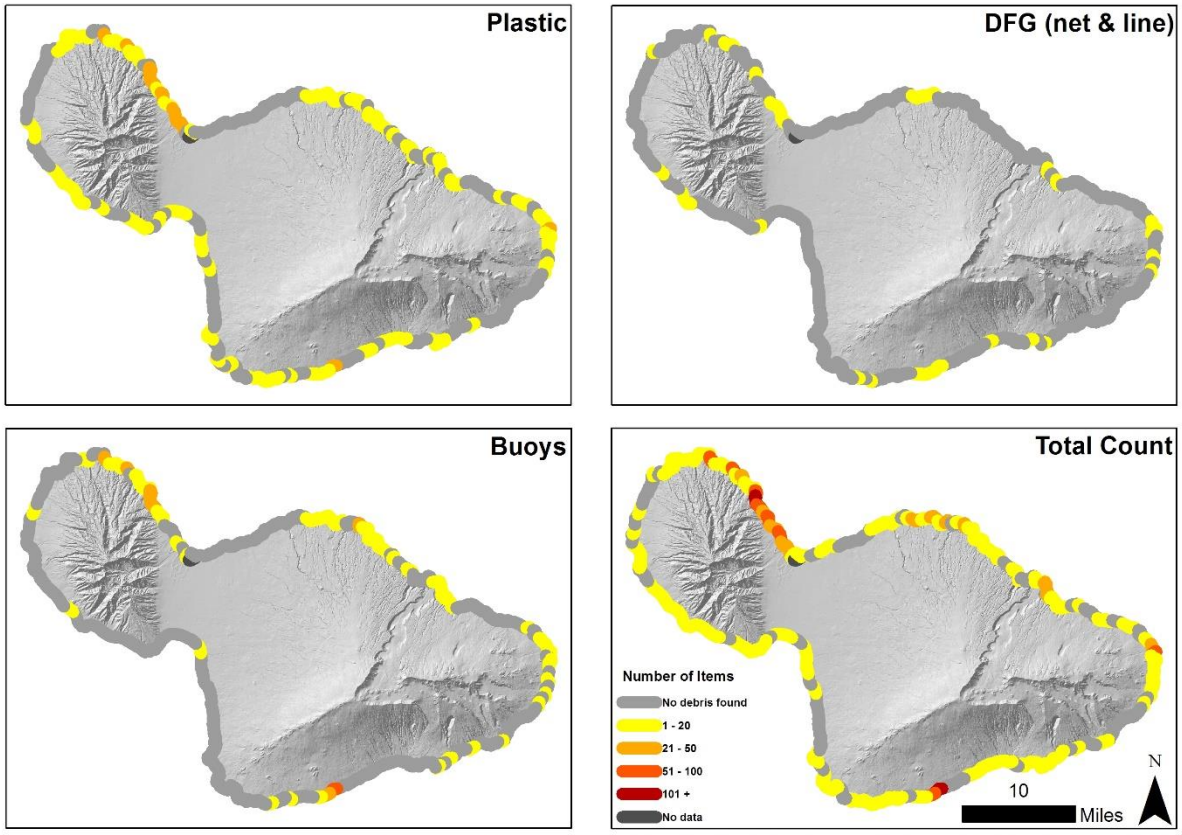
Maui Marine Debris Density by Item Type

Number of debris items per 1-mile segment of coastline for three main debris types



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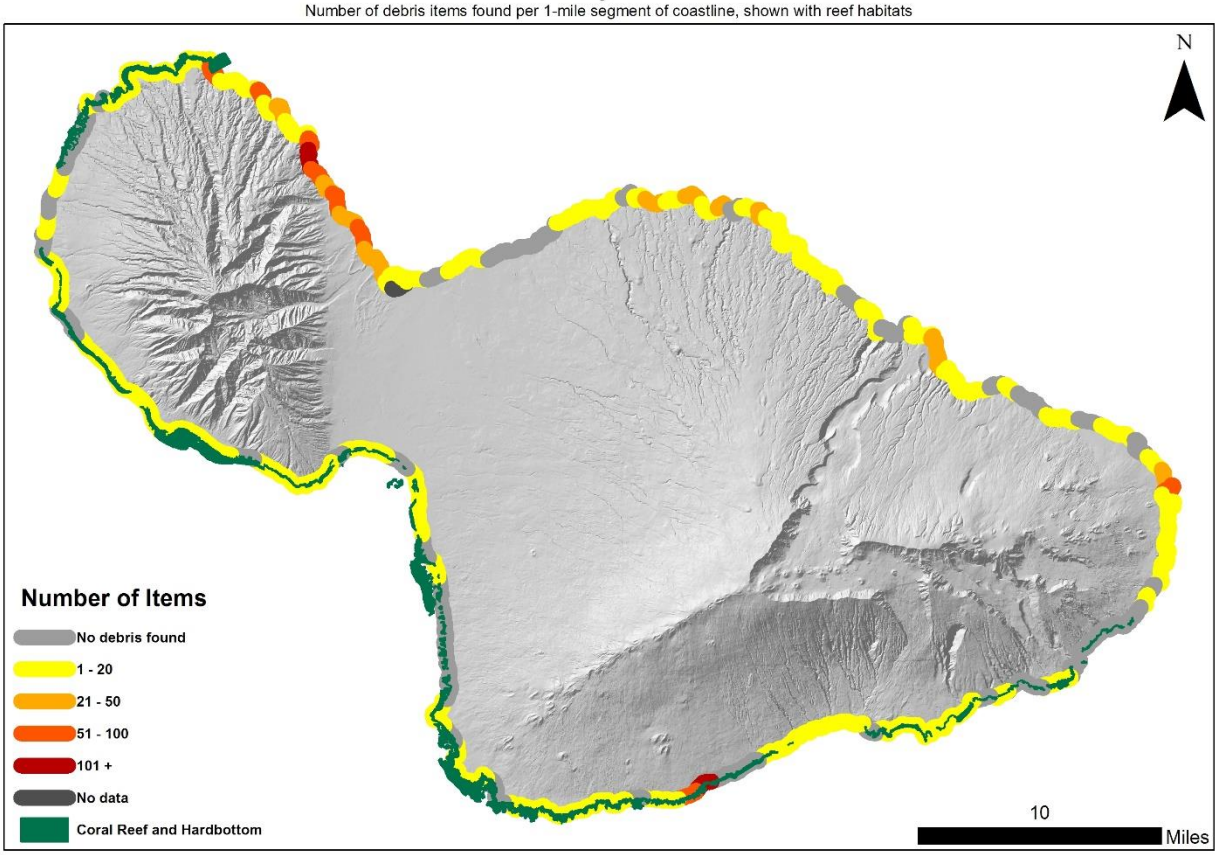
Maui Marine Debris Density in Relation to Reef Habitat

Number of debris items found per 1-mile segment of coastline, shown with reef habitats



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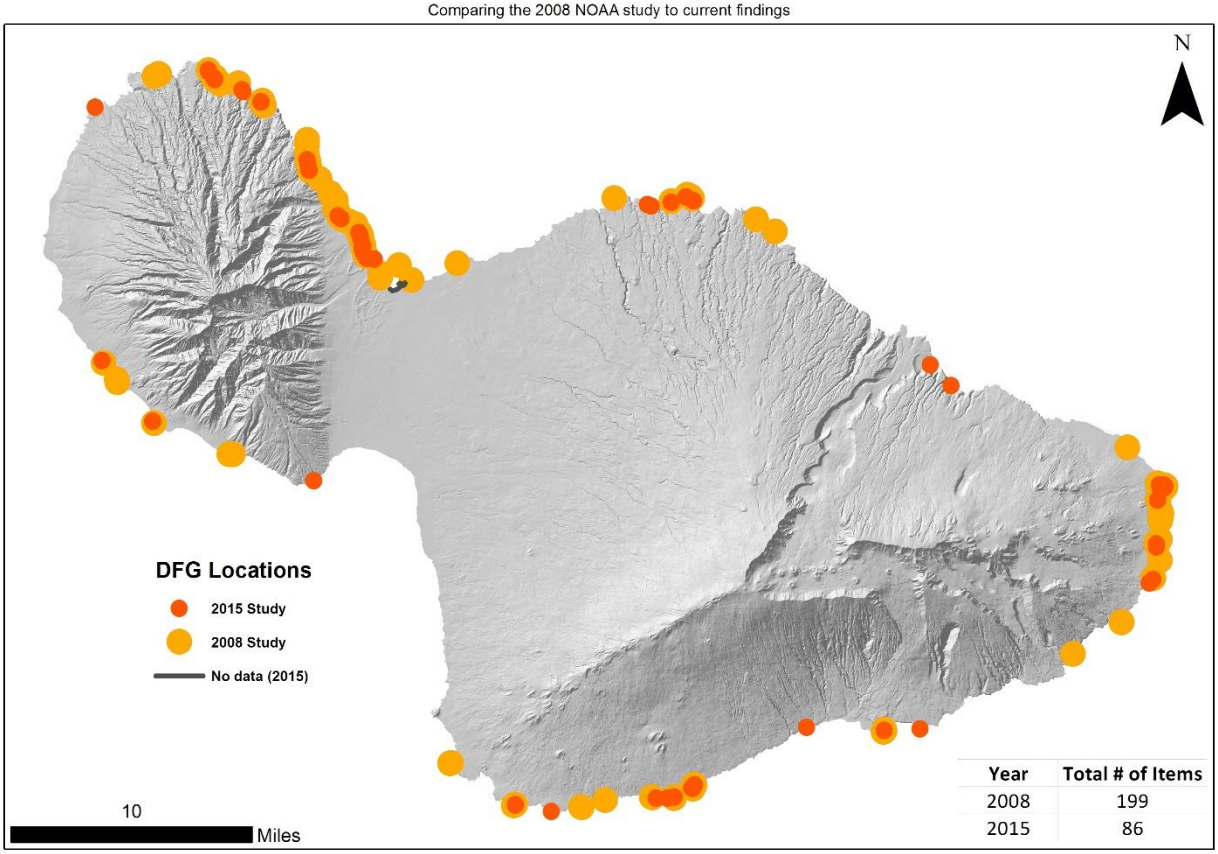
Maui Derelict Fishing Gear

