Spatial analysis of marine turtle stranding data in the Hawaiian Islands for the period 2002 -2007: Is turtle health an indicator of environmental quality?

by

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Capstone Project

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Abstract

Geographic Information Systems (GIS) is becoming a very important and useful tool in conservation planning and is applied here to examine the relationship between marine turtles and their environment in the Hawaiian Islands. This project spatially analyzed the locations of marine turtle strandings reported in Hawaii over a six-year period (2002 – 2007). The data include location, assigned cause of stranding, and other related characteristics relevant to the strandings such as presence of Fibropapillomatosis (FP, a tumor-forming disease) and evidence of fishing gear interaction. The use of spatial analysis for both coastal fishing gear interactions and hawksbill turtle strandings was useful for a visual representation of these events; however, no significant patterns were discovered. The spatial analysis of the stranding data in combination with environmental parameters proved most interesting. Overall, there is a strong correlation between FP-related strandings and areas of limited water quality and human population, respectively, and a moderate correlation between FP-related strandings and agricultural lands. A high prevalence of FP has been shown in previous studies to correspond to coastal waters characterized by habitat degradation and pollution, suggesting that one or more of these factors could serve as an environmental cofactor in the development of FP. A clear target for mitigation strategies that would benefit not only marine turtles afflicted with this disease, but all other organisms that share the same ecosystem, is water quality improvement in coastal areas of the Hawaiian Islands.

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Introduction

Geographic Information Systems (GIS) is a tool that can be used to assimilate data and spatially examine distribution of events over an area. GIS is becoming a very important and useful tool in conservation planning, since sound environmental management relies on studying and protecting areas utilized by various species. Additional information about species, environmental parameters, and a fine-scale resolution can be generated using GIS that is complimentary to other forms of analyses. GIS is applied here to examine the relationship between marine turtles and their environment in the Hawaiian Islands.

Marine turtle stranding data have been systematically collected and recorded in the Hawaiian Islands since 1982 by the National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Marine Turtle Research Program centered in Honolulu, Hawaii (Murakawa et al. 2000). The majority of data are from Hawaiian green turtles, *Chelonia mydas,* with a minority from hawksbill turtles, *Eretmochelys imbricata* (Chaloupka et al. 2008). The green turtle population in Hawaii (the most abundant species found in nearshore waters around the islands) is categorized as Threatened, and the hawksbill turtle population as Endangered, under the U.S. Endangered Species Act. While recent data suggest the Hawaiian green turtle population is on the road to recovery (Balazs and Chaloupka 2004), there are still anthropogenic and natural threats to the survival of marine turtles that are a concern for scientists and policy managers. A spatial analysis of these threats may help the organizations charged with marine turtle research and protection by providing additional information to develop or improve mitigation strategies. These methods may also be useful to managers of other marine protected species or areas.

Earlier years of the data used in this analysis were previously analyzed as a means to describe causes of mortality for Hawaiian marine turtles, population trends, and disease implications. A recent publication analyzed spatial and temporal trends in strandings from this dataset for the period 1982 – 2003 utilizing the primary cause of stranding and advanced statistical methods (Chaloupka et al. 2008). The results of this study include a detailed summary of temporal trends in strandings, mortality related to various causes of stranding, and a comprehensive summary of causes of marine turtle strandings. Work et al. (2004) utilized GIS analysis to examine spatial distribution of 255 stranded marine turtles that were afflicted with fibropapillomatosis (FP), a tumor-forming disease. Strandings were mapped by age, sex, disease severity, and time, but no patterns were detected. Strandings were clustered on Oahu and Maui, the two most populous islands, but again, no explanation was detected beyond natural environmental factors (winds and currents).

FP, as the cause of stranding, is the focus of this paper. This disease primarily affects green turtles but has been documented in every species of marine turtle worldwide (Aguirre and Lutz 2004). FP is a tumor-forming disease that ranges from a mild to severe affliction. With more severe cases, the tumors impair the turtles' ability to see, feed, or move and can be quite debilitating. Tumors are commonly found on internal organs impairing their function and can cause turtles to strand or die (Work 2004). FP has been associated with an alpha-herpesvirus specific to marine turtles, but much is still unknown, including the causative agent (Herbst 1995; Work 2004; Greenblatt et al. 2005). There seems to be an additional environmental factor or stressor, or multiple factors, which contribute to expression of tumors, possibly by weakening the immune system and contributing to the onset of the disease (George 1997) or by exposure to a tumor-promoting substance (Herbst 1994). It is suggested that a high prevalence of FP is associated with increased anthropogenic activity in the environment (Herbst 1994; Foley et al. 2005). Even though marine turtles are physically rugged animals, they are susceptible to biological and chemical insults. Chronic pollution from industrial, agricultural, and urban runoff is a threat to the health of marine turtles in coastal waters (Lutcavage et al. 1997). Green turtles have a strong site fidelity to coastal foraging grounds and a relatively small home range (Brill et al. 1995; Seminoff and Jones 2006) once they recruit to nearshore waters from the pelagic phase of their life cycle. FP has not been documented in newly recruited turtles from pelagic waters (Aguirre et al. 1998), which suggests the disease is related to their coastal environment. Previous attempts to quantify contaminant and trace metal levels in Hawaiian populations of green turtles have not detected any harmful levels present in the tissues examined (Aguirre et al. 1994) with the exception of elevated PCB levels (Miao et al 2001). However, knowledge of contaminant effects on the unique physiology of marine turtles is limited (George 1997), and thus, these previous studies often compare their findings to baseline levels of other marine species or reptiles.

