

A NEW MAP OF GLOBAL ISLANDS

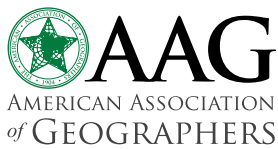
The U.S. Geological Survey (USGS), Esri, the Group on Earth Observations (GEO), and the American Association of Geographers (AAG) are pleased to present A New Map of Global Islands. This publication describes the development of a new global islands geospatial data resource, and presents maps and a web-based explorer application for visualizing the data. The islands were mapped from satellite imagery, and represent a high spatial resolution, globally comprehensive characterization of over 340,000 islands. The islands range in size from very large continental mainlands to islands as small as half of a soccer field.

The islands and associated shoreline data were developed as a first step towards the mapping and characterization of global ecological coastal units (ECUs). The work to delineate the ECUs follows previous efforts to map global ecological land units (ELUs) and ecological marine units (EMUs). These global ecosystem mapping resources have been commissioned by GEO, a consortium of over 200 nations seeking to advance the use of satellite and in-situ observations of the planet for societal benefit. With this Special Publication, AAG recognizes the work to better characterize the world's islands as a fundamental exploration in physical and ecological geography.



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The American Association of Geographers is a nonprofit scientific and educational society with a membership of almost 12,000 individuals from more than 60 countries. AAG members are geographers and related professionals who work in the public, private, and academic sectors to advance the theory, methods, and practice of geography.



The U.S. Geological Survey (USGS) was created in 1879 as a science agency charged with providing information and understanding to help resolve complex natural resource problems across the nation and around the world. The mission of the USGS is to provide relevant, impartial scientific information to 1) describe and understand the Earth, 2) minimize loss of life and property from natural disasters, 3) manage water, biological, energy, and mineral resources, and 4) enhance and protect our quality of life.



Esri is an international supplier and leader in geographic information system (GIS) software, research and development. Its flagship product, ArcGIS, is the world's most powerful mapping and spatial analytics software, applying The Science of Where to connect everyone, everywhere through a common visual language. This combination of mapping and analytics reveals deeper insight into the world's data, and is enabling over 350,000 organizations worldwide in creating responsible and sustainable solutions to problems, from local to global scales.



The Group on Earth Observations (GEO) is a voluntary, international partnership of governments and scientific and technical organizations collaborating to develop a Global Earth Observation System of Systems (GEOSS). GEO's vision is to realize a future wherein decisions and actions for the benefit of humankind are informed by coordinated, comprehensive and sustained Earth observations and information. GEO BON is GEO's Biodiversity Observation Network, and GEO ECO is an initiative to map and monitor global ecosystems.

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A New Map of Global Islands

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Earth, sea and sky — A view of a small island off the coast of Eriskay in the Outer Hebrides, Scotland (Photo by Becky Pendergast)



Foreword

A New Map of Global Islands

Following on the publication of Global Ecological Land Units (2014) and Global Ecological Marine Units (2017), AAG is pleased to present a third booklet in its Special Publication Series on Global Ecosystem Mapping. AAG is collaborating with the U.S. Geological Survey, Esri, and the Group on Earth Observations (GEO) to publish standardized, robust and practical maps of global ecosystems for a variety of research and management applications. The global ecosystem mapping work is commissioned by GEO, a consortium of nations dedicated to advancing the use of earth observations for societal benefit.

This publication maps hundreds of thousands of islands in greater detail than previous efforts. The islands range in size from continental mainlands to tiny islets smaller than a fraction of a square kilometer. The work was done at a very fine spatial resolution, and the shorelines and islands were mapped from hundreds of 2014 Landsat images.

The publication also describes an elegantly simple tool, the Global Island Explorer, which was designed as a window for users of the data. The Global Island Explorer is an online visualization and query tool, which allows anyone with an internet connection to explore any of the world’s islands in an easy to use app.

Like the global ecological land and marine units before them, the production of the new Global Islands resource was strongly supported by Esri. Jack Dangermond is to be commended for his appreciation of the importance of mapping and understanding global ecosystems, and for engaging in the work and hosting the content. The USGS is also to be commended for their leadership in the global ecosystems mapping initiative, and Roger Sayre’s unwavering dedication to advancing the work. The AAG is pleased to contribute to this ongoing global ecosystem mapping work. We recognize and celebrate this important exploration in applied physical geography.

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A New Map of Global Islands

By Roger Sayre, Jack Dangermond, Dawn Wright, Sean Breyer, Kevin Butler, Keith Van Graafeiland, Charles Frye, D. Karagulle, Steve Kopp, Suzanne Noble, Jill Cress, Devon Burton, Madeline Martin, and Jac Steiner.