Comparing the 2008 NOAA study to current findings



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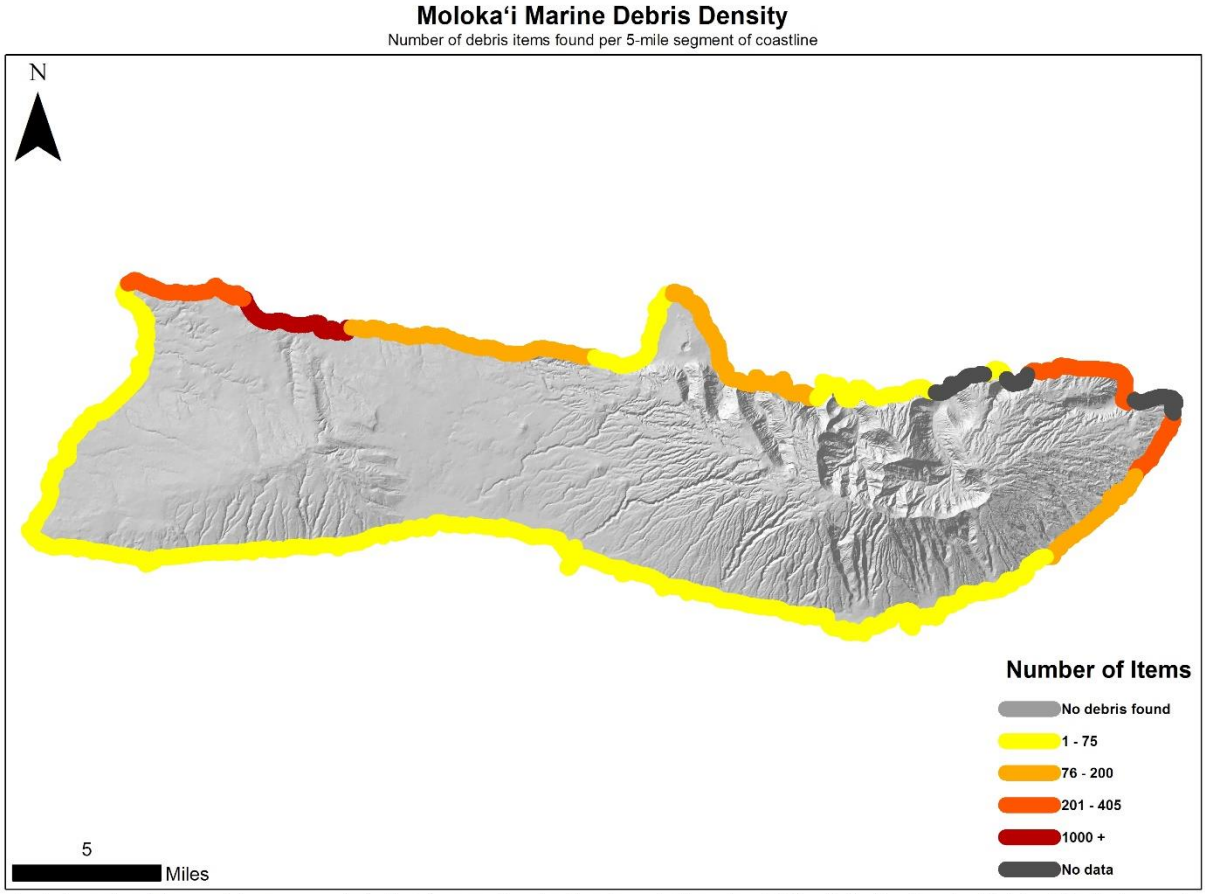
Moloka‘i



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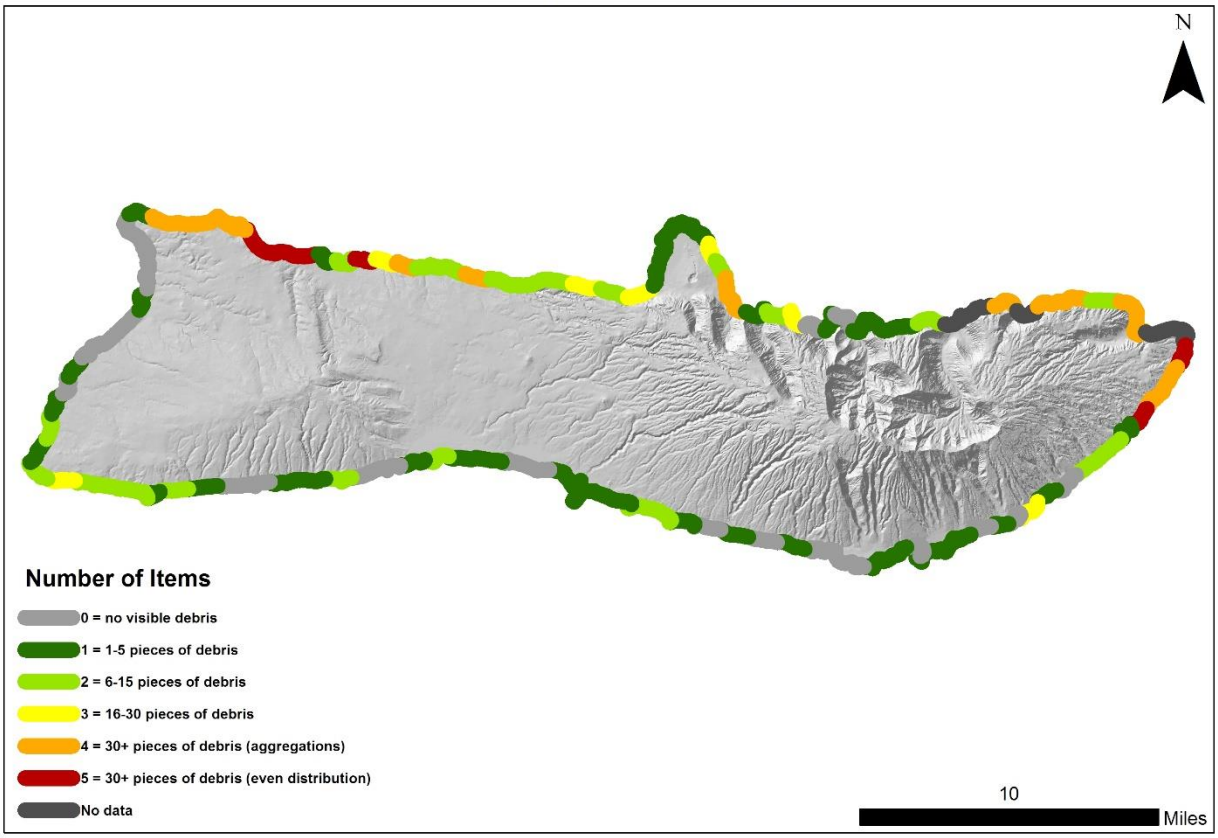
Moloka‘i Marine Debris Density

Debris density rating for each 1-mile segment of coastline



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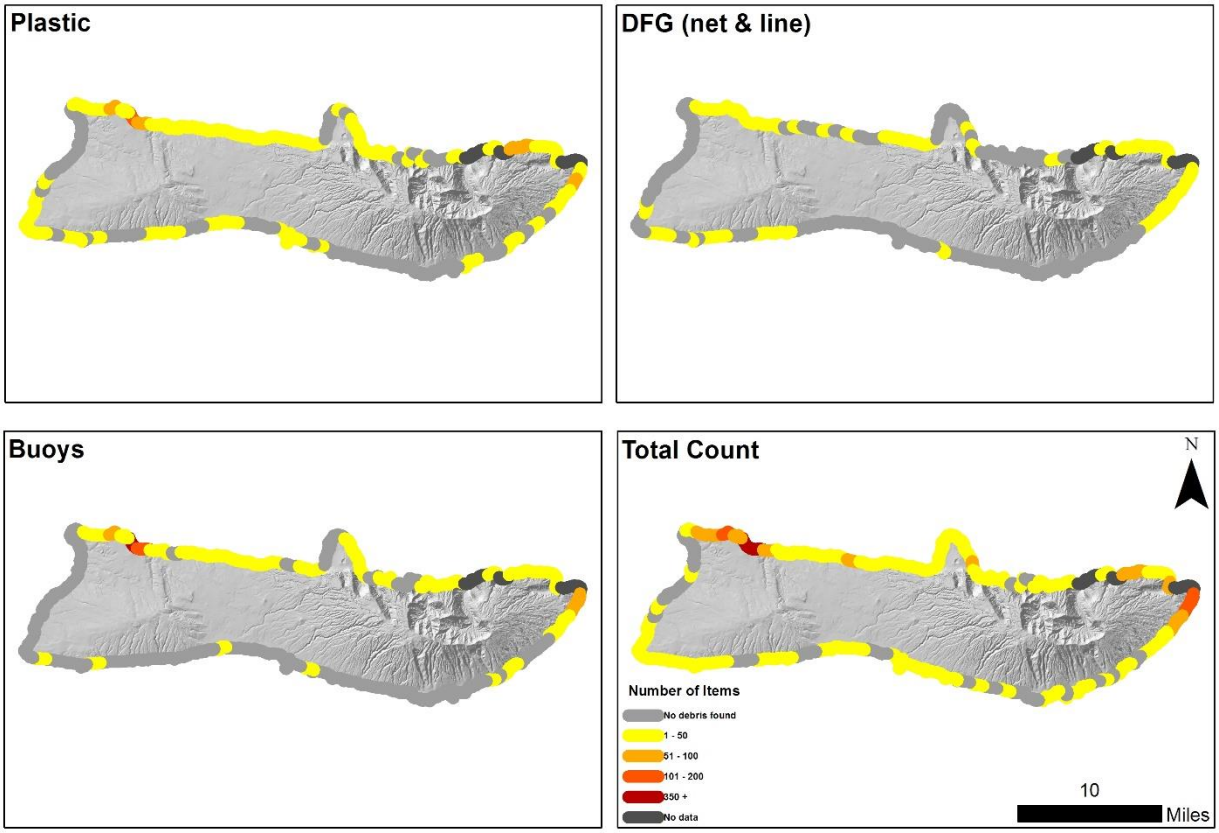
Moloka‘i Marine Debris Density by Item Type