While FP contributes to the majority of marine turtle strandings in the Main Hawaiian Islands with an attributable cause, coastal fishing gear is the major anthropogenic cause of strandings, and turtle-fishing gear interactions have been increasing since 1982 (Chaloupka et al. 2008). These general categories include hooks, fishing line entanglement or ingestion, or gillnet entanglement. The probability of mortality associated with coastal fishing gear is nearly five times lower than the mortality associated with FP (Chaloupka et al. 2008). The State of Hawaii restricted the use of gillnets in many state waters in March 2007. This action may have mitigation impacts and declining trends in coastal net entanglement may be detected in the future.

The purpose of this project is to spatially analyze the dataset that describes GPS locations of all marine turtle strandings reported in Hawaii over a six-year period (2002 – 2007). The data include location, assigned cause of stranding, and other related characteristics relevant to the strandings such as presence and severity of disease, species, morphometrics, and evidence of fishing gear interaction. These characteristics can be isolated and represented visually, and analyzed with respect to spatial location and trends. As green turtles are the most abundant nearshore species in Hawaiian waters, they make up the majority of cases analyzed and all of the FP cases. Environmental parameters related to water quality were incorporated into this spatial analysis, which has not previously been examined using this dataset.

The State of Hawaii Department of Health (DOH) Clean Water Branch has designated 18 areas of Limited Water Quality, or impaired waters, in the Main

Hawaiian Islands. In each case the designated water body is impaired due to high pollution emissions discharged by nonpoint sources of pollution and consistently do not meet water quality regulations. Characteristics such as turbidity, excessive nutrients, sewage overflow, pesticides, metals, and pathogens are monitored and can contribute to a listing of impaired quality. The DOH states that polluted runoff is mostly due to human activity, and that urban runoff and agriculture are the two main contributors. In this study, urban runoff and agriculture are represented by areas of relatively high human population determined from the U.S. Census Bureau (www.geographynetwork.com) and areas of agricultural land use determined from GIS layers from the State of Hawaii Office of Planning (http://hawaii.gov/dbedt/gis.htm).

The prevalence of FP can be used as a method to monitor ecosystem health in warm-water, coastal habitats (Aguirre and Lutz 2004). Coastal marine turtles most often strand near where they live, and so are reliable representations of the ecosystem they reside in. Understanding the spatial elements of these stranding events and potentially related environmental parameters contributes to stronger management of marine turtle populations and threats.

Methods

Sick, injured, or dead marine turtles regularly strand on the coastline or nearshore in the Hawaiian Islands due to natural and anthropogenic causes. Global Positioning System (GPS) coordinates were collected on each stranding reported to the Marine Turtle Research Program using a Garmin Etrex handheld GPS unit. The precision of the Etrex is approximately 15m. The GPS coordinates for each stranding event were combined in a dataset with other information about the stranding including presence and severity of disease, species, morphometrics, and fishing gear interaction. Missing GPS coordinates were approximated using Google Earth. ArcMap version 9.2 (ESRI Inc.) was used to analyze the data. Eleven cases were not included due to the location of stranding being only the island they were reported from, and 15 cases from the Northwestern Hawaiian Islands were not included. There were 1,635 cases included in this analysis, averaging approximately 250-300 cases per year.

Strandings are reported to a network of responders on Kauai, Oahu, Maui, Molokai, Lanai, and the Island of Hawaii. When Marine Turtle Research Program biologists or trained associates responded to a stranding, data were collected on the turtle's health status, injuries, and basic morphometrics. If a live injured or ill turtle was collected, detailed information from a subsequent veterinary exam was included in the case report. Turtles collected dead or ones euthanized due to illness or injury beyond veterinary treatment were necropsied for further data collection and investigation into cause of stranding. For each stranding event, a formal "Cause of Stranding" was assigned to each case. This formal cause is determined to be the explanation for why the turtle stranded itself for each case. In nearly 38% of cases used in this analysis the cause of stranding was "unknown" due to severe decomposition of the carcass, no apparent cause determined in a gross exam, or insufficient information available in the stranding report. However, data were also collected on other factors found upon examination of the carcass that may not have been attributed to the official cause of stranding. For the purposes of this report, data on factors attributed to each stranding were utilized (particularly presence of tumors, fishing hooks, line, or net entanglement) regardless of whether it was considered a primary cause of stranding.

The data were added to ArcMap as an events layer, then transformed from the World Geographic System 1984 (WGS84) projection used by the Garmin Etrex handheld units to the North American Datum 1983 (NAD83), Universal Transverse Mercator in order to align with other basemaps used. Coastal fishing activity data were obtained from the State of Hawaii Office of Planning and selected for activities that involved hooks, fishing lines, or gillnets in coastal areas. The 3D Analyst Tools were used to develop a human population density map layer using data from the U. S. Census Bureau. Agricultural land use was extracted from the State of Hawaii Land Use shapefile. Areas of limited water quality were approximated based on qualitative descriptions from the DOH and locations of water quality monitoring stations. The 3D Analysis Tools were used to generate a correlation matrix between presence and absence of tumors in all strandings and Limited Water Quality areas, high human population density areas, and agricultural land use areas, respectively. The matrix was a 0-1 scale, with tumored turtles assigned a value of 1, non-tumored or unknown FP-status turtles assigned 0. Areas immediately adjacent or within a 5km buffer of each water quality parameter analyzed were assigned a value 1, and coastal areas not adjacent to those areas assigned a value of 0. Once the matrix was developed, the average correlation coefficient for each island or area could be calculated between the presence or absence of FP-relates strandings and each environmental parameter described. The Spatial Statistics Tools in ArcMap was used to analyze spatial correlations of all strandings, hawksbill strandings, tumored strandings, and coastal fishing gear interactions.

Results

The dataset used for this analysis contained 1,635 stranded marine turtle cases for the period 2002 - 2007. In total, 1,157 were from Oahu (70.8%), 243 from Maui (14.8%), 158 from Hawaii (9.7%), 62 from Kauai (5.4%), 11 from Molokai (0.7%) and 4 from Lanai (0.2%). Nearly 97% of all strandings were green turtles (1,584), 2% were hawksbill turtles (32) and less than 1% were olive ridley turtles (*Lepidochelys olivacea*) or unidentified species of marine turtles.