Abstract

As part of an intergovernmental commission for a high spatial resolution and data-derived global coastal ecosystems map, a new datalayer and map of global islands was produced. The new data represent the most standardized, current, and detailed global islands data yet available. The 340,691 mapped islands were classed by size into 5 continental mainlands, 21,818 big islands ($>1\text{km}^2$), and 318,868 small islands ($<1\text{km}^2$). The GIS data are available in the public domain as high spatial resolution (30 m) polygons. Herein we 1) summarize the objectives and methods for producing the new islands data, 2) describe the ongoing effort to name the bigger islands ($>1\text{km}^2$), 3) present a series of graphics for a visual depiction of the islands at global, regional, national and local scales, 4) present the Global Islands Explorer as an online visualization and query tool developed as a simple window into the data for use by a variety of audiences, and 5) describe the availability of the data.

Introduction

Geographic Data on Global Islands

The surface of the earth can be viewed as primarily an ocean matrix with emergent land areas of varying sizes. Regardless of the size of these land areas, which range from very large landmasses like the Eurasian mainland to tiny coastal rock outcrops, every land area on Earth is ultimately surrounded by ocean waters, and is therefore an island. Islands are increasingly easy to detect in satellite imagery, and even very small ones can be universally explored in broadly accessible technologies like Google Earth®. There are also several list-based compendia of information on islands such as the UNEP Islands Directory (Dahl, 1991) and Wikipedia's Lists of Islands (https://en.wikipedia.org/wiki/Category:Lists_of_islands), which are organized by several subcategories including name, size, continent, nation and ocean. Detailed, global characterizations of specific types of islands such as barrier islands (Stutz and Pilkey, 2000) and atoll islands (Goldberg, 2016) are available. However, current, accurate, high resolution digital datasets containing polygonal geospatial representations of all global islands are not generally available in the public domain. We present herein a new, globally comprehensive, high spatial resolution (30 m), GIS dataset of the islands of the earth.

Islands and Biodiversity

Except for the most remote and climatically inhospita-

ble areas on the planet, islands are generally inhabited by a variety of plants and animals, often including humans, if they are big enough to support these organisms. High levels of endemism in flora and fauna are often characteristic of islands due to their geographic isolation (Whittaker and Fernández-Palacios, 2007). This isolation and remoteness represents a barrier to the geographic dispersal of propagules, and over time favors evolutionary adaptations and speciation. Darwin formulated much of his thinking on evolution from his observations of differences in species' traits recorded in his travels to the Galapagos Islands. While species richness on islands is generally regarded as lower than counterpart mainland areas, "endemism richness," an index of species richness scaled by endemism, is relatively high (Kier et al., 2009).

High levels of both endemism and endemism richness on islands suggests that they should be considered as important candidate geographies for biodiversity conservation efforts. This is particularly true given that extinctions and other losses of biodiversity on islands are disproportionally rapid (Spatz et al., 2017). Island species are often vulnerable to human-caused disturbances such as the introduction of invasive species, hunting, and the agriculture-related destruction of relatively small and fragile habitats which contain small populations of rare species (Szabo et al., 2012). A focus of conservation attention on global islands is clearly warranted because 1) their biodiversity importance is high (Kier et al., 2009),

and 2) that biodiversity is highly threatened (Spatz et al., 2017).

Conserving global island biodiversity necessarily requires a knowledge of where islands are, what ecosystems are found on those islands, what condition those ecosystems are in, and what rare and endangered species are found in those ecosystems. To advance understanding of the island distributions of globally threatened vertebrates, the Threatened Island Biodiversity Database (TIBD, <http://tib.islandconservation.org/>) was developed (Spatz et al., 2017). The TIBD is a globally comprehensive database on 1,189 highly threatened vertebrate species breeding on 1,288 islands. In addition to threatened vertebrate species and invasive species information, the TIBD provides attribute information on islands such as coordinate location, name, and size, and locates islands as points on a world map.

A geospatial datalayer which allowed for the visualization, query, and spatially explicit analysis of species and ecosystems' distributions on all islands would considerably advance understanding of global island biodiversity. Such a layer would permit geospatial analysis of species presence/absence data, population locations, range sizes, and areas of threat, and would support conservation priority setting within and across islands. As mentioned above, such a geospatial global islands database was not heretofore available, and was produced as part of an intergovernmental commission.

The GEO (Group on Earth Observation) Global Ecosystem Mapping Task

The Group on Earth Observations (GEO) is a consortium of over 100 nations which seeks to leverage the use of Earth observations to help solve some of society's greatest challenges (GEO, 2005). To that purpose, GEO has developed an intergovernmental protocol and associated workplan which includes an initiative (GI-14 GEO ECO, <http://www.earthobservations.org/activity.php?id=116>) on global ecosystems. The initiative formally commissions the development of a standardized, robust, and practical map of global ecosystems for terrestrial, freshwater, and marine environments (Sayre et al., 2007). The United States is the member nation of GEO leading this activity, and the U.S. Geological

Survey (USGS) is the designated federal agency implementing the work.