Number of debris items per 1-mile segment of coastline for three main debris types



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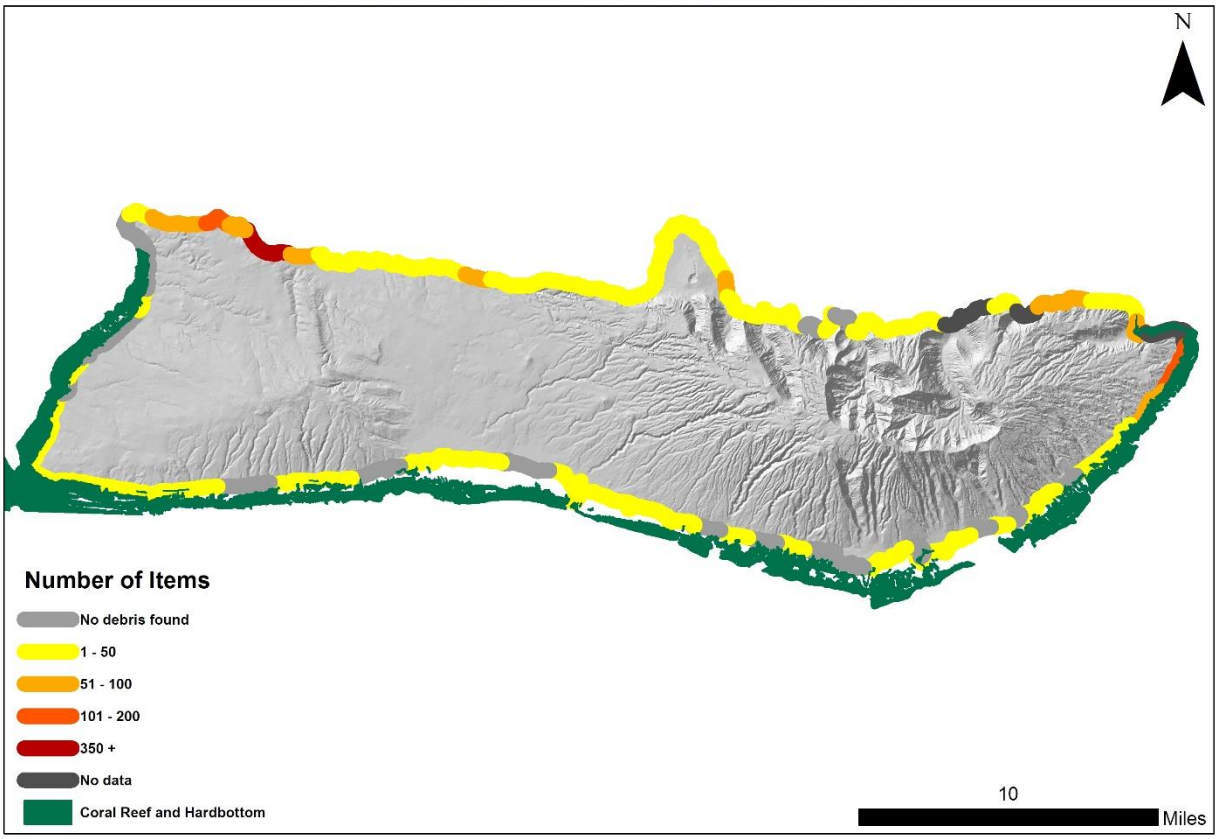
Moloka‘i Marine Debris Density in Relation to Reef Habitat

Number of debris items found per 1-mile segment of coatline, shown with reef habitats



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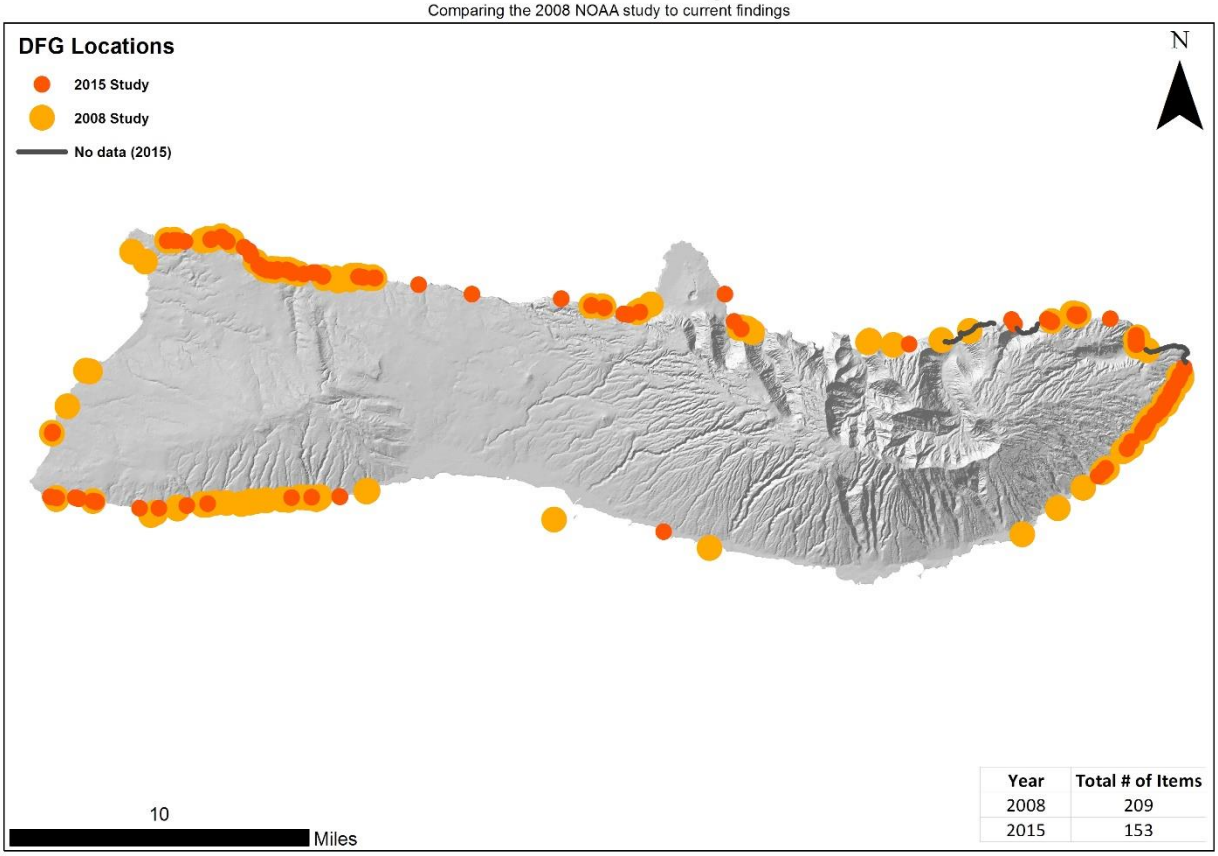
Moloka‘i Derelict Fishing Gear

