Title

Exploring the Spatial Relationships between Resorts and Reef Fish in the Maldives

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Abstract

Over the last few decades, the tourism industry in the Maldives has experienced exponential growth. This rise in tourism has created a new demand for reef fish and anecdotal reports indicate that exploitation of reef fish is increasing; however, currently, there is little monitoring of the reef fish fishery. This project integrated fish biomass data from underwater visual fish surveys with locations of resorts to examine correlations between fish populations and tourism development. Maps of human presence throughout the archipelago were used to classify surveyed reefs as community, resort or uninhabited. Spatial statistics and regression analysis suggest that distance to a resort has no significant impact on the amount of fish biomass found at nearby reefs. However, the breakdown of biomass by trophic level show an absence of apex predators across all sites, which likely indicates fishing pressure and resource exploitation of large-bodied species readily caught through hook and line fisheries. Additionally, a high level of herbivore biomass across all sites could be playing an important role in reef recovery. As the fishery develops and reef fish demand grows, the Maldives will need to create a management plan that allows for the recovery of apex predators, as well as protects the abundance of herbivores.

Introduction & Background

Located in the Indian Ocean, the Maldives is comprised of 1,192 islands grouped into 26 atolls (Ministry of Environment & Energy, 2015). Of those islands, 193 are inhabited by local communities and 152 are occupied by resorts. The country's local population is around 400,000 people (Prideaux & Pabel, 2018). One-third of the population lives in the capital city of Malé and another one-third lives on islands with less than 1,000 residents (Prideaux & Pabel, 2018). The Maldives is truly an island nation, with ocean making up 99% of its total area (Prideaux & Pabel, 2018). Its marine environment is renowned for its biodiversity and includes a range of habitats including coral reefs, mangroves, seagrass beds and seamounts. The survival and growth of the Maldives' population and economy are closely tied to the marine environment and its resources. It is estimated that fish and marine biodiversity provides 77% of the protein to local diets, and contributes to a large portion of the GDP including the country's two major industries: tourism and fisheries (Dhunya et al., 2017).

Tourism

Maldivian tourism started with the opening of the first resort in 1972 (Prideaux & Pabel, 2018). The industry has since experienced rapid growth. The resort industry follows a "one island, one resort" model in which each resort occupies its own private island. This model, established in the 1978 Quality Tourism Strategy, was created in response to tourists exhibiting behaviors and dress that were disrespectful to local customs and religion (Scheyvens, 2011). The Quality Tourism Strategy stated that all resorts were required to be separate from islands inhabited by Maldivian communities. As a result, the development of resorts is done by converting uninhabited islands into "resort islands." There are currently 152 resorts in operation, and 118 islands where resort development is either planned or in progress (Ministry of Tourism, 2019). These resorts range in size from small, boutique resorts with 11 units, to mega-resorts with over 450 units. In 2008, new political leadership and efforts to enhance opportunities for Maldivians resulted in a loosening of the “one island, one resort” model and allowed guesthouses to open on local, inhabited islands (Scheyvens, 2011). This has opened a new sector of “budget” travel; however, luxury tourism is still the industry’s primary focus. The majority of tourists travel to the Maldives for its natural beauty, with roughly half of visitors citing snorkeling and SCUBA diving as primary reasons (Prideaux & Pabel, 2018). In 2017, 1.4 million tourists visited the Maldives, bringing in ~$1.47 billion USD (Ministry of Finance & Treasury, 2019).

Fisheries

Until the boom of the tourism industry, fishing was the main contributor to the country’s GDP, with coastal pelagics, including tuna, being the primary fishery. The traditional method of pole-and-line fishing has been used for thousands of years and targets skipjack and yellowfin tuna (Yadav et al., 2019). In 1994, a grouper fishery was established in response to the growing demand from Asian markets (Yadav et al., 2019). The grouper fishery management plan protects spawning areas and limits the size of individuals that can be harvested.

All non-tuna and non-grouper catch are grouped together into the broad category of “reef fish.” In comparison with the tuna fishery, the reef fish fishery is relatively small – reef fish only make up 10% of recorded landings (Prideaux & Pabel, 2018). However, reports suggest that since the late 1990s, the demand for reef fish has been growing (Prideaux & Pabel, 2018). This increase is being driven by the demand from tourists. Additionally, survey data indicates that local fish consumption patterns are changing, with households reporting decreases in tuna consumption and increases in reef fish consumption (Sattar et al., 2014). The causes of these shifts are not well documented.

Past Reef Fish Assessments & Trends

Since 1991, there have been four reef fish fishery assessments, the most recent being with 2012 data (Van der Knaap, 1991; Anderson et al., 1992; Sattar, 2008; Sattar et al., 2014). These assessments were based on landings data, observer data, surveys of households and consultations with fishermen. A comparison of the assessment findings indicates that there are changes happening within the fishery **(Table 1)**. While there is variation, Jacks (*Carangidae*), snappers (*Lutjanidae*), and emperors (*Lethrinidae*) are the most common recurring families targeted in the reef fishery and most are caught using handlines or trolling. Tourism consumption is difficult to measure due to lack of reporting from resorts. As a result, most estimates were calculated by using data volunteered by participating resorts and extrapolating to the number of beds or units across the country. The most recent assessment in 2014 estimated that 5,300 tons of reef fish were being consumed across all resorts each year. While there was a drop in consumption estimates between the 2008 and 2014 assessments, the average price per kilogram of reef fish increased from an average of 10 MRf/kg in 2008 to an average of 35 MRf/kg in 2014, indicating an increase in resource value. This reflects surveys with reef fishermen that identify high income, without having to travel as far from home, as a key attraction to reef fishing. The 2014 assessment included a formal survey component which found that over 70% of surveyed fishermen believed that the reef fishery had changed, and that catch quantity was decreasing.

Table 1: Trends over time as seen in past reef fish fishery assessments

Author & Year	**Region Sampled**	**Most Common Species**	**Tourism Consumption**	**Characterization of the Fishery**
Van der Knaap **1991** (data 1986-87)	North Male Atoll	Carangids *C. ignobilis* *C. sexcasfiatus* Lethrinids *L. elongatus* *L. rubrioperculatus* Lutjanids *A. virescens* *L. bohar* *L. gibbus*	• 1988: 1,067 tons of reef fish consumed across all resorts • 1.67 kg total fish/tourist (38% of which is reef fish)	• Handline with small sinker is the main method • Most fishing done at night/early morning
Anderson **1992** (data 1989-91)	Shaviyani, Alifu, Laamu Atolls	Carangids *A. ciliaris* *Carangoides* Lutjanids *A. virescens* *L. bohar* Lethrinids *L. rubrioperculatus*	• Projected 1992: 1,227 tons of reef fish consumed across all resorts	
Sattar **2008** (data 2006-2007)	Atolls with highest resort presence Islands where reef fishery are primary income	*Percent of catch:* Carangids 42% Lutjanids 22% Scombrids 14% Fistularids/Sphyraenids 9% Lethrinds 7% Serranids 6% Coryphaenids .25% Xiphiids .22% *Top Species:* E. bipinnulata A. virescens	• Estimated 7,000 tons of reef fish consumed across all resorts/year • 1.29 kg total fish/tourist • Less per tourist, but tripling in total reef fish purchase due to increase in tourism • Avg 10 MRf/kg; 1800 MRf/fishing trip	• High abundance of reef resource, reduced effort = attractive to fishermen • Opportunistic fishing or part-time employment • A few communities carry out reef fishing as primary income • Daily schedule: .5-3 hrs baitfishing; 3-9 hrs fishing; 2-3 locations; sell to resorts (if no demand from resort, then small scale processors) • Fishermen stay within their atoll
Sattar **2014** (data 2012)		Carangids *E. bippinulata* *Caranx* Lutjanids *A. virescens* *L. bohar* *L. gibbus*	• 2012: 5,300 tons of reef fish consumed across all resorts/year • Avg 35 MRf/kg • 2012: ~185mill MRf spent on purchase of reef fish	• Main methods: handline, dropline, trolling Reef fishermen Survey Results: • Fishermen chose reef fishery because of good income, and close to home • 53% claim fishing as sole income earning activity • 76% say fishery has undergone change • 34% report decrease in size of individuals caught • 72% report decrease in catch quantity

While these assessments provide valuable insight into trends, there are still gaps in the knowledge and monitoring, which make it difficult to fully understand the status of reef fish in the Maldives. Reef fish brought to landing sites are recorded; however, any catch sold directly to resorts is not. Additionally, "reef fish" is a catch-all term to describe any non-tuna or non-grouper species. These assessments suggest that Jacks (*Carangidae*), snappers (*Lutjanidae*), and emperors (*Lethrinidae*) make up the majority of the catch; however, there are still significant unknowns around the prevalence of other target species (Yadav et al., 2019).

Both scientific literature and anecdotal reports indicate that the reef fishery is undergoing changes, with the tourism industry driving an increase in demand for reef fish. A maximum sustainable yield (MSY) was calculated in 1992 for the reef fishery. The 2014 assessment indicated that catch was approaching MSY (Sattar et al., 2014). Additionally, a potentially large portion of the reef fish catch is going directly to resorts or residents, rather than passing through monitored landing sites. This unaccounted biomass, plus the lack of differentiation amongst reef fish species hinders the ability to monitor the true impact of fishing on reef ecosystems. With a GDP largely dependent on the availability of ocean resources, an understanding of the population statuses of reef fish is essential.

To gain a better understanding of reef fish populations in the Maldives and determine potential impacts from tourism development, a spatial analysis was used to detect potential relationships between reef fish biomass and a reef's distance to resort islands. We expect that reefs closest to resorts will have less fish biomass, particularly for targeted species. There were four phases to complete this analysis: (1) literature review of available data on reef fish and past fishery assessments in the Maldives, (2) creation of current data sets and map layers; (3) analysis of fish biomass across sites; and, (4) analysis of the fish biomass as a function of site classification (resort, community or uninhabited).