In response to that commission from GEO, the USGS and Esri established a public/private partnership and mapped terrestrial ecosystem distributions using a structure-based mapping approach where the ecosystems were delineated from a vertical integration of the climate regime, landforms, substrate, and land cover (Sayre et al., 2014). That effort produced a set of global ecological land units, or ELUs, as physically distinct areas and their associated vegetation. Subsequent to that terrestrial ecosystem mapping effort, and again responding to the GEO intergovernmental charge to produce standardized, robust, and practical global ecosystem maps for marine environments, the USGS/Esri team then developed a similar method for stratifying the global ocean into physically and chemically distinct volumetric regions. These oceanic, three dimensional, pelagic regions are called ecological marine units, or EMUs (Sayre et al., 2017a; Sayre et al., 2017b).

While the EMUs characterize the distinct chemical and physical environments in the oceanic water column, they do not adequately identify coastal ecosystems, which are smaller, often linear, sometimes densely populated ecosystems at the interface of the land and the sea. The team therefore decided to produce a set of global ecological coastal units (ECUs), and developed a methodology for the approach (Sayre et al., 2018). The work to produce the ECUs is underway.

The Global Shoreline Vector and the New Global Islands Datalayer

One of the prerequisites for the ECU mapping was the development of a new, high spatial resolution, image-derived global shoreline vector (GSV), which was produced using composite 2014 Landsat satellite imagery at a 30 m resolution (Sayre et al., 2018). The GSV was then used as the source geospatial linework for the development of the new global islands datalayer (GID). The GID was therefore produced "indirectly," i.e. it was not a primary objective of the team to produce a new global islands dataset. As an intermediate product associated with the mapping of global coastal ecosystems, the GID resource has considerable additional value beyond characterizing ecosystems.

Summary of Method and Results

Detailed methods and results for the production of the GSV and the GID are presented in Sayre et al. (2018). In summary, a shoreline vector was extracted from 30 m spatial resolution Landsat imagery from 2014 by visual feature interpretation. An analyst manually “ran” the entire global coastline and interpreted two feature classes, land and ocean, from all of the Landsat images of the planet that contained a segment of shoreline. Antarctica was not included in the analysis due to difficulty in separating ice features from land features. The interpretation was implemented in the cloud (Google Earth Engine®) to minimize the local storage and manipulation of hundreds of Landsat images. Training points collected by the analyst were used to classify the imagery with a semi-automated, statistically rigorous classification algorithm.

A minimum mapping unit of four contiguous 30 m landsat pixels (3600m², or .0036km²) was used, such that any island smaller than this delineation threshold size is not included in the GID datalayer. The classified coastline was subsequently brought down from the cloud, converted

from raster to vector format, and cleaned. All segments were joined, and topology was applied to the data to convert line segments to polygons.

Following conversion of coastline segments to island polygons, 340,691 polygons were produced. The five largest polygons were the mainlands of the five continents (North America, South America, Africa, Australia, and Eurasia), with an algorithmic separation of the Americas at the Panama Canal, and a separation of Africa from Eurasia at the Suez Canal. These five polygons were assigned a size class of “continental mainlands.” The remaining set of islands greater than 1km² were then attributed as “big islands,” and all remaining polygons (<1km²) were attributed as “small islands.” Table 1, reproduced from Sayre et al. (2018), shows the number of islands in each of the three size classes, as well as their summed areas and coastline lengths. The 1 km size threshold for separating small and big islands has no ecological basis, and was arbitrarily chosen for ease of understanding and use.

Table 1. The number, size, and coastline length for islands in three size classes. Reproduced from Sayre et al. (2018).

Landmass type	Number of polygons	Area (km²)	Length of coastline (km)
Continental mainlands	5	125,129,046	813,467
Islands > 1 km²	21,818	9,938,964	1,304,762
Islands ≤ 1 km²	318,868	20,589	321,774

Naming the Islands

Having derived the 340,691 islands from primary interpretation of satellite imagery, no attribute information on the islands other than the feature counts and geometric information in Table 1 was initially available. The first attribution step was to manually name the largest islands using the UNEP Islands Directory (Dahl, 1991). The 1,000 largest islands on the UNEP list were located in the GID, and their names were manually added to the feature attribute table. Three sources of information were consulted when searching for names for islands: Esri’s

WorldImage Basemap®, Open Street Map®, and Google Maps®. This manual naming process was considered accurate, but was quite time-intensive. When naming the largest 1000 islands, an additional ~2000 islands were opportunistically named (i.e. when zoomed in to name one of the 1000 largest islands it was often expedient to name several islands in the immediate vicinity at that zoom level). At the end of this first phase of manual naming, 3,156 big islands (>1km²) were named, and 686 small islands (<1km²) were named.