Comparing the 2008 NOAA study to current findings



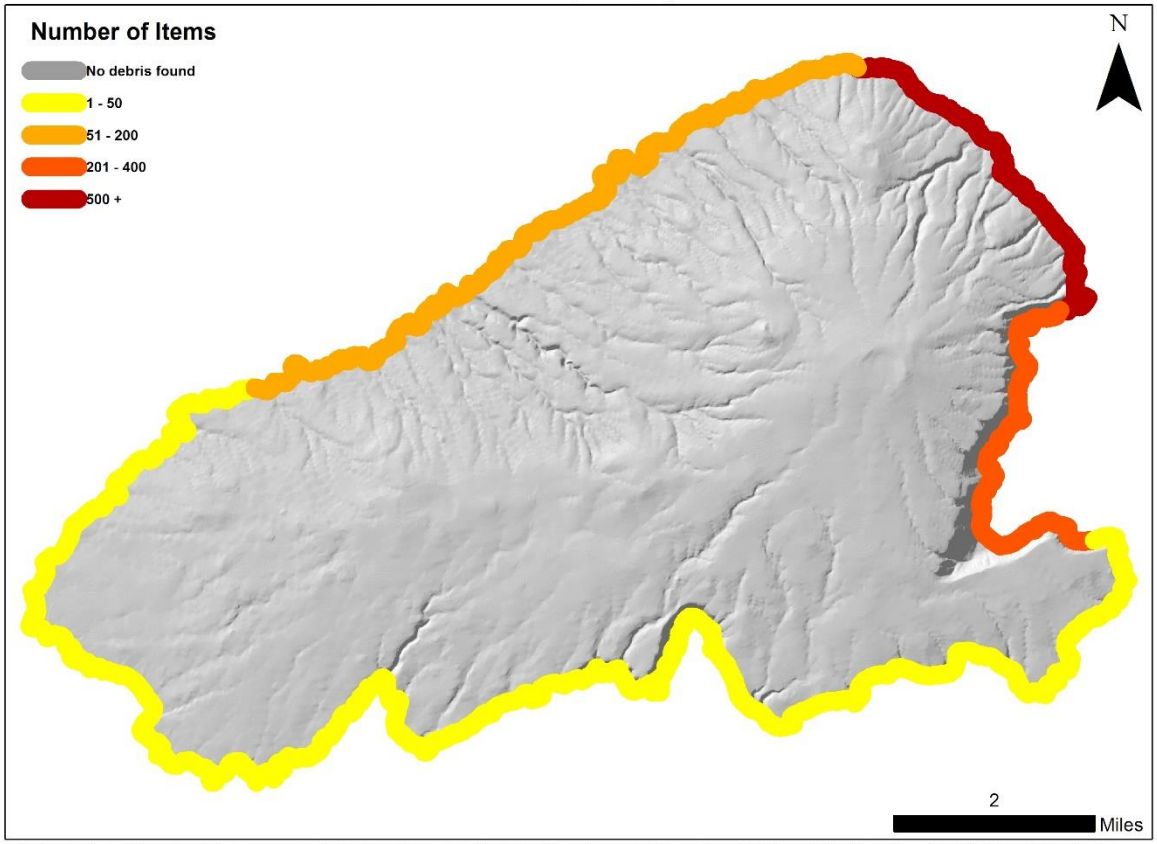
Year	Total # of Items
2008	209
2015	153

Analysis produced from aerial surveys conducted by Resource Mapping from August - November, 2015, with funding from the Ministry of the Environment of Japan through Hawaii Department of Land and Natural Resources (DLNR) and the North Pacific Marine Science Organization (PICES). GIS analysis performed by the University of Hawaii, Social Science Research Institute, Hawaii Coral Reef Initiative, with funding from Japanese Gift Funds through DLNR.

Kahoʻolawe

Kahoʻolawe Marine Debris Density

Number of debris items found per 5-mile segment of coastline



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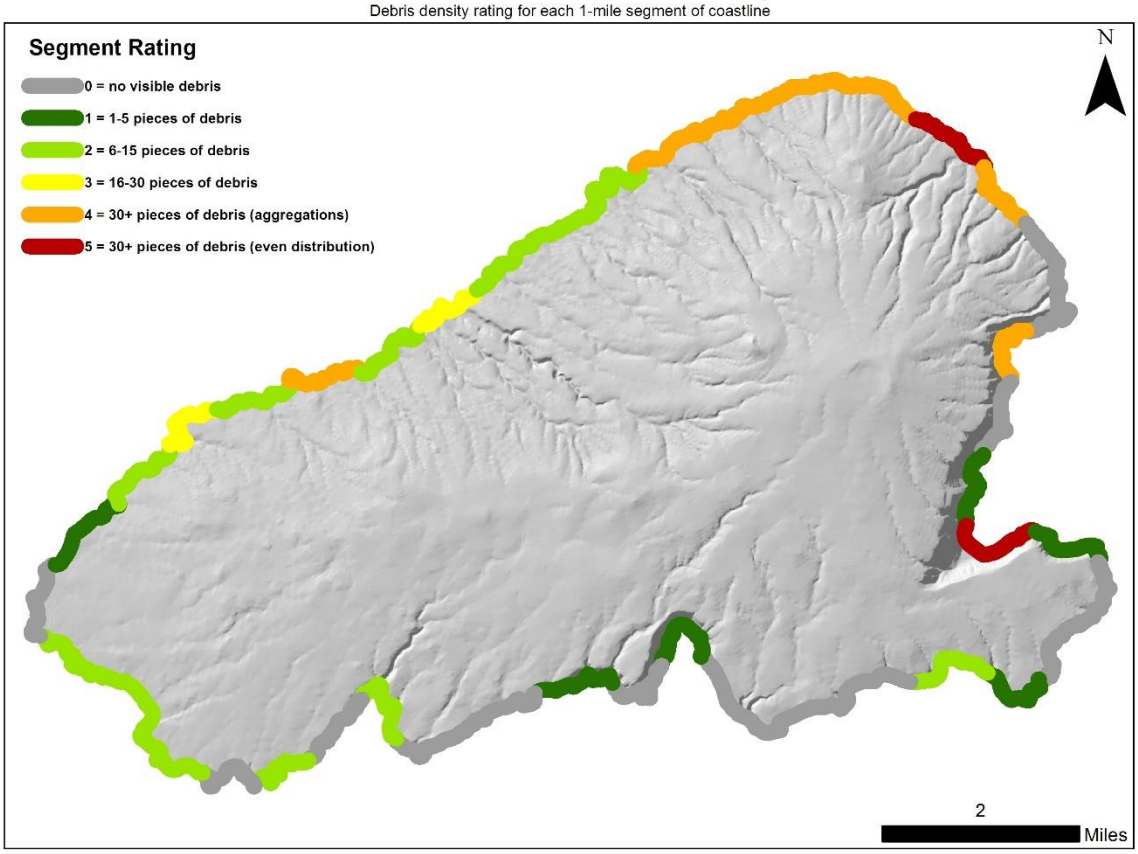
Kaho‘olawe Marine Debris Density

Debris density rating for each 1-mile segment of coastline



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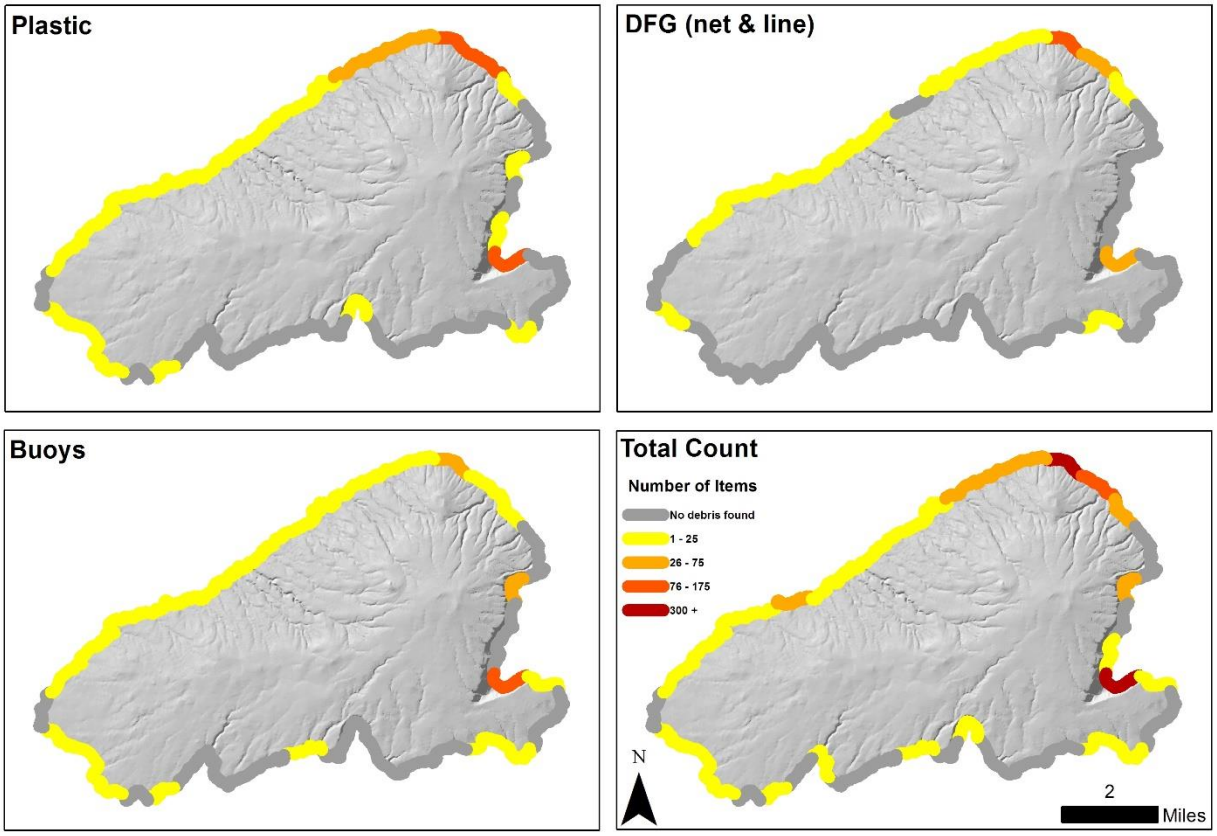
Kaho‘olawe Marine Debris Density by Item Type