Project Description and Methods

Map Layers

The following describes the various data sets created, including how data were collected and displayed in ArcGIS Pro. See Appendix 1 for images of map layers.

Currently Operating Resorts (Appendix 1a, 1b)

Resort data were collected by aggregating information from various online resources, including the Maldives Ministry of Tourism's list of registered resorts, resort websites, Maldives travel guidebooks and websites, and a visual assessment on Google Earth. The list of currently operating resorts included geographic coordinates, size of the resort (as quantified by the number of units), and the date of establishment (based on original ownership, if different from the current owner).

Community Islands (Appendix 1c)

The locations of community islands were determined by cross-referencing 2014 census data information with a visual assessment on Google Earth. The geographic coordinates of the community epicenter were used to represent community locations.

Docks & Harbors (Appendix 1d, 1e)

A visual assessment on Google Earth was used to identify major docks and harbors on inhabited islands. On resort islands, the dock point was placed at the geographic coordinates at the end of any large docks. On community islands, the point was placed at the geographic coordinates of the middle of any harbors.

Survey Sites & Classification (Appendix 1f, 1g, 1h)

The locations of all survey sites were mapped and then classified as either Resort, Community or Uninhabited using a point-based method. Buffer zones with a 5 km radius were created around all resort and community points. Any survey site within a buffer zone was given the classification of the respective buffer. If a survey site fell within both a community and resort buffer, it was classified as the closest linear point. Survey sites that were not within any buffer were classified as uninhabited. Distance traveled during a reef fishery trip can vary depending on the targeted catch and the fisher's home island. Fisher surveys from 2008 indicated that most reef fishers take day trips, including any time spent on bait fishing, and will visit between one and two locations during the day. With these considerations, a 5 km radius was chosen to represent the distance a *dhoni* fishing vessel could travel in 30 minutes.

Reef Type Classified by Adjacent Island Usage

Shapefiles for all the reefs in the Maldives were provided by the Waitt Institute. Each reef was classified as either Resort, Community, Industrial or Uninhabited, as determined by the use type of the reef's adjacent island. For the purposes of this study, the shapefile was spot-checked to confirm classifications, and updated to reflect recent changes in island usage (e.g., conversion of uninhabited islands into resort islands).

Navigable Waters (Appendix 1i, 1j, 1k)

Using the Reef Type shapefile, the polygons were edited to exclude boat channels, docks and harbors on resort and community islands. This shapefile was converted into a raster with cell values indicating the presence or absence of water.

Planned Resorts (Appendix 1l)

Data was sourced from a list of planned development sites posted to the Maldives Ministry of Tourism website. The list was updated October 2019 and included development sites for resorts, hotels, and training facilities. Only the resort development data was used to create this data layer.

Fish Biomass Data

The fish biomass data was collected and provided by the 100 Island Challenge and Blue Prosperity Coalition project during a reef assessment expedition in January 2020. Surveys were conducted on reefs along the western sides of northern and central atolls in the Maldives. At each site, underwater visual surveys were conducted using a belt transect method at a 10m depth. To summarize, a pair of divers set and swam along three 25m transect lines, completing two passes on each line. On the outbound pass, divers surveyed an 8m swatch (4m per diver with transect tape serving as the center line) and identified individuals >20cm total length (TL), and on the return pass, individuals ≤20cm TL in a 4m swatch (2m per diver) were recorded. Fish were identified to the species level and TL was estimated to the nearest 5cm.

Fish biomass data were processed by the 100 Island Challenge project to convert diver estimates of numerical abundance and length using allometric scaling relationships and length-weight parameters from published and online sources (i.e. fishbase.org). Output data included total fish biomass per site, biomass by trophic level, and biomass by family. To narrow the focus to potential impacts of reef fishing pressure, data were filtered for "target fish." The criteria for target fish were individuals larger than 20 cm TL, and species with the potential to be caught by hook and line fisheries. Data were also filtered to analyze the biomass of families identified as targets in previous fisheries assessments. Using this criteria, additional data outputs were created for total target fish biomass per site, target biomass by trophic level and biomass by target family.

Data Analysis

Calculating distance between sites and resorts

Distance was calculated using the Near Analysis function on ArcGIS Pro. This tool calculated the Euclidean (linear) distance between a survey site and the nearest resort.

Spatial Statistics in ArcPro

The Spatial Autocorrelation/Global Moran's Index was used to identify spatial autocorrelations between fish biomass and the site location. The test was run for both "All species biomass" and "Target species biomass." Additionally, an Ordinary Least Squares regression analysis was used to identify any relationship between fish biomass and reef distance to the nearest resort. A spatial autocorrelation of the residuals was used to confirm that there were no spatial patterns.

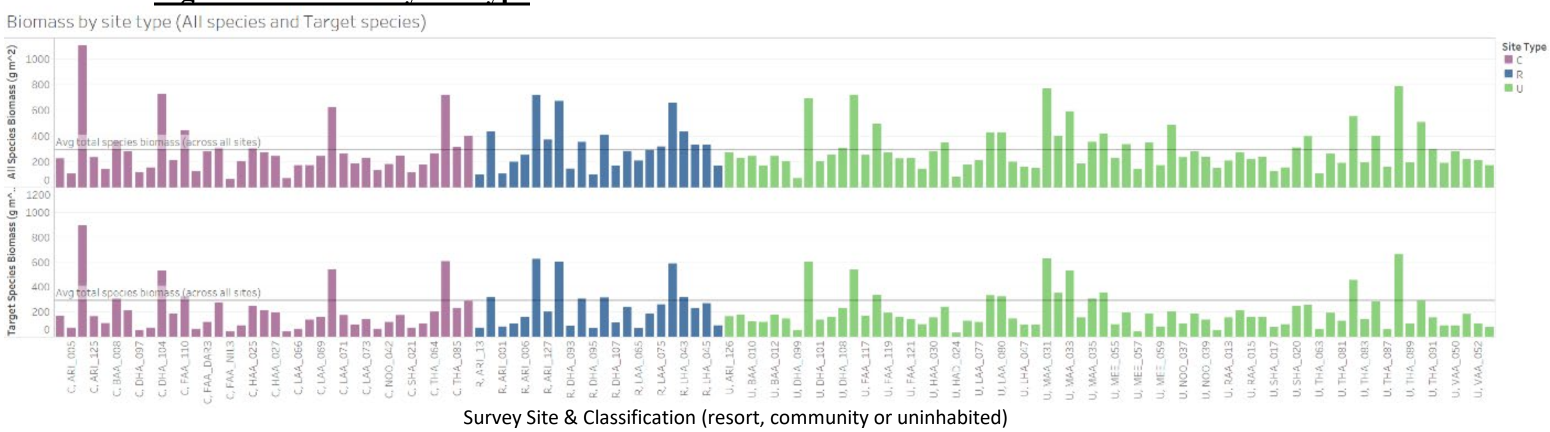
Comparison of biomass by site categorization

Box plots were created to show biomass of all species and biomass of target species for each site type. A one-way ANOVA test was used to detect any difference between the three site types. Biomass was also broken down into various subcategories, such as trophic level and family, and graphed in stacked bar charts.

Results & Discussion

The distribution of biomass across all sites was relatively consistent with no impact from the site classification **(Figure 1).** The ANOVA test F-values and p-values for both "All species biomass" and "Target species biomass" indicated that there is no significant difference between the three site types (p-value >0.05) **(Figures 2 and 3).** This supports the results from the Spatial Autocorrelation analysis where the p-value for both the "All species biomass" (p = 0.8158) and "Target species biomass" (p = 0.9817) indicate random distribution and no strong geographic pattern to fish biomass. The results of the Ordinary Least Squares regression for both "All species biomass" (p = 0.114) and "Target species biomass" (p = 0.156) had p-values >0.05, indicating no strong relationship between fish biomass and distance to the nearest resort.

<u>Figure 1: Biomass by site type</u>



<u>Figure 2: Box Plot - Total Biomass of All Species</u>

F-value: 0.341; p-value 0.712

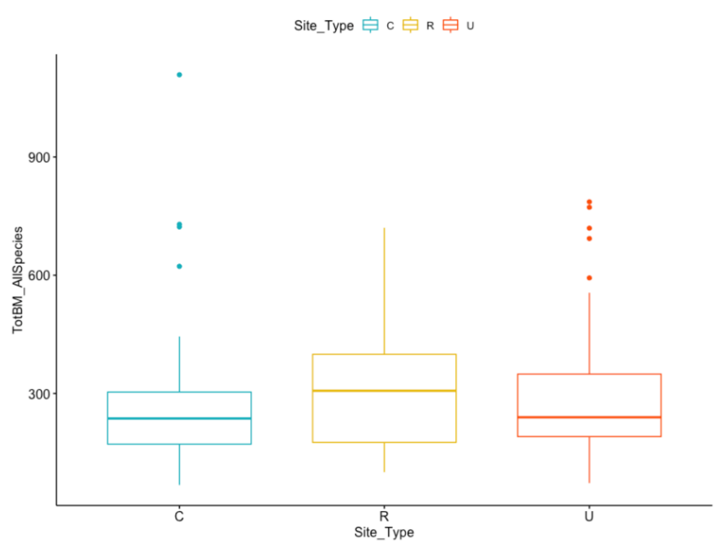
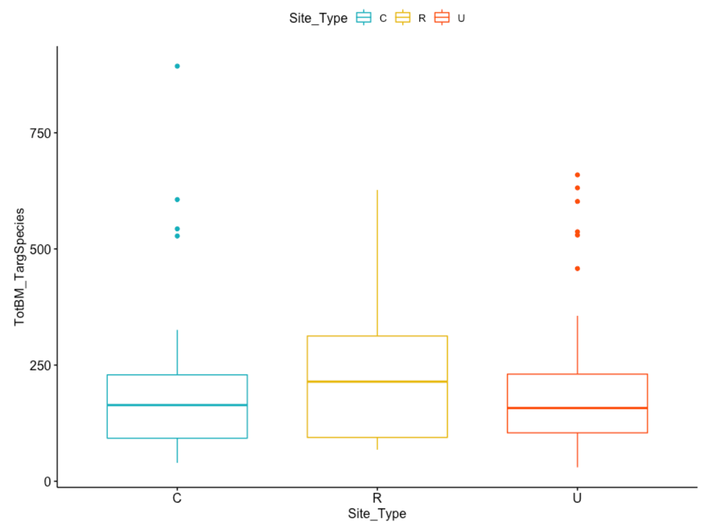