To facilitate and hasten the naming, an automated approach was then adopted. The GID was intersected with

the GeoNames server. GeoNames is a geographical names database freely available in the public domain containing over eleven million point-based placenames for a variety of features, including islands (<https://www.geonames.org/>). The GeoNames island placename (any placename with an ISL feature class) that was closest to the centroid of an island polygon was added as the name attribute to the GID. The placename was only used if it was located inside the island polygon. Any island that had previously been manually named retained that name. The reconciliation of the GeoNames database with the GID resulted in the addition of 5,340 automated big island names, and 12,253 automated small island names. The total number of named islands at the conclusion of the automated phase was 12,939 (0.04 %) small islands and 8,496 (38.9 %) big islands. The automated naming approach was successful in retrieving and assigning thousands of names, but more than 60 percent of the big islands and 99 percent of the small islands still lacked names.

At this point in the process, a decision was made to discontinue the naming effort for the small islands, due to the enormity of the effort that would be required to name the approximately 305,000 remaining small islands, many of which were likely small outcrops that lacked a name. Work is now underway to complete the naming process for the remaining approximately 13,000 big islands with a return to the labor intensive manual naming method, again using Esri’s WorldImage Basemap®, Open Street Maps®, and Google Maps® as the source datalayers for the names.

A number of conventions were used in the naming process. Only the proper noun, in English, was included in the attribute field. For example, the polygon corresponding to Assateague Island was given a name attribute of “As-

sateague,” not “Assateague Island.” This convention was sometimes difficult to enforce with islands with non-English names, and exceptions to the convention were made. For example, there is an island in the Dominican Republic called Isla Saona. An English equivalent would be Saona Island, which would then be attributed simply as Saona. However, the island is universally referred to as Isla Saona, by English speakers and non-English speakers alike. The name was therefore attributed as Isla Saona. Whenever possible, however, the name attribute was limited only to the proper noun.

Only the 26 letters of the English alphabet (ISO basic Latin alphabet) were used. For simplification, diacritical marks (accents, cedillas, tildes, umlauts, etc.) were eliminated from placenames, such that all names have been reduced to the simplest possible English language formulation. The attribute “UNNAMED” was given to islands when either a name was not found, or a name was available but not with English language characters. In the latter case, it is understood that the attribute UNNAMED more accurately means the name was not available in English.

Many of the islands identified by the classification algorithm were fluvial islands or islands near strongly dissected coastlines. In these deltaic systems, where islands are dynamic and island shapes are often changing, the islands often lack names in the source data. In these cases, islands were left unnamed, or were in some cases named according to the river in which they were located. For example, several unnamed islands in the mouth of the Orinoco River were given an attribute name of “Orinoco Delta.” Other islands, for example in coastal or mangrove habitats, that lacked a name in the source data were simply attributed as UNNAMED, as described above.

Island Maps

A sequence of graphics is presented depicting islands at global (Figure 1), continental (Figure 2, the Americas; Figure 3, Africa and Europe; Figure 4, Australia and the southwest Pacific Ocean), regional (Figure 5, the Caribbean Sea; Figure 6, the Aegean Sea; Figure 7, Patagonia) national (Figure 8, New Caledonia; Figure 9, Belize), and subnational (Figure 10, Florida Keys; Figure 11, Outer Hebrides) scales. These maps are presented as a visual

exploration of the global islands data, and demonstrate both what is discernible and the level of linework detail at resolutions ranging from very coarse to very fine. At coarse resolutions and small page formats, small islands are generally not visible. They appear with increasing detail as the resolution is increased. These maps are intended to provide visual impressions of the numbers and variety of shapes and sizes of Earth’s islands.

Figure 1. Global islands. All islands except continental mainlands are depicted in a green color. Small islands, not visible at this coarse resolution and page format size, have been rendered visible through visual exaggeration using increased point sizes for feature symbols.