Number of debris items per 1-mile segment of coastline for three main debris types



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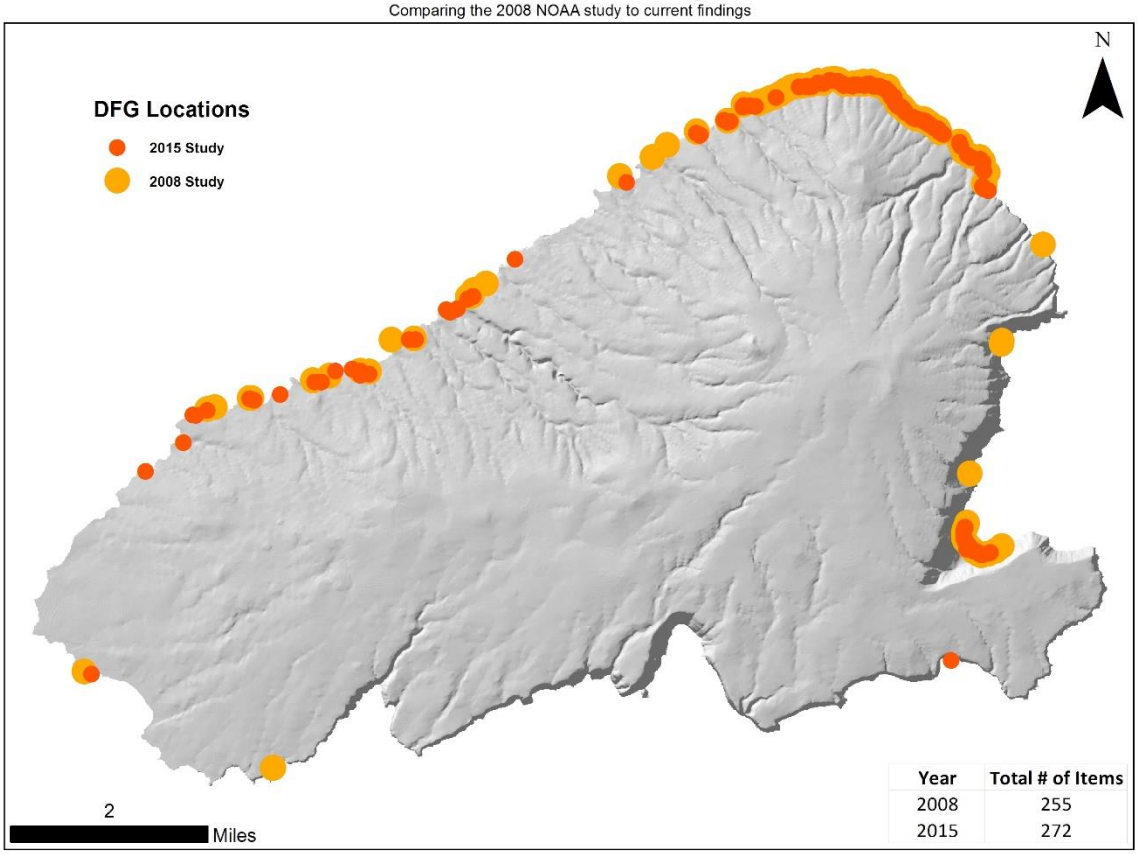
Kaho‘olawe Derelict Fishing Gear

Comparing the 2008 NOAA study to current findings



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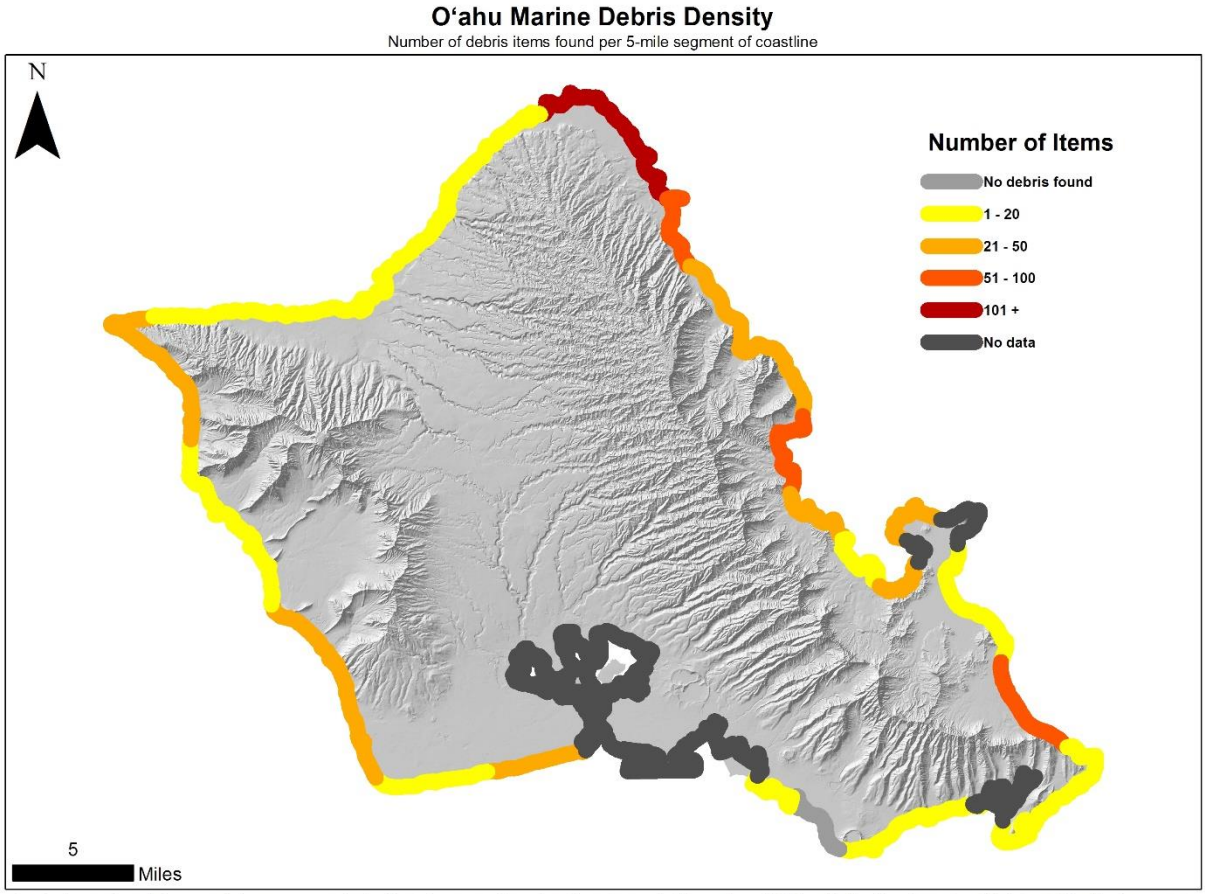
O‘ahu



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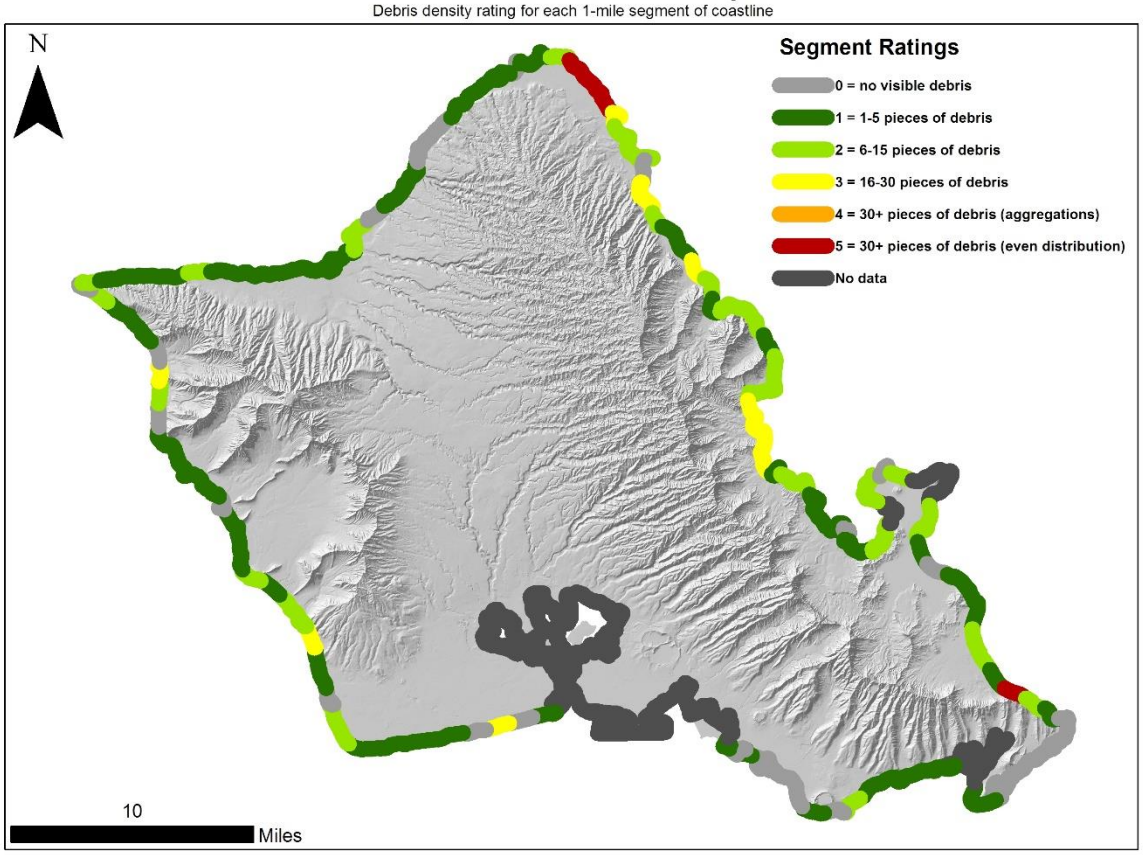
O‘ahu Marine Debris Density