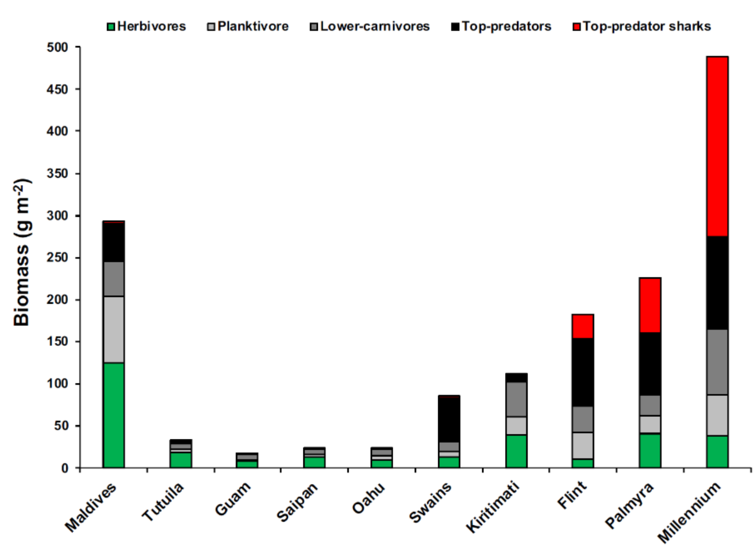
Figure 3: Box Plot - Total Biomass of Target Species

F-value: 0.624; p-value: 0.537



The average biomass across all sites is 293 g/m2 with considerable variability. In comparison with other islands around the world, the Maldives supports a relatively high amount of total fish biomass as estimated through diver-based surveys. A 2016 study found that the Maldives and other remote islands, such as Chagos and the Seychelles, supported the highest levels of biomass in the Indian Ocean (McClanahan et al., 2016). In comparison with islands in the Pacific, the Maldives' biomass is equivalent to some of the more remote islands **(Figure 4)**. However, one of the notable differences is that while total fish biomass is relatively high compared to other inhabited islands, there is an under-representation of large-bodied species, including sharks and other top predators. In an intact system, one would expect to see representation of every trophic level, as there are species within each group that fulfil different ecological roles and are necessary to maintain a healthy ecosystem.

Figure 4: Fish biomass in the Maldives compared with other islands



As seen in **Figure 4**, apex predators (sharks) and top predators (large-bodied, bony fish) make up a small portion of the actual biomass. This can also be seen at the Maldives site level breakdown of biomass by trophic level **(Figure 5)**. Across all 127 study sites, apex predators were only recorded at nine sites. Top predators make up an average of 15% (median of 10%) of the target species biomass. This lack of apex and top predators indicates the presence of fishing, as species in these trophic levels are more aggressive and therefore more likely to be caught by hook and line fishing methods. On the other hand, there is a significant amount of herbivore biomass across all sites. On average, herbivorous fish biomass made up 52% of the target species biomass, with a range of 4% to 90%. The abundance of herbivores, especially of large parrotfish **(Figure 6)**, may play an important role in maintaining coral-dominant reefs and increasing a reef's capacity for recovery.

Figure 5: Target species biomass by trophic level

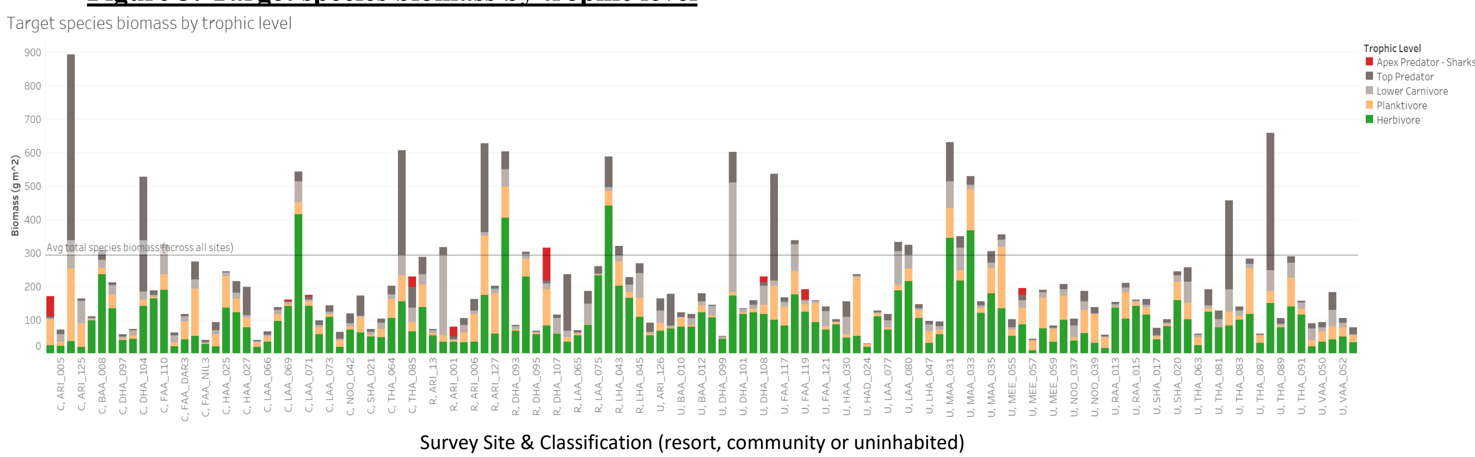
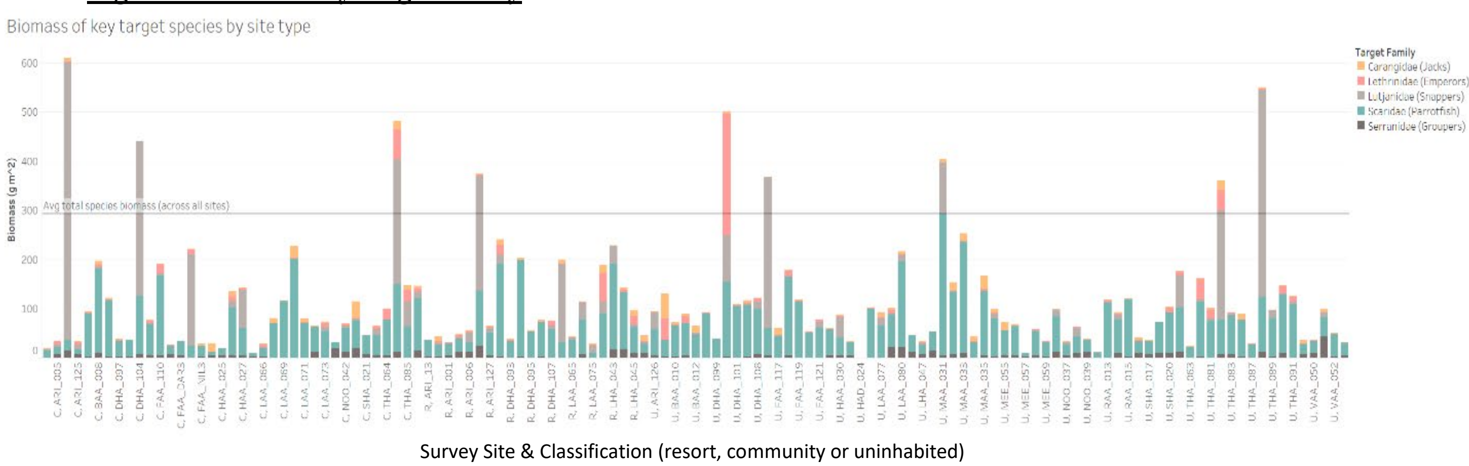


Figure 6: Biomass by target family



Overall, the Maldives fish biomass is impressive, in both quantity and diversity. This preliminary assessment suggests that there is significant biomass across all sites, regardless of proximity to a resort. However, the absence of large-bodied apex predators could indicate early exploitation and fishing down the food web. These observations, in conjunction with the trends and anecdotal evidence seen in past assessments suggest that the reef fish fishery for these species is active. Currently, the primary form of reef fish fishing is hook and line, which targets only certain species, such as top predators. However, as fisheries develop and consumer demand grows, it is likely that more methods of fishing, such as spearfishing, nets and traps, will become more common. The addition of fishing methods will also broaden the variety of targeted species. Parrotfish, for example, are not targeted in hook and line fishing; however, they are vulnerable to spearfishing. The expansion of fishing methods without regulation, could result in over-exploitation of these species. Herbivorous fish currently make up a large percentage of the biomass in the Maldives and could be playing an important role in supporting reef ecosystem resiliency. In recent years, the Maldives has experienced several serious coral bleaching events that left many of the reefs either bleached or dead. However, many of the survey sites visited during the Blue Prosperity Coalition expedition (January 2020) were showing signs of coral recruitment. The presence of herbivores and their constant grazing of algae could be reducing the amount of competition between algae and coral, thereby allowing for the recruitment and growth of new corals.

As the tourism industry continues to expand, and the demand for reef fish grows, it will become increasingly important for the Maldives to monitor and manage their reef fish fishery. This includes management that would allow for the recovery of top predators, as well as regulations to protect the abundance of parrotfish. Fish biomass is distributed without any strong geographic pattern throughout the archipelago, which suggests that there are a wide range of locations where protective measures could be impactful. By developing a sustainably managed reef now, the Maldives has the opportunity to be proactive rather than reactive when it comes to maintaining healthy reef ecosystems. A key step towards managing this fishery will be the collection and management of data from a variety of sources, including landings data, resort fish purchasing data, fisheries-independent data, etc.