There were 401 strandings with evidence of coastal fishing gear interactions (24.5% of all strandings). There was no spatial correlation among the stranding events with coastal fishing gear interactions and they were fairly evenly distributed along the coastlines of each island they occurred on (Kauai, Oahu, Lanai, Maui, and Hawaii) with a Moran's I=-0.8 (not significant, Z=-1.37). The stranding locations were overlaid with coastal fishing activity from the State of Hawaii (Fig. 1). There was no apparent relationship between the two data layers. The coastal fishing activity data layer is presence/absence data only.

Distribution of hawksbill turtle stranding locations were mapped, with a subset of hatchling hawksbill turtles (those of 5cm straight carapace length or less) also represented (Fig. 2). There was no spatial correlation of all hawksbill turtle stranding locations, yet a correlation among hawksbill hatchling stranding locations (Moran's I=1.74) but it was not significant (Z=1.76).

Locations of turtles that stranded with tumors were also mapped. Nearly 36% of all strandings involved tumored turtles (n = 580). All turtles that stranded with tumors were green turtles. The majority of stranded turtles with FP were found on Oahu and Maui (47% of all green turtle strandings, or 37% and 47% of the respective island's total green turtle strandings). Oahu and Maui are also the two most heavily populated islands. For the purposes of analysis, Oahu is divided into five regions by coastlines, with Kaneohe Bay on the northeast facing coastline considered a separate region. Nearly 40% of all green turtles stranded along the northwest-facing coastline of Oahu were tumored, 18% along the northeast coast, 50% in Kaneohe Bay, 48% on the south-facing coast, and almost 18% on the southwest coast. The ratio of tumored strandings on Molokai was high at 60%, but the total number of reported strandings was only 11, so may not be representative of a trend. There were no strandings of tumored turtles reported on Lanai. The Island of Hawaii is also divided into the western, or Kona/Kohala, coastline, and the eastern/southeastern coastline due to its size and differing regional characteristics. Tumored turtles are rare on the Kona/Kohala Coast of the Island of Hawaii. The number of strandings along the Kona/Kohala coastline with FP was 5, which corresponds to only 6% of all strandings for that coastline during this time period. It is thought that the few turtles documented from this area (live or dead) with tumors were not residents of the area and instead were passing through on their way to another foraging location. Along the eastern coast, there were 32 green turtle strandings with FP, accounting for nearly 48% of all green turtle strandings for that coast (Fig. 3).

Eleven of the 18 areas of limited water quality are found on Oahu, including Kaneohe Bay and Kahana Bay on the northeast coast, a region of the southern coastal area spanning from the Ala Wai area to Pearl Harbor, and Kaiaka and Waialua Bay along the northwest coastline, including Haleiwa Boat Harbor. The limited water quality regions on Maui include Kahului Bay on the north coast and all of West Maui coastal areas extending south to the Kihei area. The entire south coastal area of Molokai is considered to be of limited water quality. Kauai has three limited water quality regions – Waimea, Hanapepe, and Nawiliwili. Around the Island of Hawaii, only the Hilo region on the west side of the island is designated as having limited water quality (Fig. 4). The results of the correlation matrix show an overall relationship between the water quality parameters examined (State-designated limited water quality regions, high human population density, and areas of agricultural land use) and the total number of stranded green turtles with FP for all islands or areas. The correlation coefficient between FP and limited water quality is 0.50, showing a strong correlation; between FP and agricultural land use is 0.38 (moderate correlation); and between FP and areas of relatively high human population is 0.46 (strong correlation). The correlations are also broken down by island or area and each water quality parameter. The strongest correlations between FP and limited water quality are Kaneohe Bay, Oahu (0.50), Molokai (0.6) and Maui (0.45). Strong correlations between the presence of FP and agricultural areas appear on the northwest-facing coast of Oahu (0.40), Maui (0.43) and the eastern coast of the Island of Hawaii (0.48). For the presence of FP vs. areas of relatively high human population density, correlations are strongest in Kaneohe Bay (0.50) and the southern coast (0.48) of Oahu (Fig. 5).

Discussion

The use of spatial analysis for both coastal fishing gear interactions and hawksbill turtle strandings was useful for a visual representation of these events. However, the patterns detected with GIS were no different than those already discovered by the biologists familiar with these data. Creating maps of these types of activities and stranding events in “real time” may prove to be more useful. In the case of coastal fishing gear interactions with marine turtles, the distribution of strandings was fairly consistent around the islands. Oahu showed very consistent distribution around all accessible coastlines. Maui showed similar patterns, as did the Island of Hawaii. This pattern of even distribution along available coastlines may represent access by coastal fishers to the same areas where strandings caused by coastal fishing gear interactions occur. This is shown particularly for the island of Oahu. The coastal fishing activity data are presence/absence of activity only, and do not represent intensity of fishing per area. If these data become available, this type of analysis may begin to reveal a spatial correlation. In the case of the hawksbill hatchling strandings, a hawksbill turtle nest had been discovered in the vicinity of the hatchling strandings prior to displaying the data using GIS. Had the location of the nest not been indentified, this analysis could be very useful for identifying a narrow region of potential coastline where the nest may have been deposited based on the locations of the stranded hatchlings.

The spatial analysis of these stranding data in combination with environmental parameters proved most interesting and highlighted the benefit of using a GIS. Overall, there is a strong correlation between FP-related strandings and areas of limited water quality and human population, respectively, and a moderate correlation between FP-related strandings and agricultural lands. Areas of high human population density and agricultural lands in relative proximity to the coastlines are major factors that can contribute to poor water quality (DOH 2000). Hence, the three water quality parameters chosen here are interrelated. However, there are other factors that also contribute to limited water quality including turbulence, consideration of activities the water bodies are used for, metals, and pathogens in levels above regulation limits (DOH 2000). In every instance, the reason an area is designated as an area of limited water quality is due to the high pollution emissions discharged by nonpoint sources, or polluted runoff (DOH 2000).