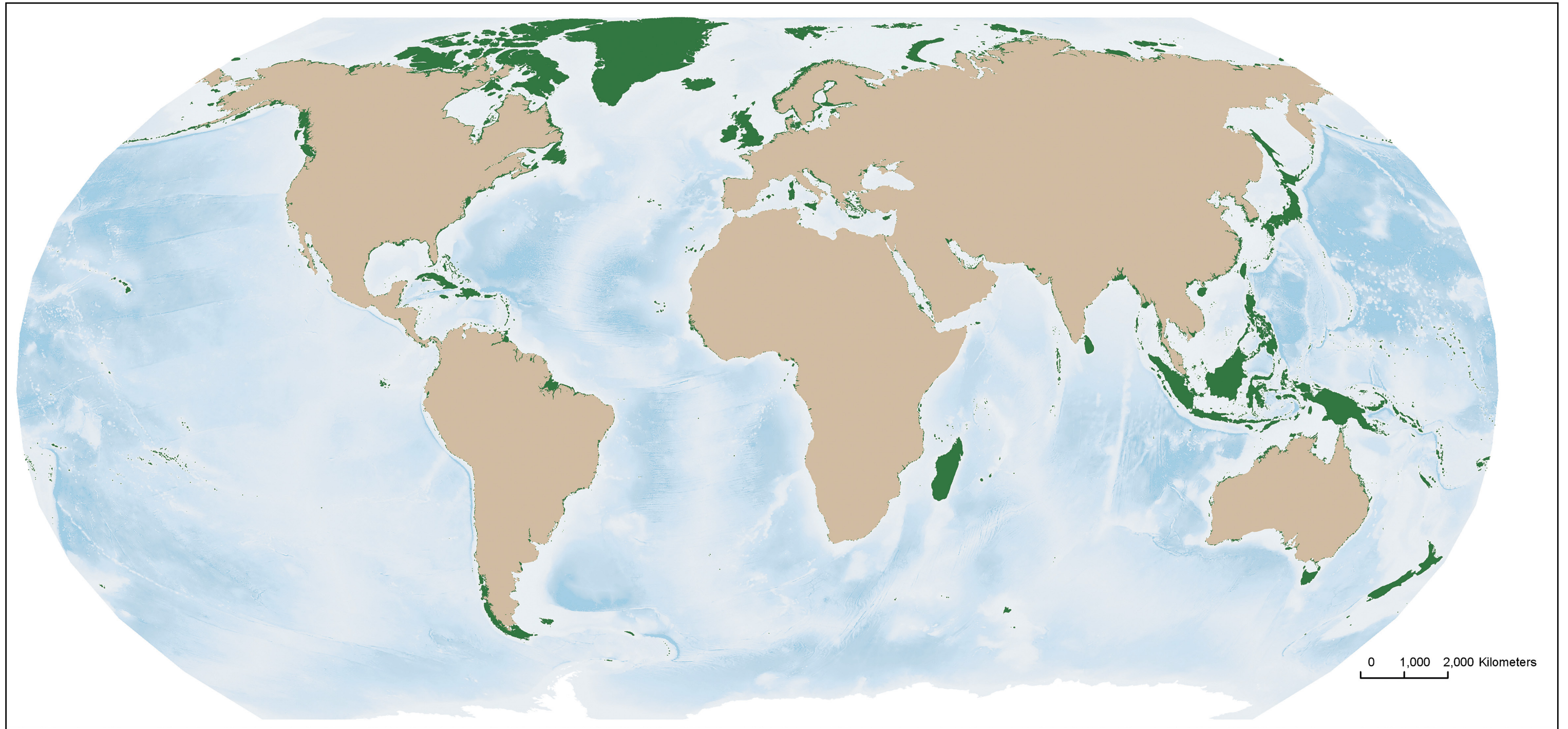


Figure 2. The islands of the Americas.