Deliverables & Audience

The final deliverables of this project are (1) an interactive web application that integrates GIS maps with fish biomass data, and (2) six different data layers that describe various aspects of human activity and/or human use of marine areas in the Maldives. The web application was built using ESRI's Operations Dashboard. This interactive layout allows the user to explore the fish biomass data with respect to spatial variables. Biomass data includes total biomass per site, biomass of "target species", biomass by trophic level, etc. The Dashboard is configured for the user to view sites individually, or simultaneously for comparison. It is a living document that can be updated to reflect new data or variables. This tool was created to support fisheries and marine resource managers in the Maldives with creating management plans. Additionally, as the reef fishery undergoes standardization, this tool can provide insight into what spatial variables should be monitored in order to best understand the impacts of the fishery. The Dashboard can be accessed here: https://tinyurl.com/resorts-fish-maldives

The six data layers include the locations of operating resorts, locations of community islands, locations of docks & harbors, locations of planned resort development, a shape file of non-accessible boat areas, and a raster of navigable waters. These data layers will be open access resources with the purpose of contributing to the catalog of spatial information available for the region.

Challenges and Future Opportunities

One of the most unexpected parts of the project was the lack of existing information available for the region. The majority of data sets that I was able to find, were either outdated or incomplete. In order to update them, data were aggregated and cross-checked using various resources, and manual redrawing of polygons and points was done using visual assessments on Google Earth satellite imagery. As a result, the creation of the data sets needed to complete the spatial comparisons took longer than expected and became a larger portion of the project than originally anticipated. However, as part of my final deliverable, these data sets will be made publicly available for use by resource managers, spatial planners and researchers.

In addition to the lack of available spatial data, there were also many unknowns regarding the operation of the reef fishery. Currently, there is no standardized monitoring of the fishery and information such as average travel distance for fishing trips, or preferred fishing grounds was not readily available or generalizable. As a result, some variables, such as the 5 km buffer were chosen based on limited information.

While the lack of available information did create challenges, it allows for future opportunities of refining and replicating the study. For example, in this preliminary project, distance between reef and resort was calculated linearly. I attempted to calculate the true navigational distance between survey site and resort dock with consideration to non-accessible boat areas. The Navigable Waters and Docks & Harbors map layers were converted into raster files using a 20m by 20m cell size. The Least Cost Path tool calculated the shortest distance from survey site to the nearest resort while taking into account avoidance of land and shallow reef (Appendix 2). However, due to project time constraints, it was not possible to calculate the distance of these paths. Refining variables, such as using a travel distance instead of the linear distance, could result in more accurate findings.

Acknowledgements

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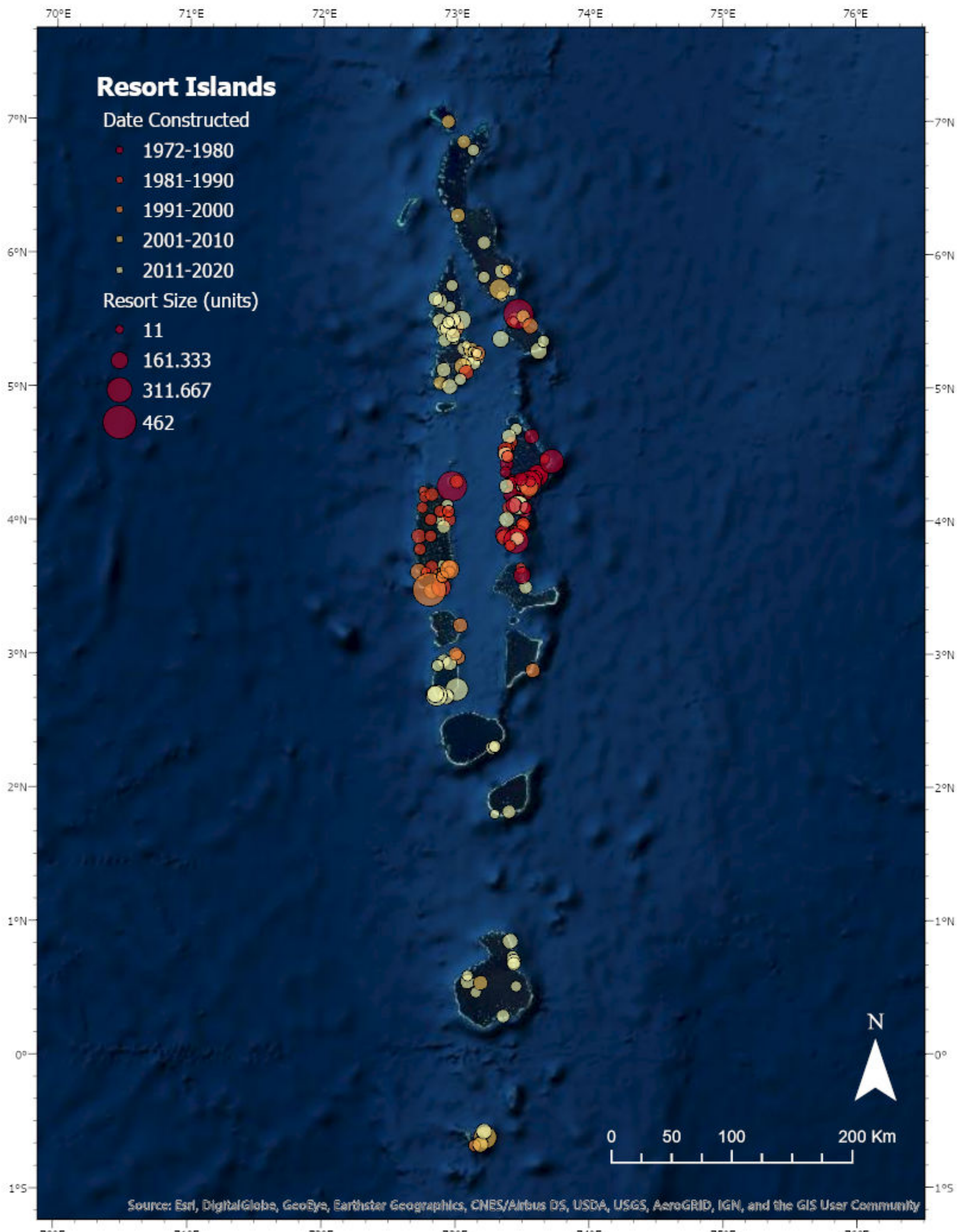
Additionally, I would like to thank the 100 Island Challenge Project, the Waitt Institute, The Blue Prosperity Coalition and the Maldives expedition team, and Hana Amir and Sarah Hashim of the Maldives Marine Research Institute for their guidance and support.