The higher human populations probably do not contribute to increased FP strandings simply due to higher numbers of people along the shorelines to report them (Work et al 2004; Chaloupka et al. 2008), but may be a factor of reduced quality of water related to increased urban runoff. In previous studies, a high prevalence of FP corresponded to coastal waters characterized by habitat degradation and pollution, relatively shallow waters, and low wave energy, suggesting that one or more of these factors could serve as an environmental cofactor in the development of FP (Balazs and Pooley 1991; Foley et al. 2005; Greenblatt et al. 2005). Wind and currents have been suggested to explain some of the stranding patterns in Hawaii (Work et al 2004; Chaloupka et al. 2008) and may also explain some of the poor water quality conditions in those areas. For example, Kaneohe Bay experiences very slow mixing and predominant onshore winds that keep pollutants and particulate suspended in the bay for extended periods of time (DOH 2000). These natural environmental factors, combined with polluted runoff, contribute to consistently impaired water quality. Similar conditions may explain the high correlations also found in areas of Kihei and Kahului, Maui and the eastern coast of the Island of Hawaii (Fig. 6). Conversely, areas of the leeward coasts of the islands such as the southwest coast of Oahu and the Kona/Kohala coastline of the Island of Hawaii appear to have lower proportions of FP-related strandings than other areas possibly due to predominate offshore winds and increased water circulation leading to improved water quality. This is not true for all leeward areas but other factors may be inhibiting water circulation and those areas may experience high levels of polluted runoff (for example, extensive agricultural lands along leeward coasts of Maui and island land masses offshore that may affect water movement.) While poor water quality is not the direct cause of FP, it has been previously suggested as a contributor and is correlated as shown here. Improving the environmental quality of coastal habitats has also been identified as an intermediate solution to FP (Balazs and Pooley 1991). A clear target for mitigation strategies that would benefit not only marine turtles afflicted with this disease, but all other organisms that share the same ecosystem, is water quality improvement. Since the U.S. enacted the Clean Water Act of 1972, and later amended the law to include nonpoint sources of pollution in 1987, the State of Hawaii has been working towards improving water quality for impaired regions. However, there is still much to improve as the 18 regions of limited water quality correspond to a substantial area of coastal waters. Since Hawaii has implemented plans to improve water quality along this timeline of federal laws, an interesting area of future study would be to compare them to trends in FP prevalence along the same timeline.

GIS can be a valuable tool in future FP research. A variety of co-factors have been shown to be possible tumor promoters, but not one has been proven to be the specific cause in a specific geographic area (Arthur et al. 2007; Landsberg et al. 1999). Using spatial analysis, areas of high prevalence of FP can be linked to areas with known tumor promoters and known degraded water quality, and a possible link can be discovered. With further analysis, the possibility exists that a link that has been missed in laboratory and field studies of this disease may be observed.

Concluding Statement

The relationship between high human population, poor water quality, and agriculture runoff seems intuitive. However, these relationships to a higher prevalence of tumored strandings suggests a correlation that warrants further investigation by researchers, managers and concern from the general public. Marine turtles are excellent sentinels of ecosystem health (Aguirre and Lutz 2004) because they are long-lived, and have a high site fidelity to a relatively small home range so they can reflect the quality of their environment and changes within it over time.

Acknowledgements

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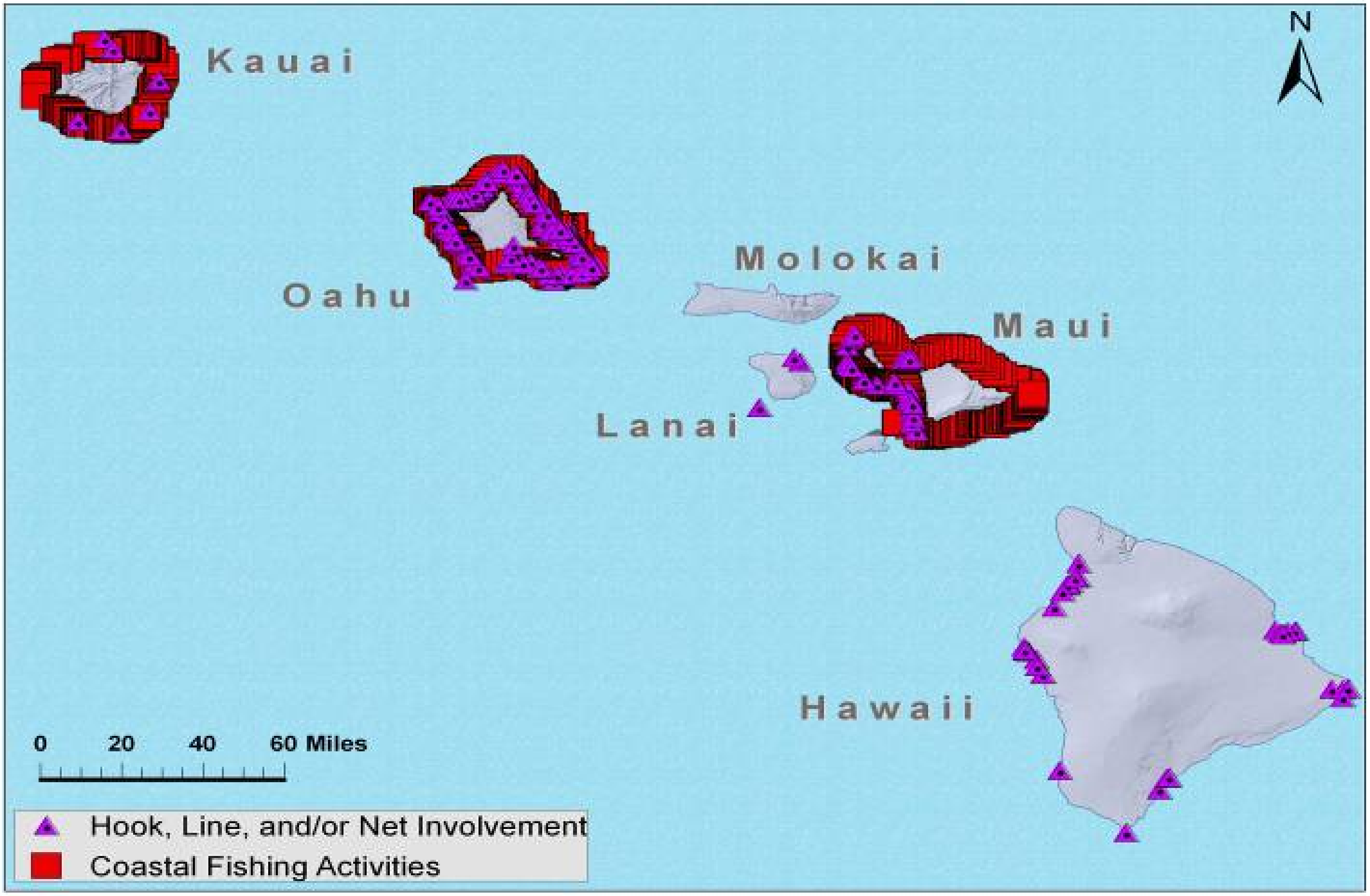