Debris density rating for each 1-mile segment of coastline



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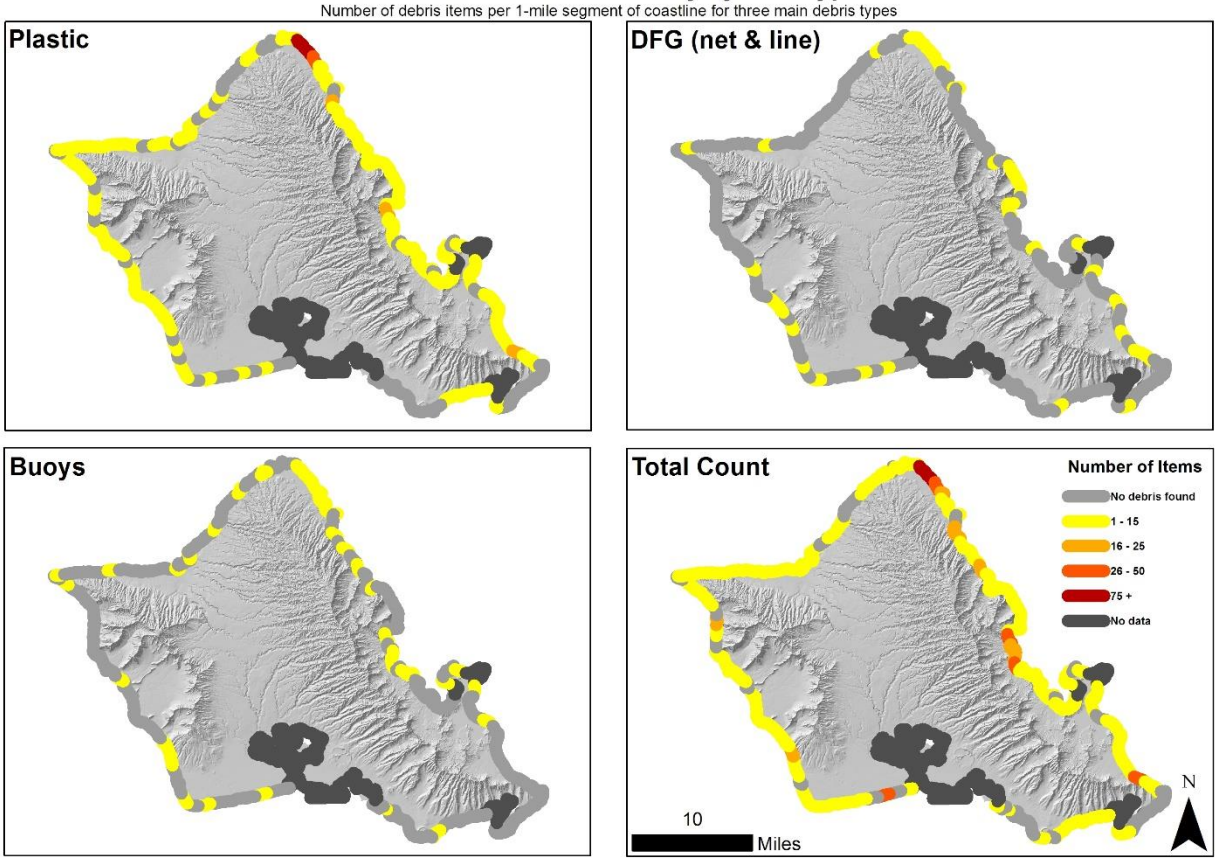
O‘ahu Marine Debris Density by Item Type

Number of debris items per 1-mile segment of coastline for three main debris types



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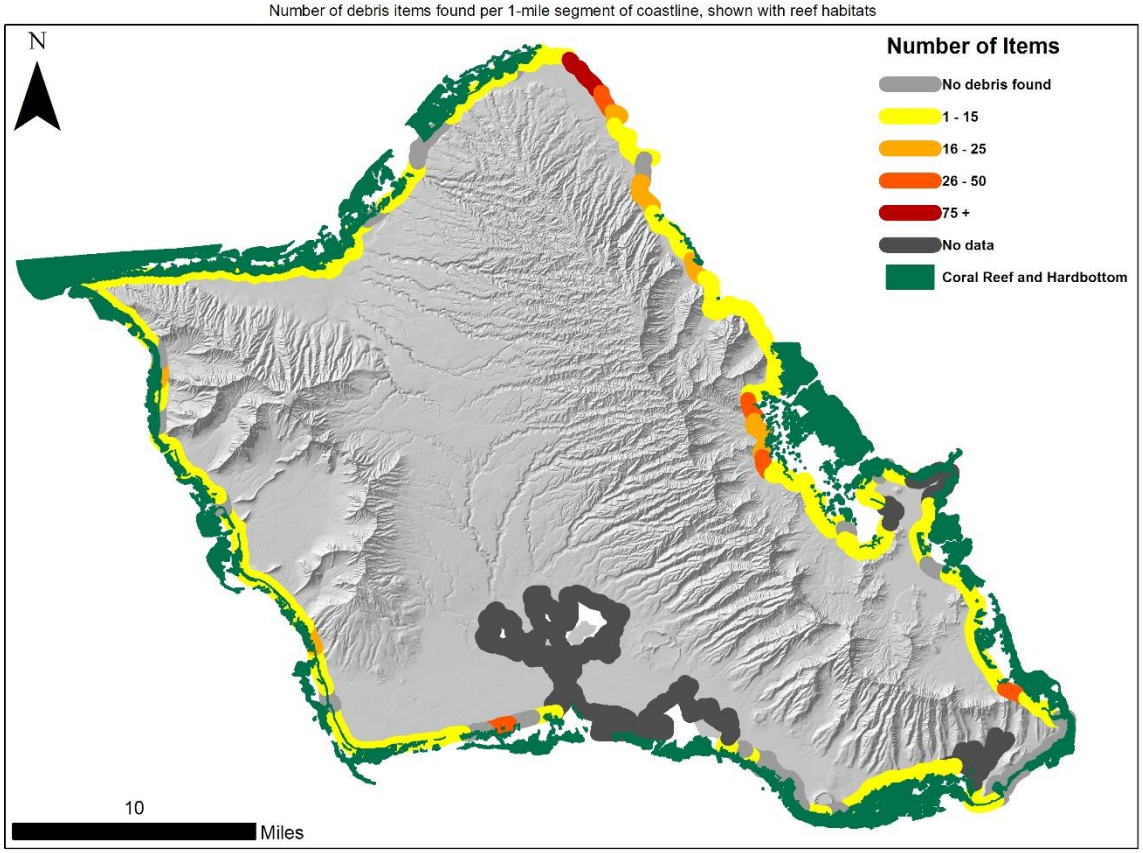
O‘ahu Marine Debris Density in Relation to Reef Habitat

Number of debris items found per 1-mile segment of coastline, shown with reef habitats



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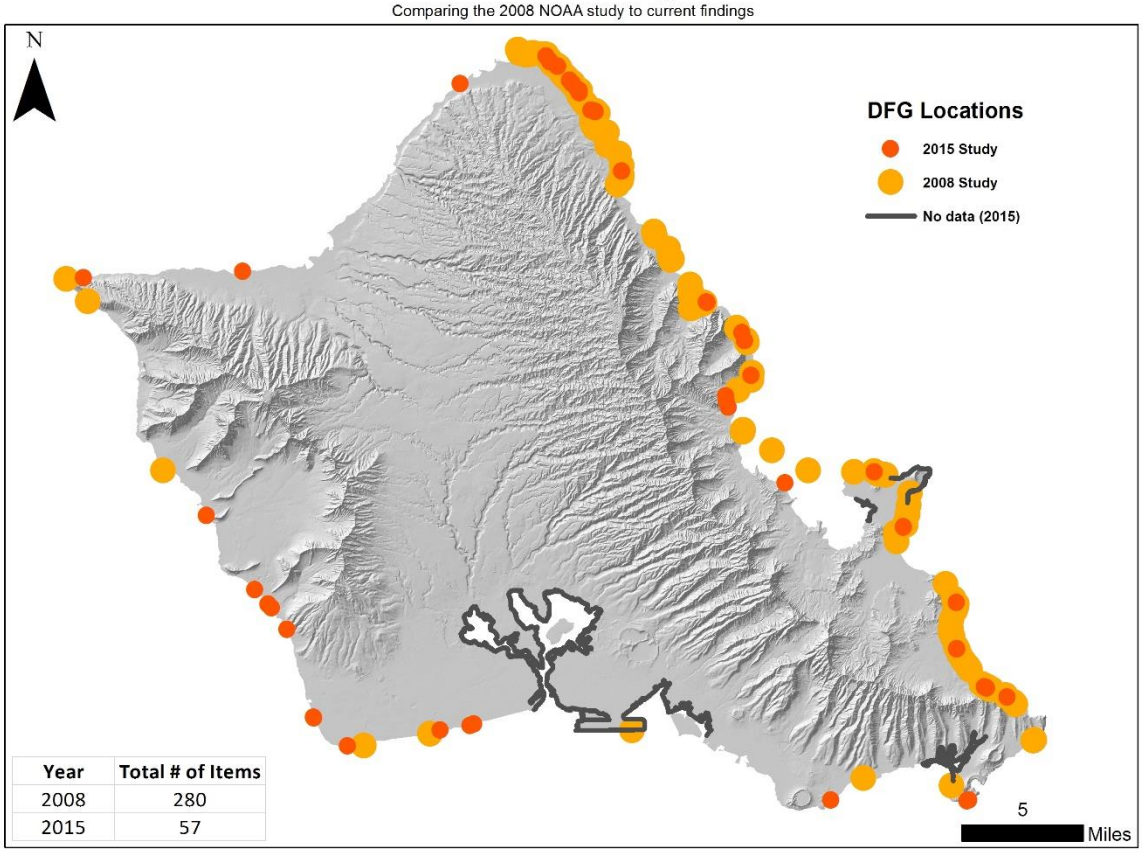
O‘ahu Derelict Fishing Gear