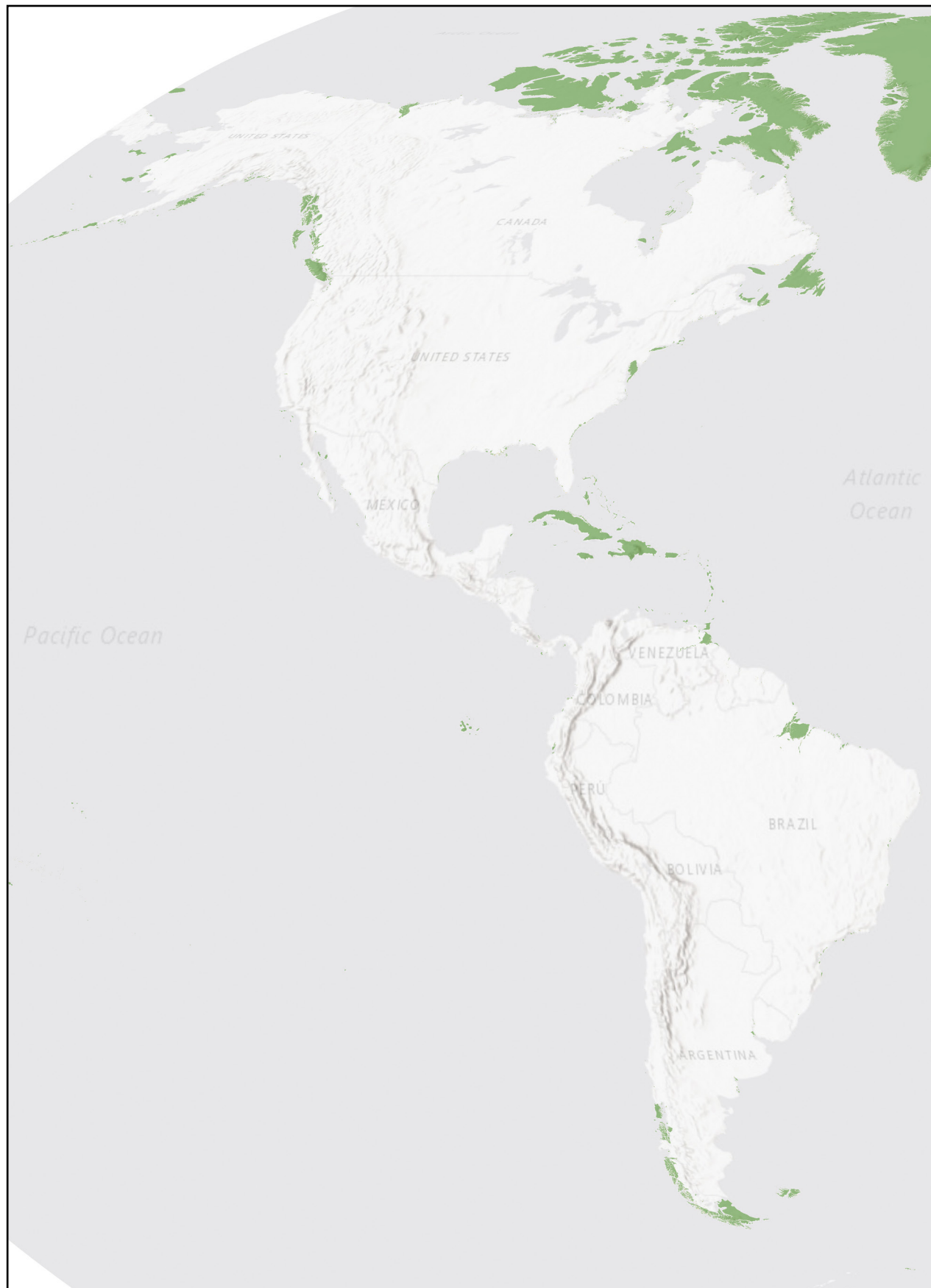


Figure 3. The islands of Africa and Europe.

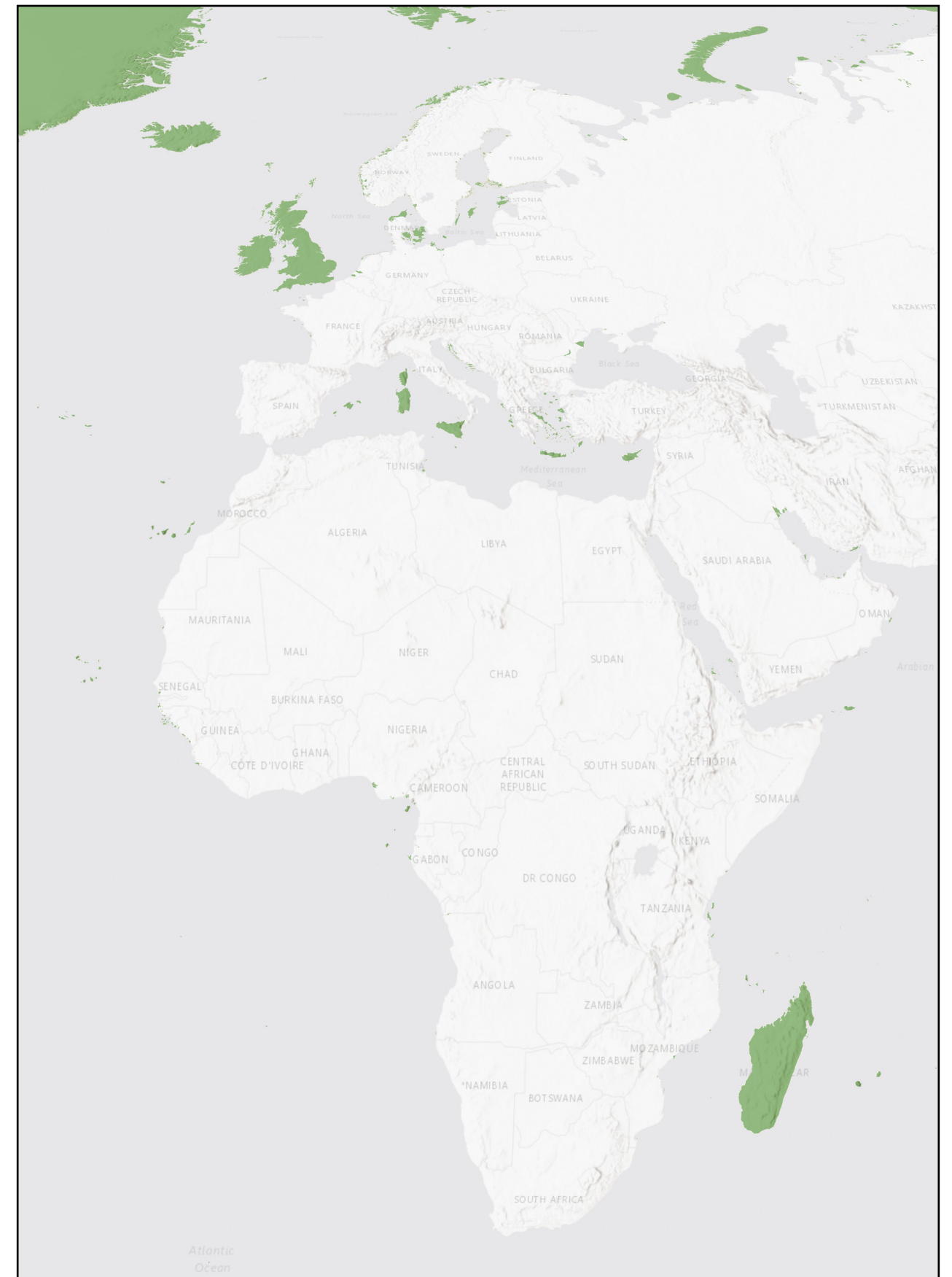


Figure 4. The islands of Australia and the southwest Pacific Ocean.