Fig. 1. Marine turtle strandings with coastal fishing interactions (purple triangles) overlaid with locations of coastal fishing activities (red squares) in the Hawaiian Islands.

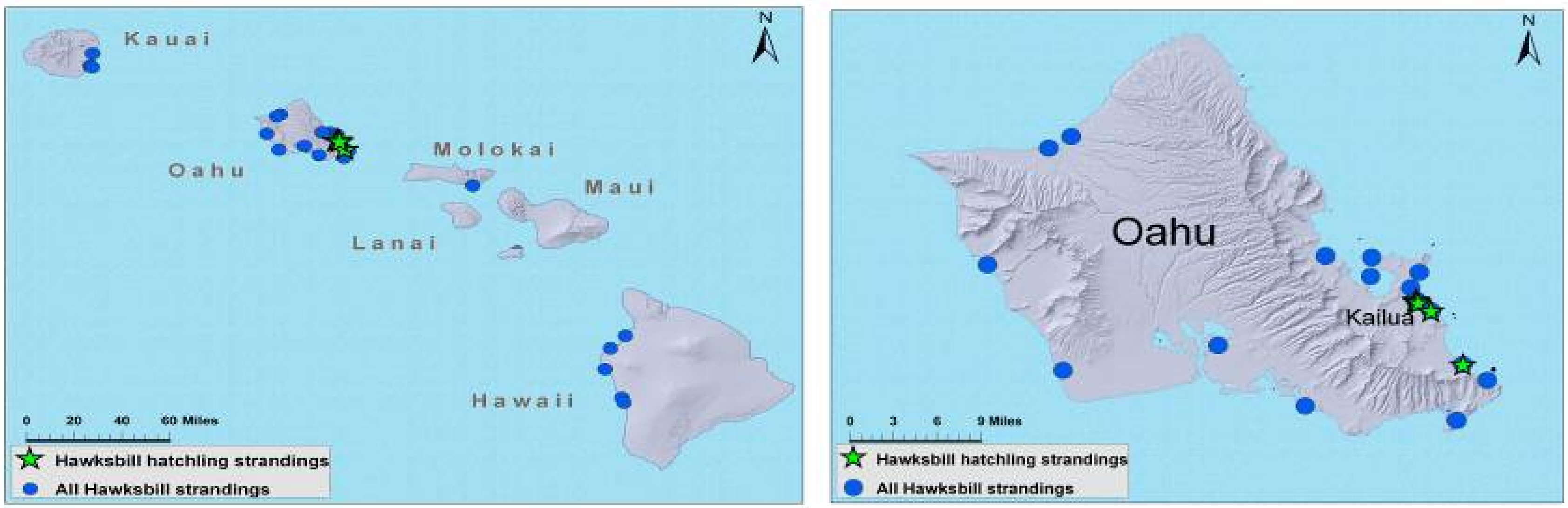


Fig. 2. Hawksbill turtle strandings on all Hawaiian Islands (left) and on Oahu (right). All hawksbill turtle strandings are represented with a blue point, and hatchlings (<5cm straight carapace length) are represented with a green star.