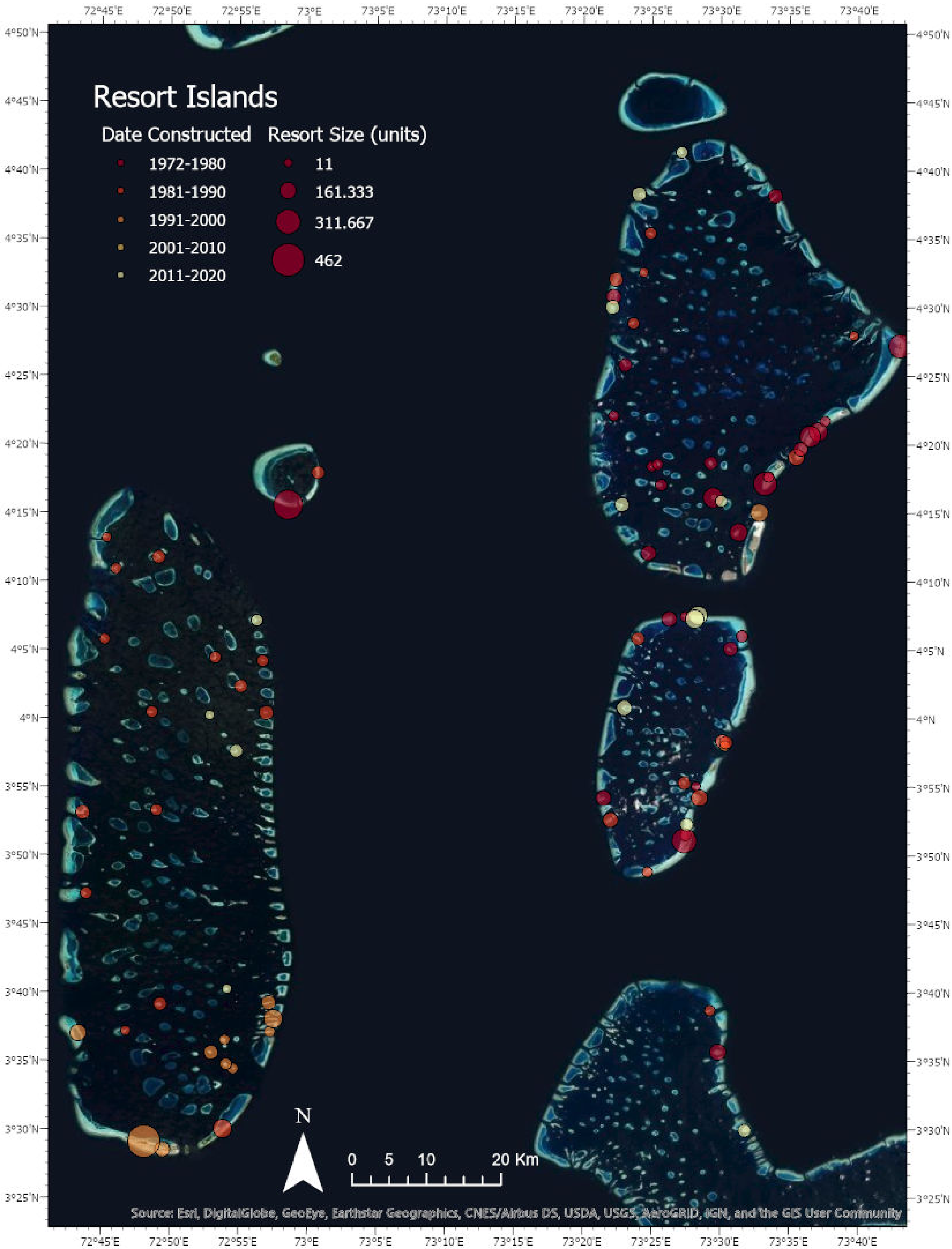
Appendices

Appendix I: Images of Mapping Layers

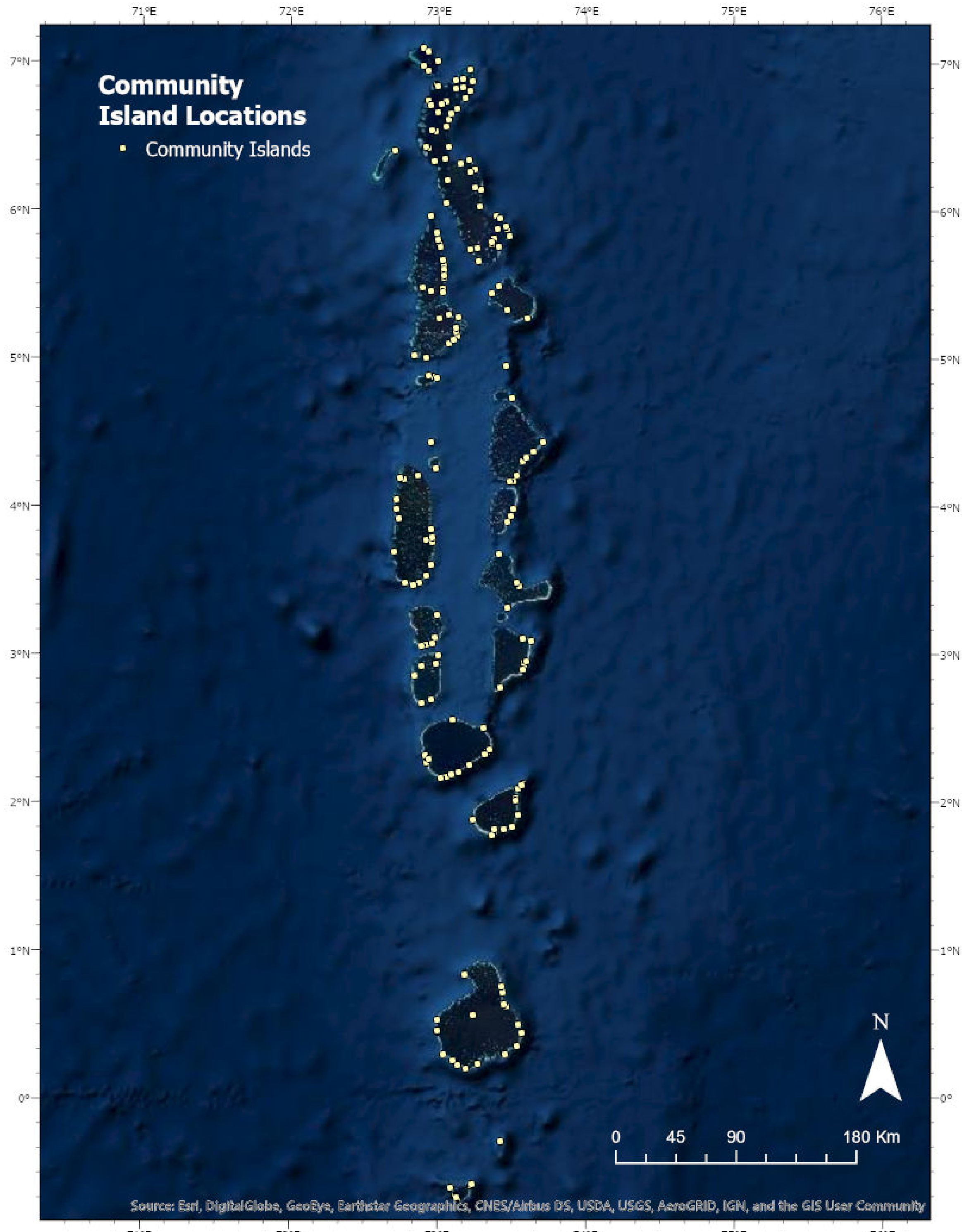
1a: Currently Operating Resorts



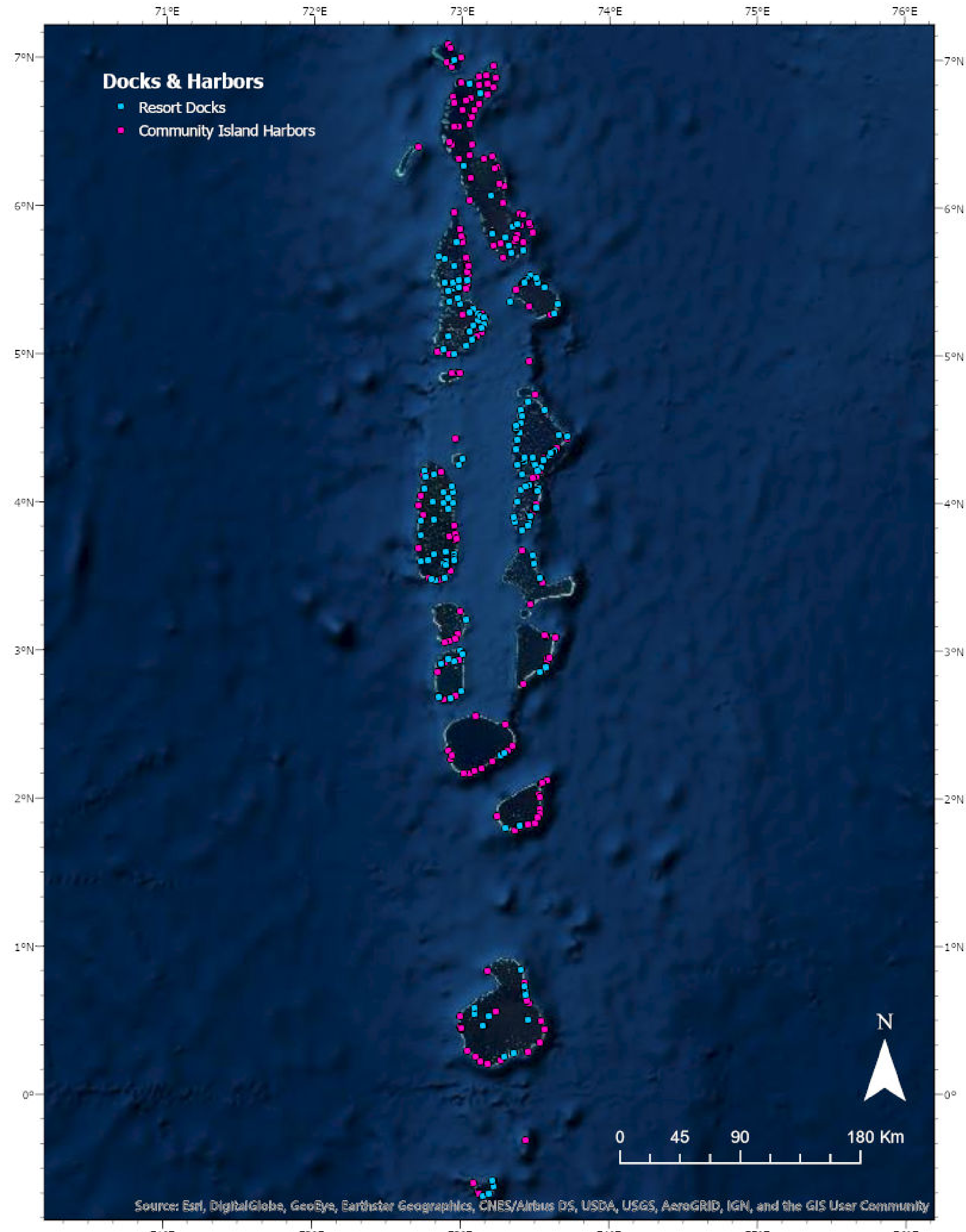
1b: Currently Operating Resorts – Zoom to Central Atolls