Figure 5. The islands of the Caribbean Sea. Large islands ($>1\text{km}^2$) are depicted in green; small islands ($<1\text{km}^2$) are depicted in gold.



Figure 6. The islands of the Aegean Sea. Large islands (>1km²) are depicted in green; small islands (<1km²) are depicted in gold.



Figure 7. The islands of Patagonia. Large islands (>1km²) are depicted in green; small islands (<1km²) are depicted in gold.



Figure 8. The islands of New Caledonia. Large islands (>1km²) are depicted in green; small islands (<1km²) are depicted in gold.



Figure 9. The islands of Belize. Large islands (>1km²) are depicted in green; small islands (<1km²) are depicted in gold.

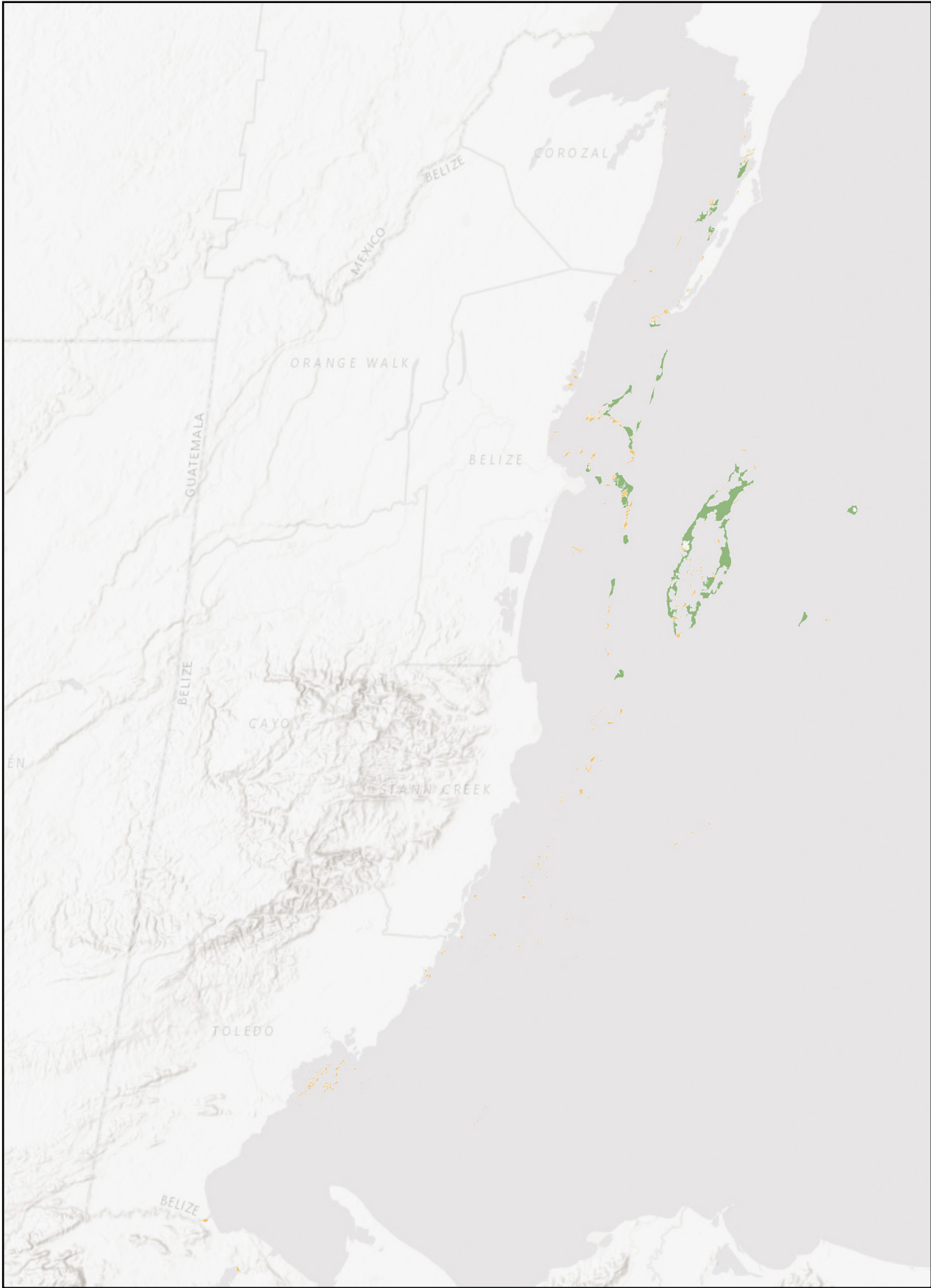


Figure 10. The islands of the Florida Keys, USA, and northwestern Cuba. Large islands ($>1\text{km}^2$) are depicted in green; small islands ($<1\text{km}^2$) are depicted in gold.