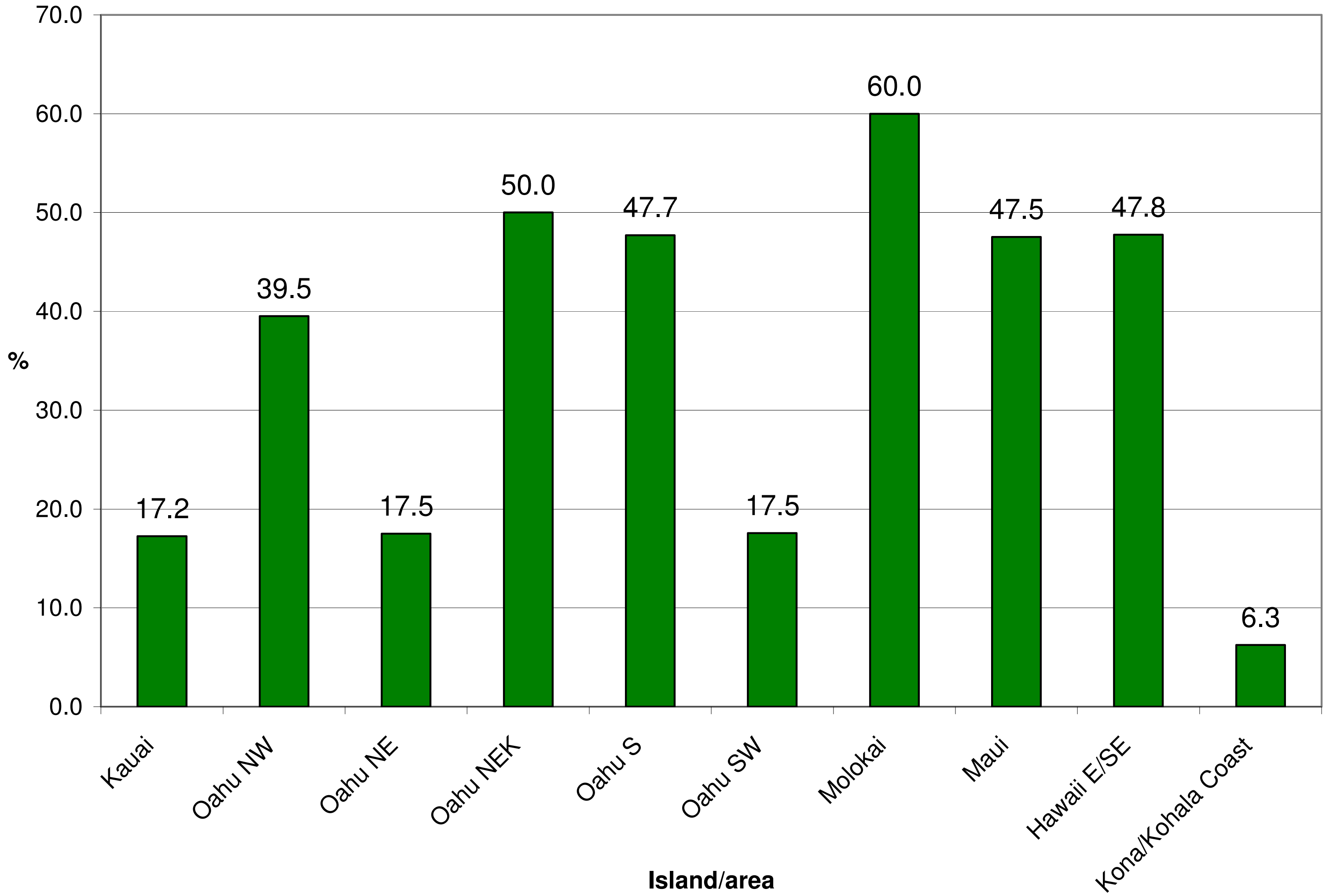


Fig. 3. Percentage of stranded green turtles with FP from 2002 – 2007 by island or area.