1c: Community Islands

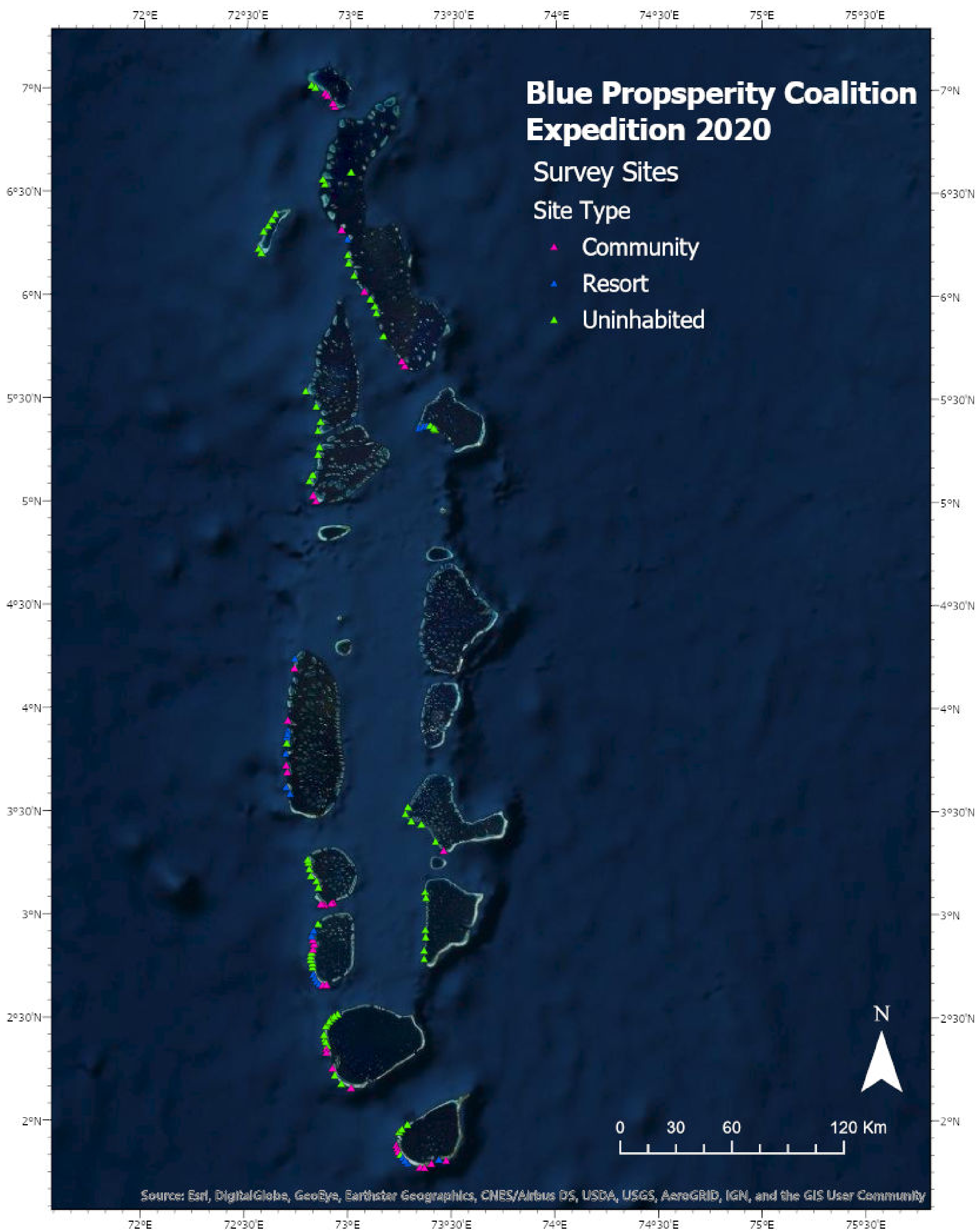


1d: Docks & Harbors

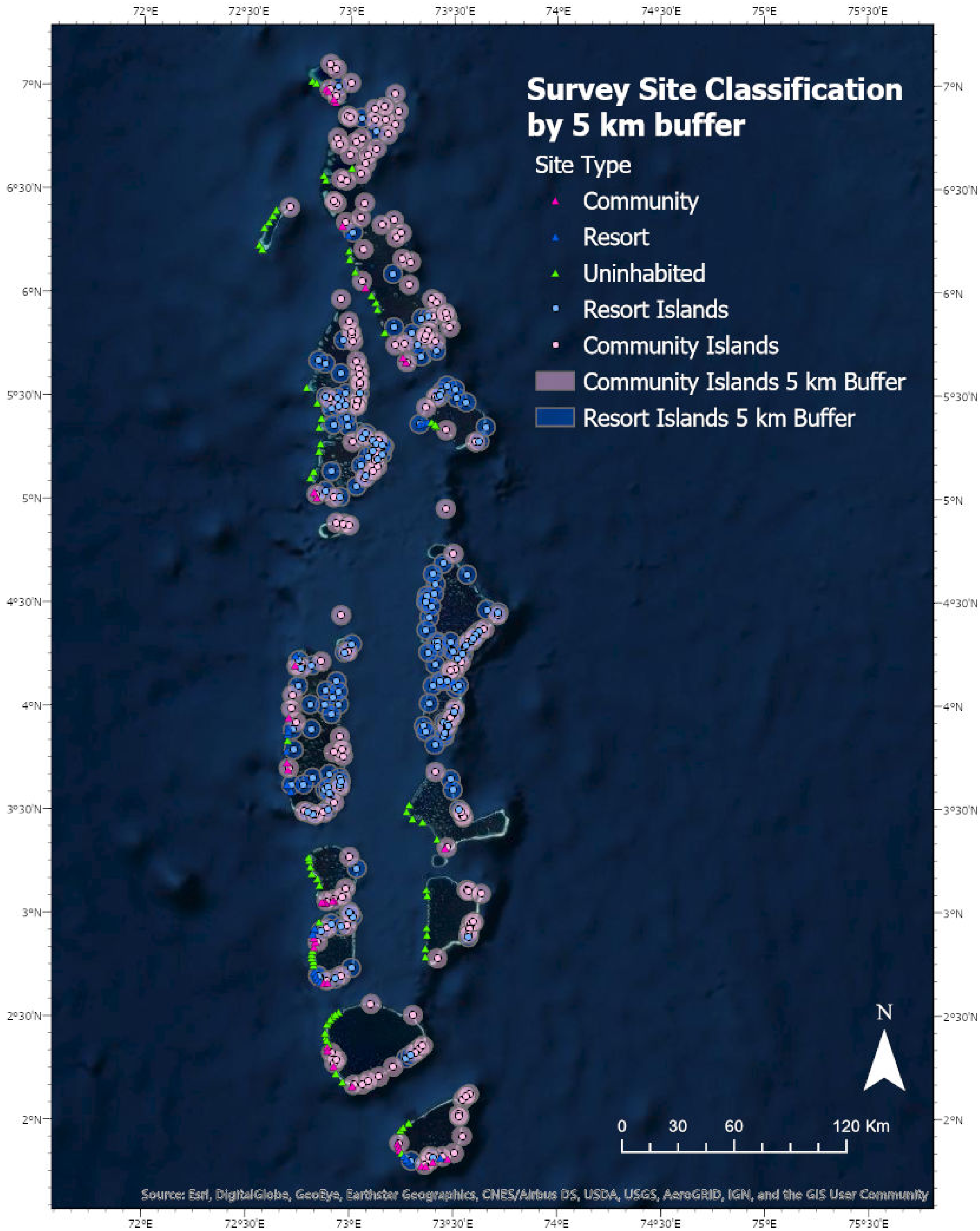


1e: Docks & Harbors – Zoom to Maamendhoo Community Island & Six Senses Resort, Laamu Atoll

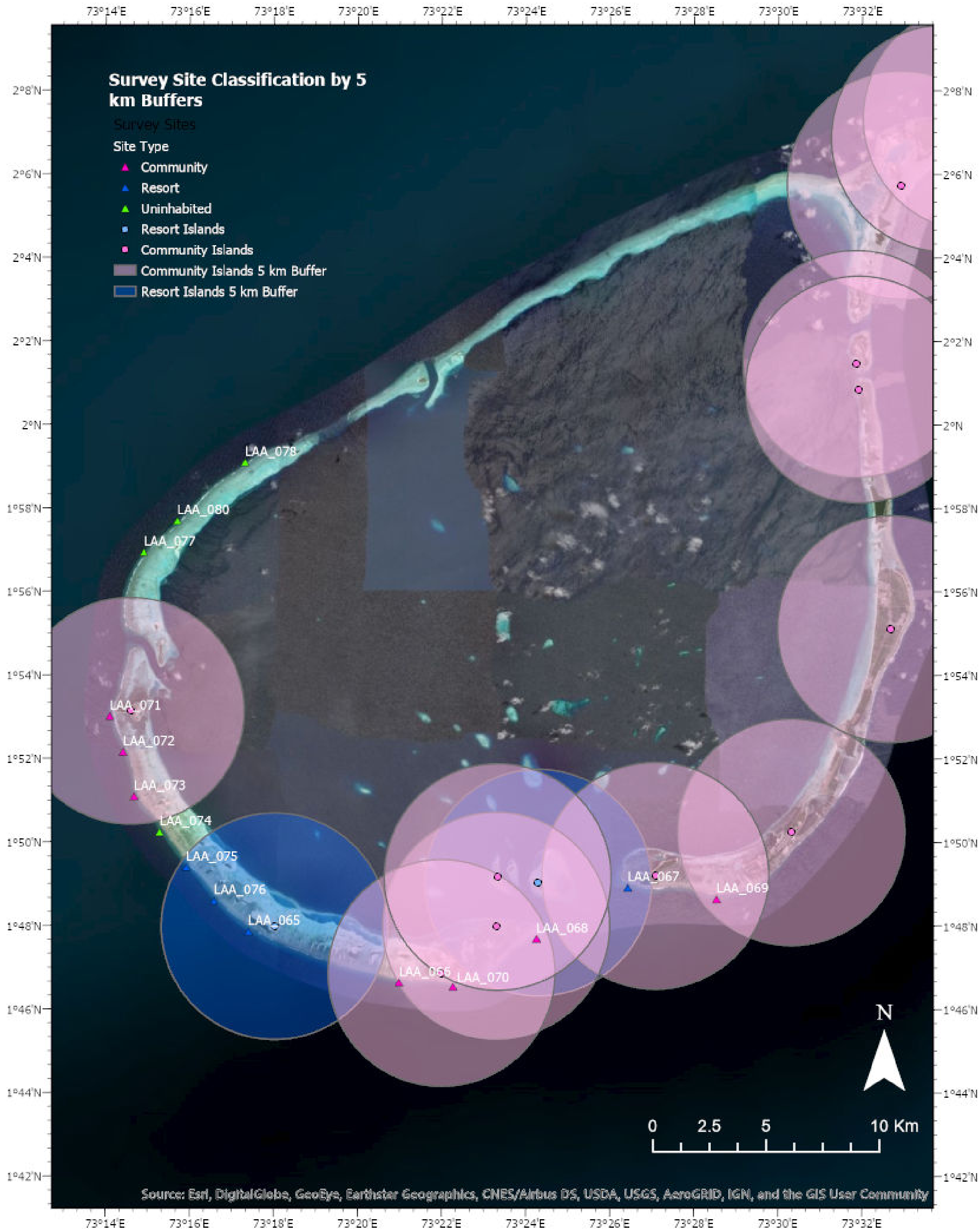
1f: Survey Sites – Location and Classification