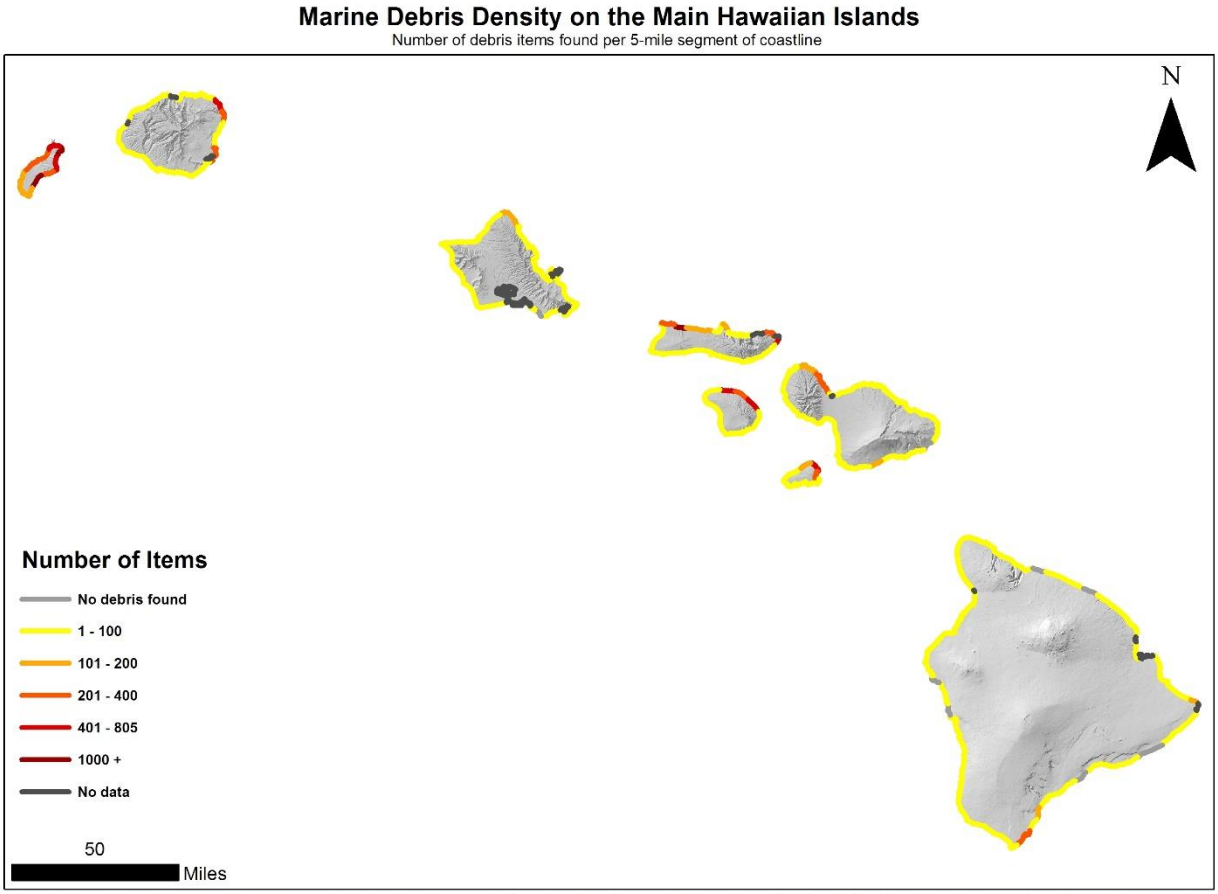
Comparing the 2008 NOAA study to current findings



Year	Total # of Items
2008	280
2015	57

Analysis produced from aerial surveys conducted by Resource Mapping from August - November, 2015, with funding from the Ministry of the Environment of Japan through Hawaii Department of Land and Natural Resources (DLNR) and the North Pacific Marine Science Organization (PICES). GIS analysis performed by the University of Hawaii, Social Science Research Institute, Hawaii Coral Reef Initiative, with funding from Japanese Gift Funds through DLNR.

Main Hawaiian Islands



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Appendix B. Examples of types of marine debris

Buoys and Floats:

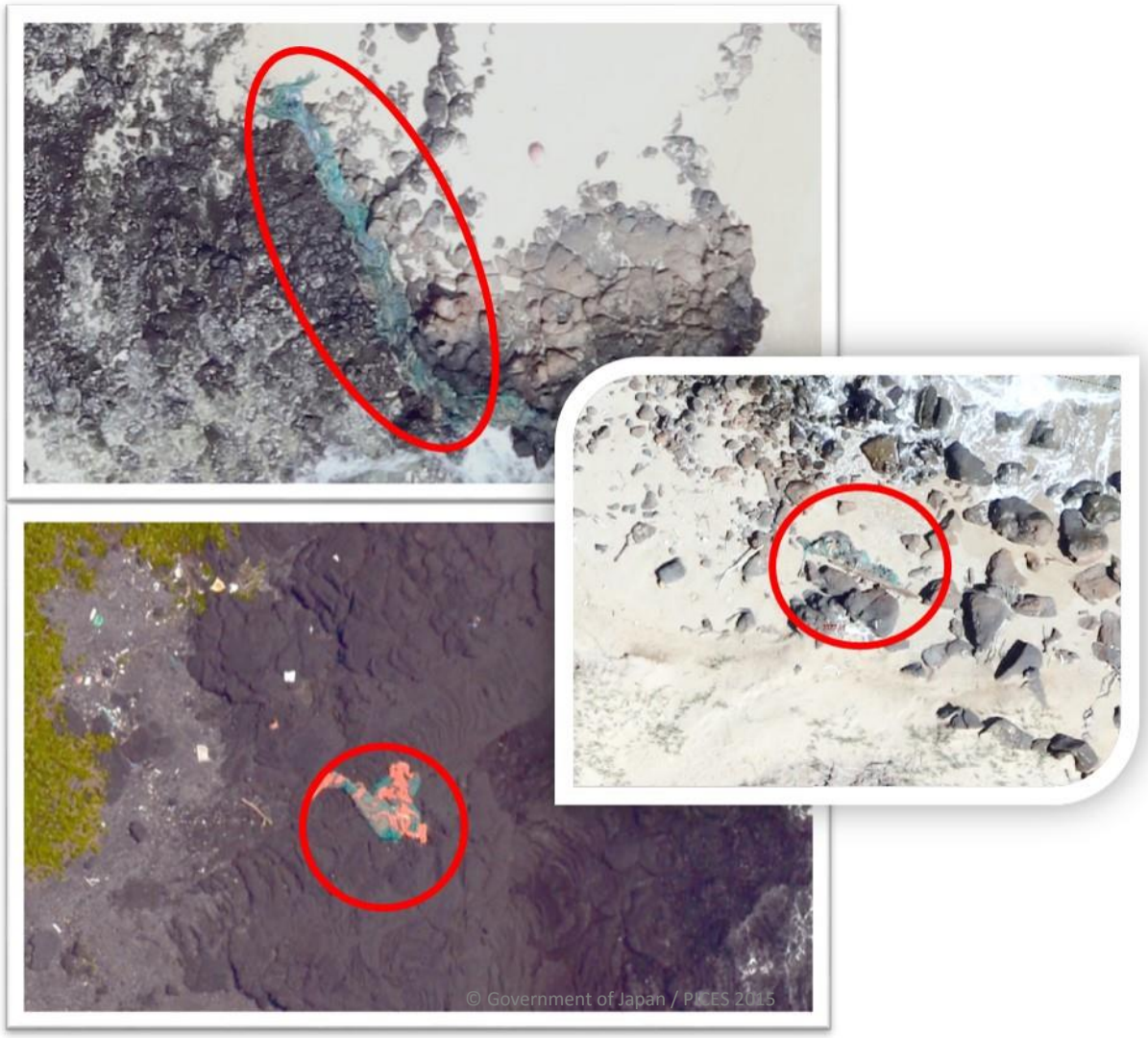
Cloth:

Foam:

Line:

Metal:

Net:



Plastic:

Tire:

Wood:

Vessel:

Inconclusive:

Appendix C. Quality Control Protocols

1. QC was performed on 1-mile coastline segments. 20% of the line segments for each island were selected at random using a random number generator.
2. Marine debris observers were not made aware of which line segments are designated as QC segments until after that segment has been completely processed.
3. Marine debris was identified in the QC segments in the exact same way as the original analysis, but with a different observer from the original analyst.
4. Once a QC line segment was fully processed, it was compared against the original and discrepancies between the datasets were quantified.