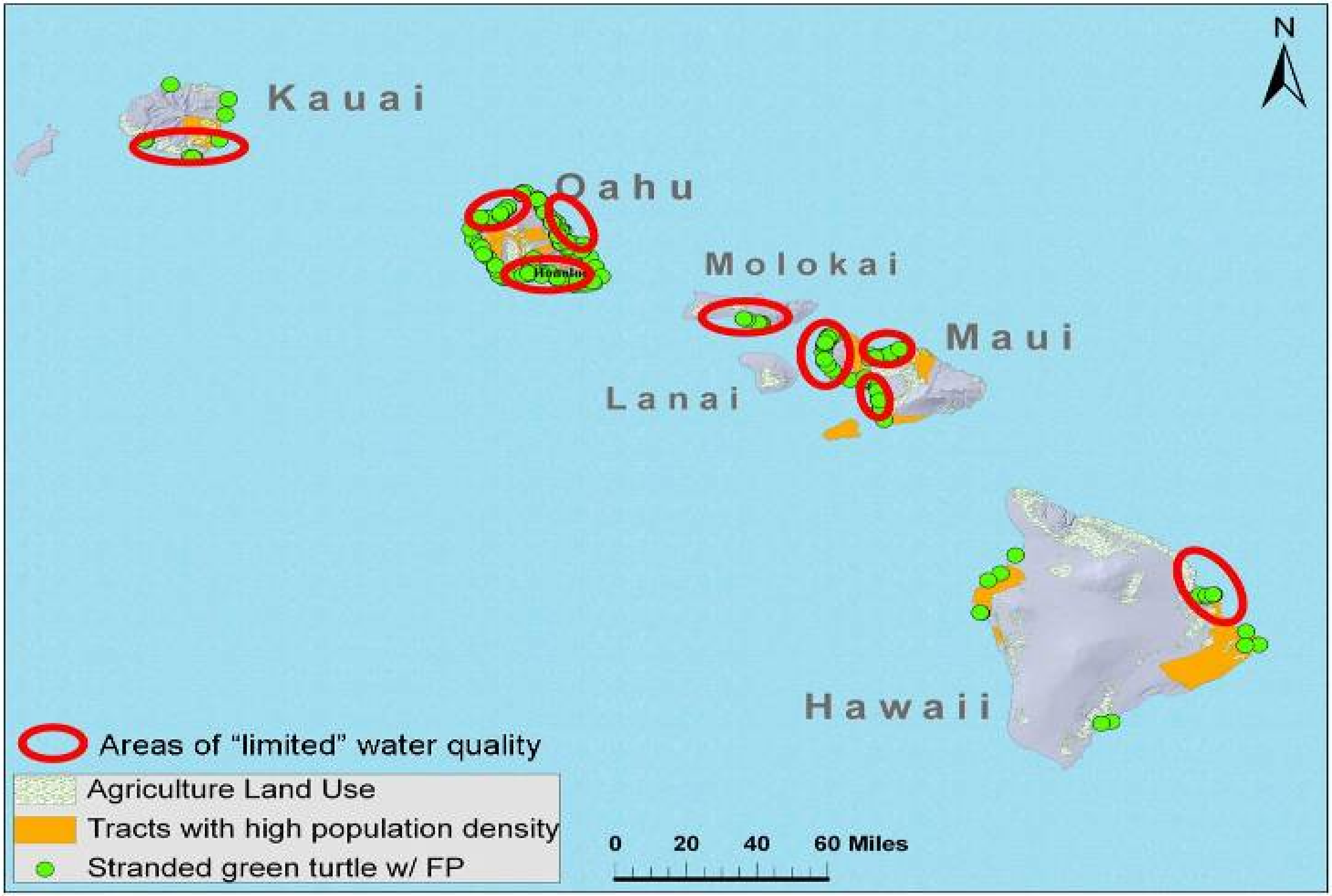


Fig. 4. Areas of the Hawaiian Islands with limited water quality, relatively high human population, and agricultural land use with locations of stranded, tumored green turtles.

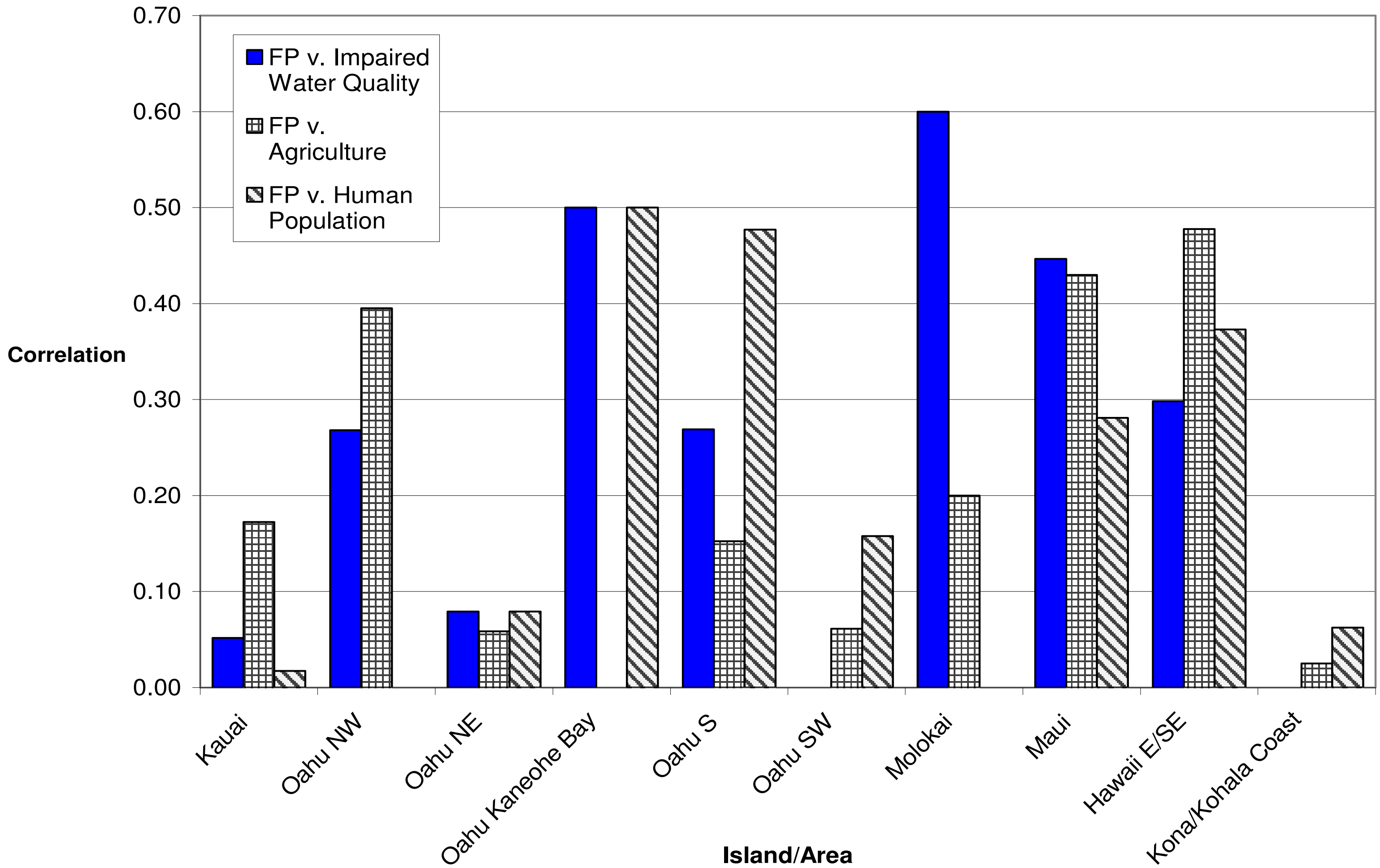
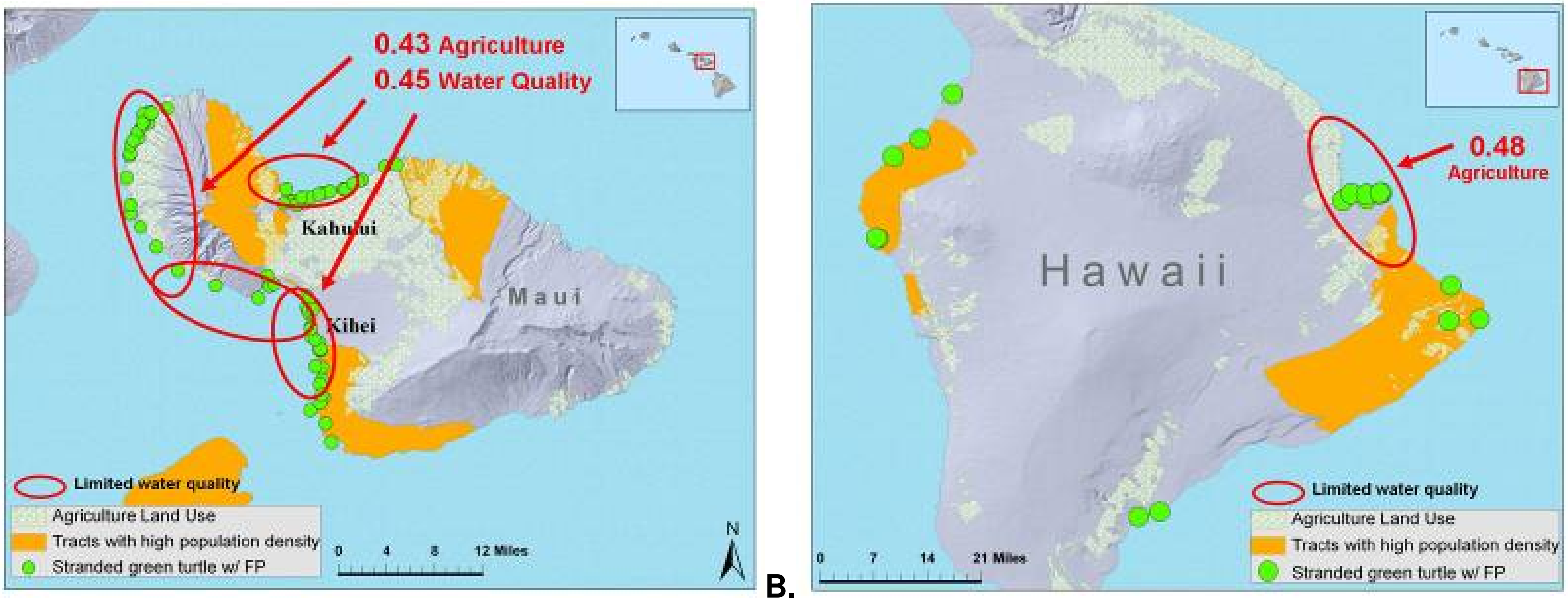