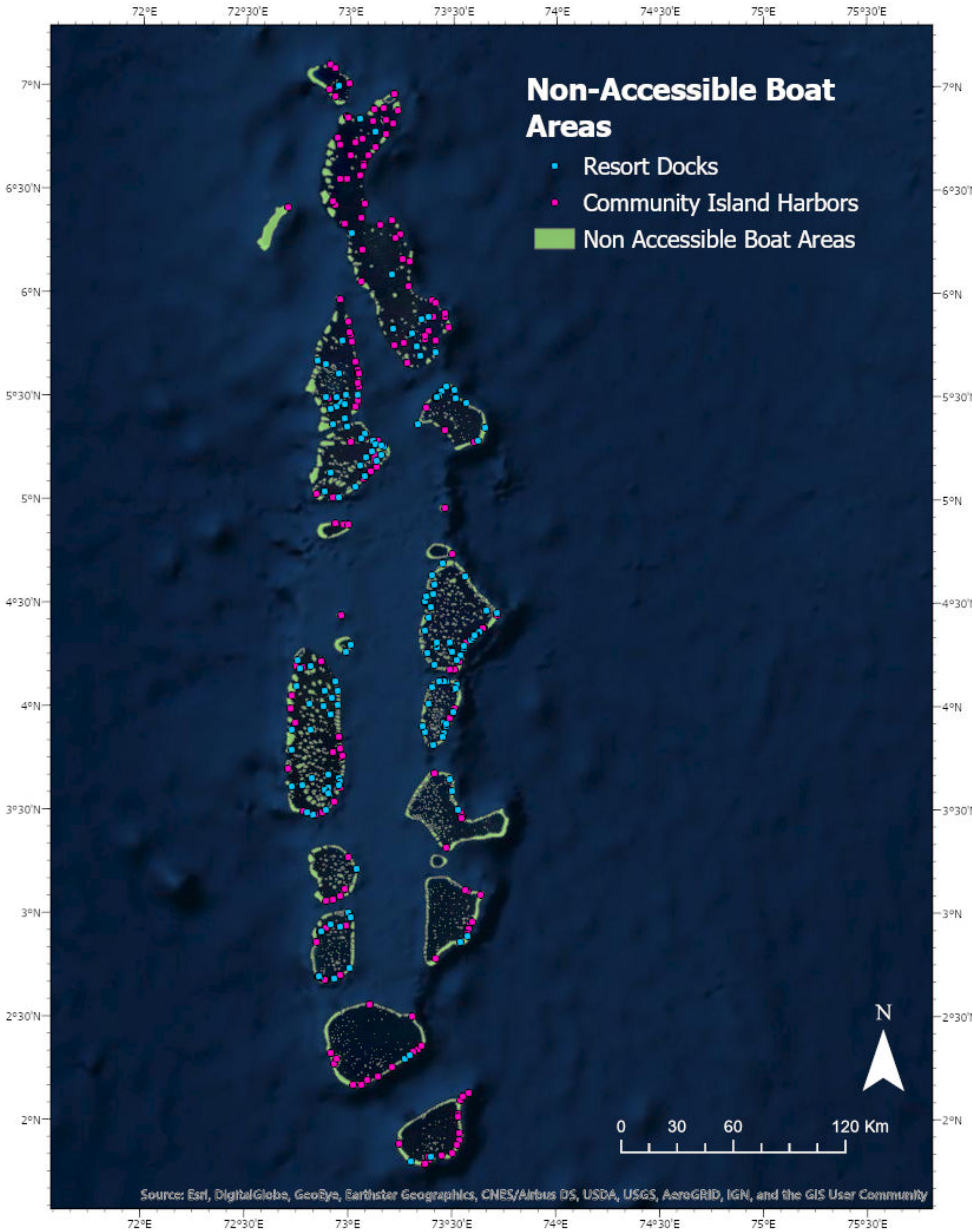
1g: Survey Sites – Buffer Classification



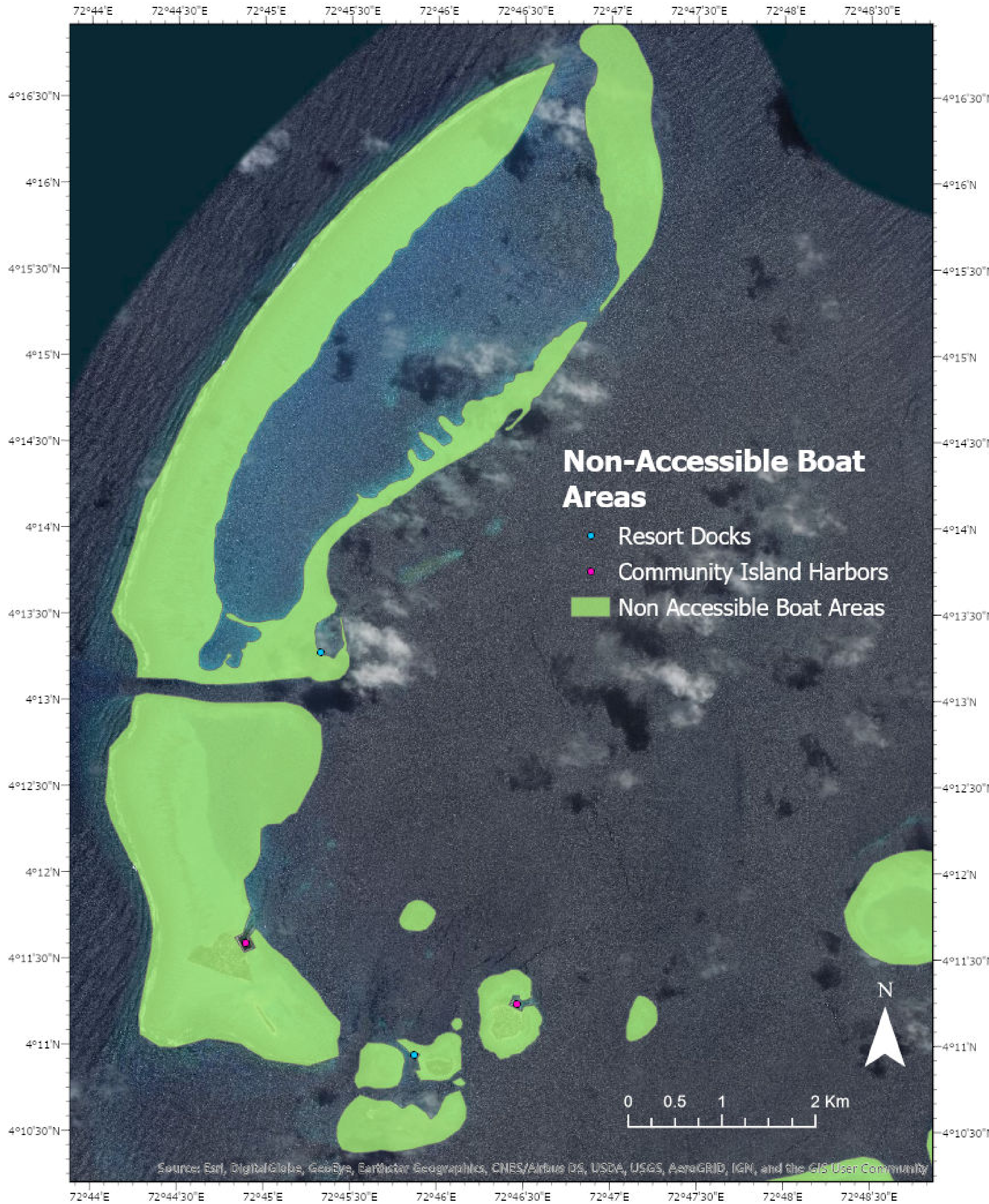
1h: Survey Sites Buffer Classification – Zoom to Laamu Atoll