To quantify how consistently observers identified debris, percent accuracy was used:

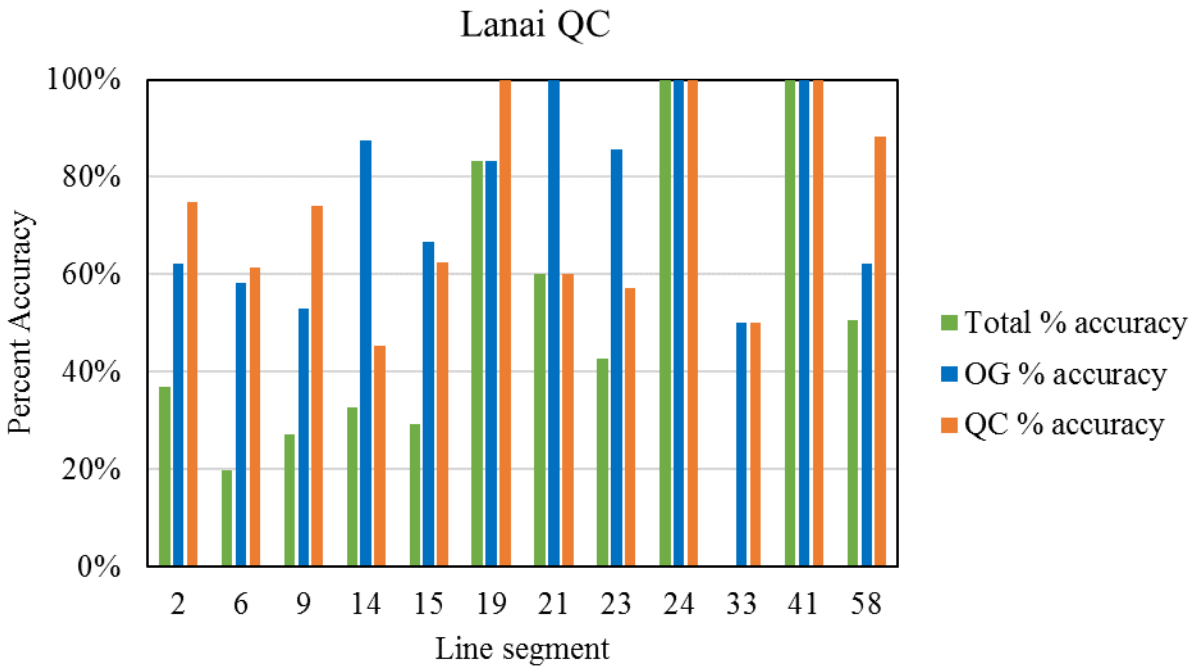
$$\text{Original analysis \% accuracy} = \frac{total\ debris\ identified - debris\ only\ indtified\ in\ QC}{total\ debris\ identified} * 100$$

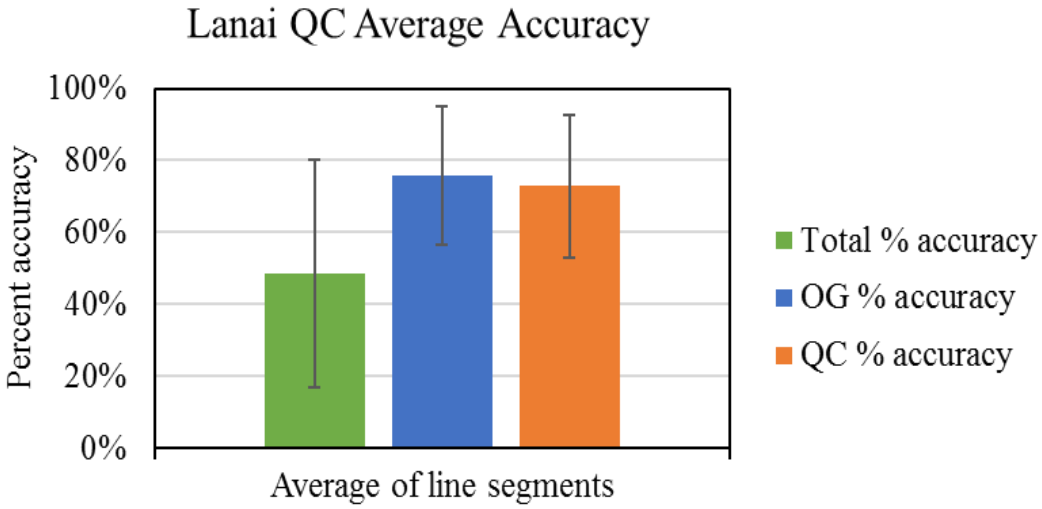
$$\text{QC analysis \% accuracy} = \frac{total\ debris\ identified - debris\ only\ indtified\ in\ OG}{total\ debris\ identified} * 100$$

$$\text{Total \% accuracy} = \frac{total\ debris\ identified - debris\ only\ indtified\ in\ QC\ and\ OG}{total\ debris\ identified} * 100$$

QC Results Summary:

Accuracy increased in later analyses and the large gap in consistency between the original analysis and QC analysis also decreased. This suggests that observers were becoming more discerning in identifying debris over time. The original and QC analysis had a statically similar percent accuracy (ANOVA, $F = 0.14$, $p = 0.72$), there was little variation between the two separate analyses in the number of debris items identified. However, there was a statistically significant difference in the total debris items identified between the two analyses (ANOVA, $F = 4.53$. $p = 0.02$). Therefore, observers should be aware of commonly overlooked items and natural items that are commonly identified as debris.





The QC process in the formation of the following marine debris identification rules:

1. If you can make out clear features of the target debris, then count it. If the object is <0.2m2 and ambiguous, disregard the item as inconclusive

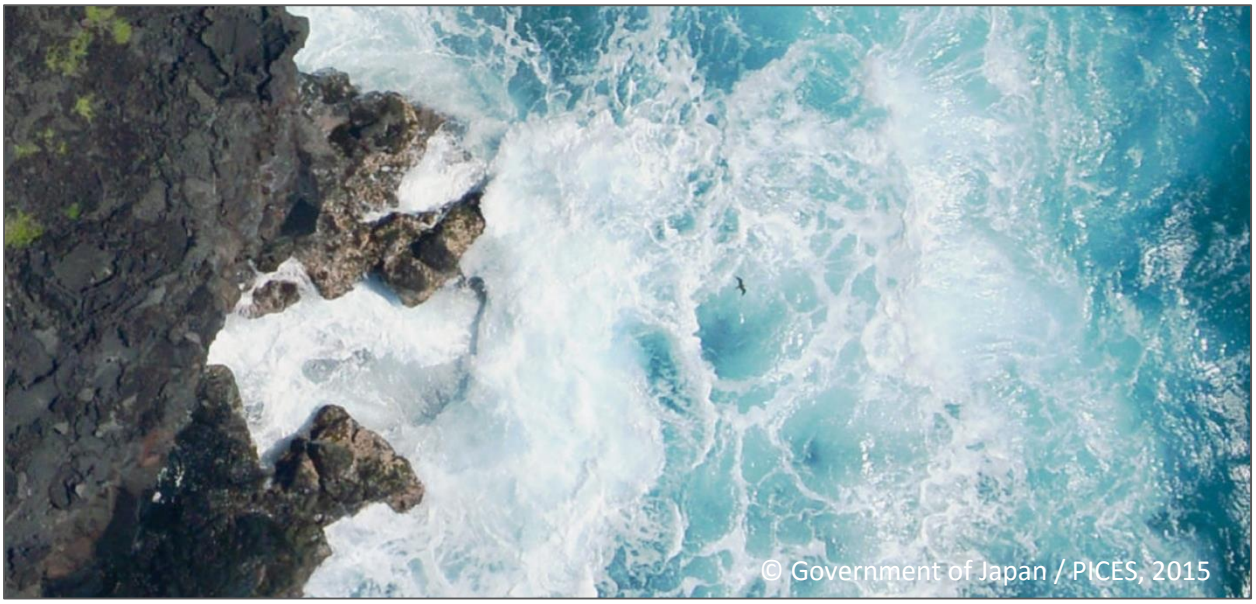
2. On most sand beaches, there is a line of small items washed up by the tide. If there is debris seaward of the high tide line, count it. If it is clear that the waves have washed the debris past the high tide line (you can see water marks and a line of debris past the high tide line), then count it. If the debris is landward of the high tide line, disregard the item as inconclusive.

3. When classifying the segments according to the debris rating, “evenly distributed” means, “are there clear areas of debris and no debris?”. If so, the segment is not evenly distributed. However, if there are not clear gaps between debris and beach, then that means the segment is evenly distributed. Also, if there is equal spacing between debris, then that segment is evenly distributed.

4. Any object that is a ‘natural’ color (white, beige, brown) has the potential to be a natural feature (coconut, driftwood, rock). Marine debris should be identified based on its shape (jagged edges, spherical, large objects), color (bright or ‘unnatural’ colors), and size (can range, but very large objects are likely to be debris).

5. If there is a clump or pile of debris, label each individual item as best you can. Marking each item is important for the final debris density statistics.

6. If it has rounded edges, it is most likely driftwood. If it has square edges, it is probably processed.



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