Fig. 5. Correlation coefficients by island or area between presence of FP and regions of limited water quality, agricultural areas, and human population density, respectively.


0.43 Agriculture
0.45 Water Quality
Kahului
Kihei
Maui
Limited water quality
Agriculture Land Use
Tracts with high population density
Stranded green turtle w/ FP
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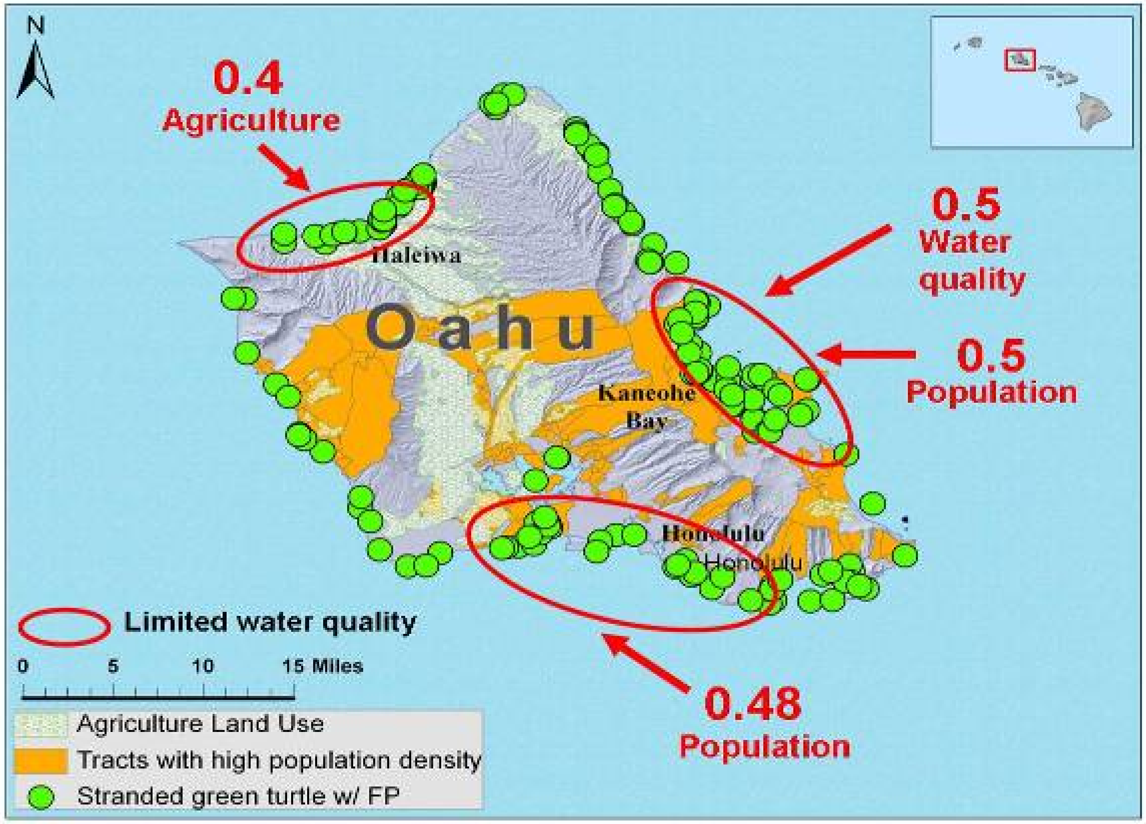
Limited water quality
Agriculture Land Use
Tracts with high population density
Stranded green turtle w/ FP
B.



C.

Fig. 6. Areas of Maui (A), the island of Hawaii (B) and Oahu (C) with limited water quality. Strong correlations to water quality parameters are noted on each map with the correlation coefficient and the region to which it corresponds. FP-related strandings are labeled with green points. Areas of agricultural use and high human population density are also identified.