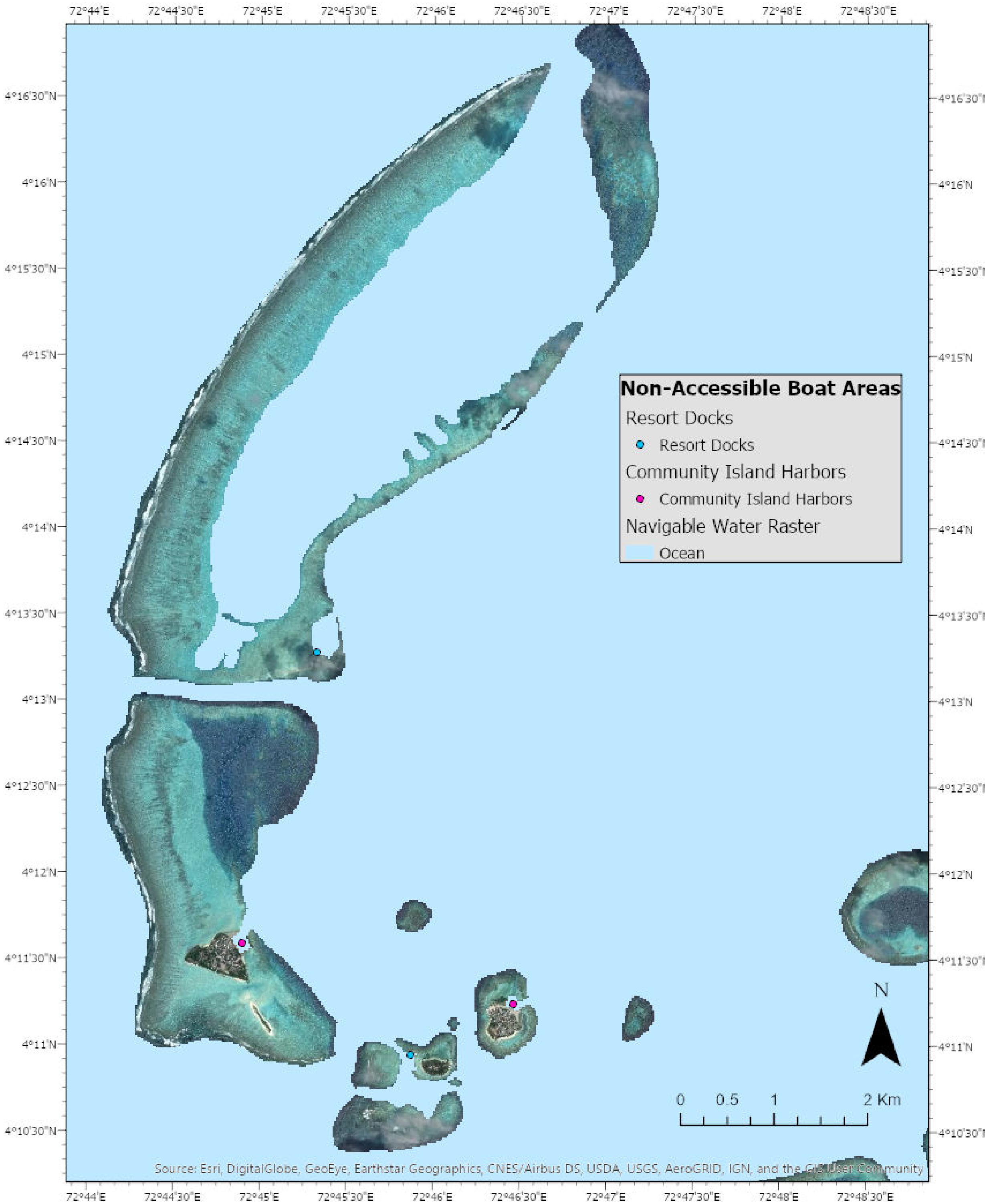
1i: Non Accessible Boat Areas



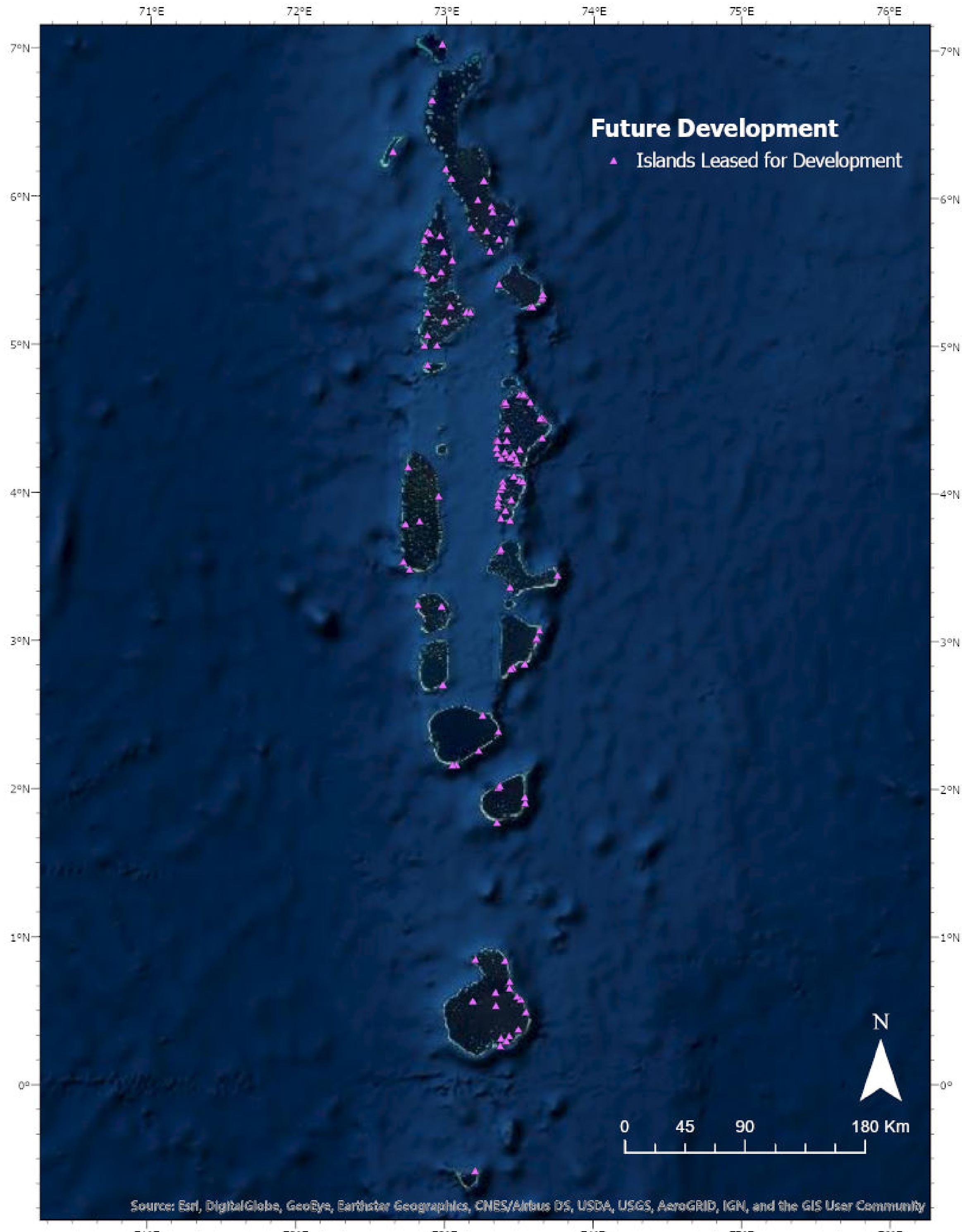
1j: Non Accessible Boat Areas – Zoom to Gangehi & Mathiveri Islands in North Ari Atoll



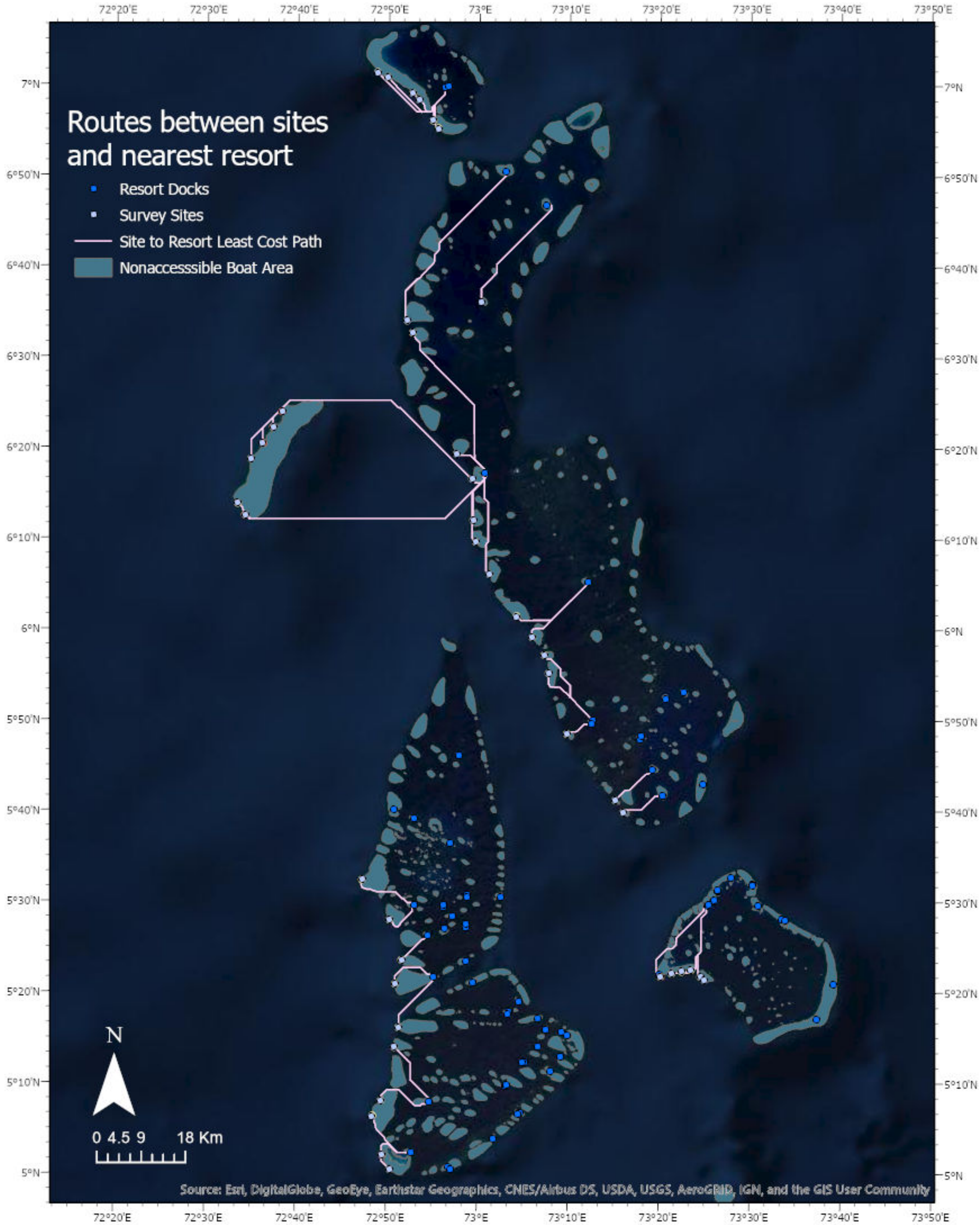
1k: Navigable Waters Raster – Zoom to Gangehi & Mathiveri Islands in North Ari Atoll



1l: Future Development



Appendix 2: Least Cost Path between Site and Nearest Resort – Zoom to Northern Atolls



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