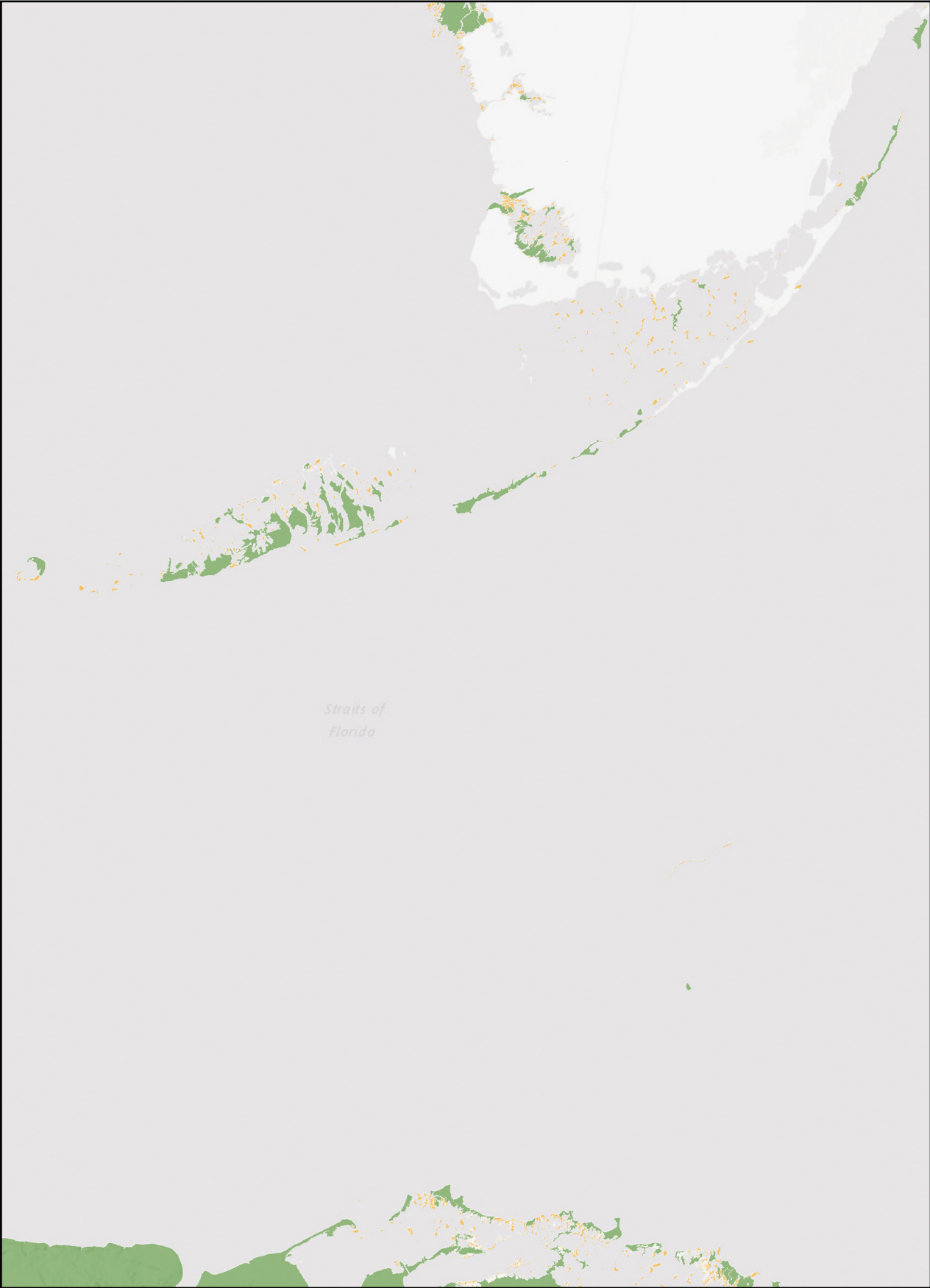


Figure 11. The islands of the Outer Hebrides Islands, Scotland. Large islands ($>1\text{km}^2$) are depicted in green; small islands ($<1\text{km}^2$) are depicted in gold.



The Global Island Explorer

The global islands data can easily be visualized, queried and analyzed using GIS technologies, but to make the data easily accessible to the broadest possible audience we also developed a Global Islands Explorer tool (GIE: <https://rmgsc.cr.usgs.gov/gie/>). The GIE is a web-based island data exploration application that only requires internet access for use. It is an open access resource which will be maintained, and GIE functionality will eventually be expanded

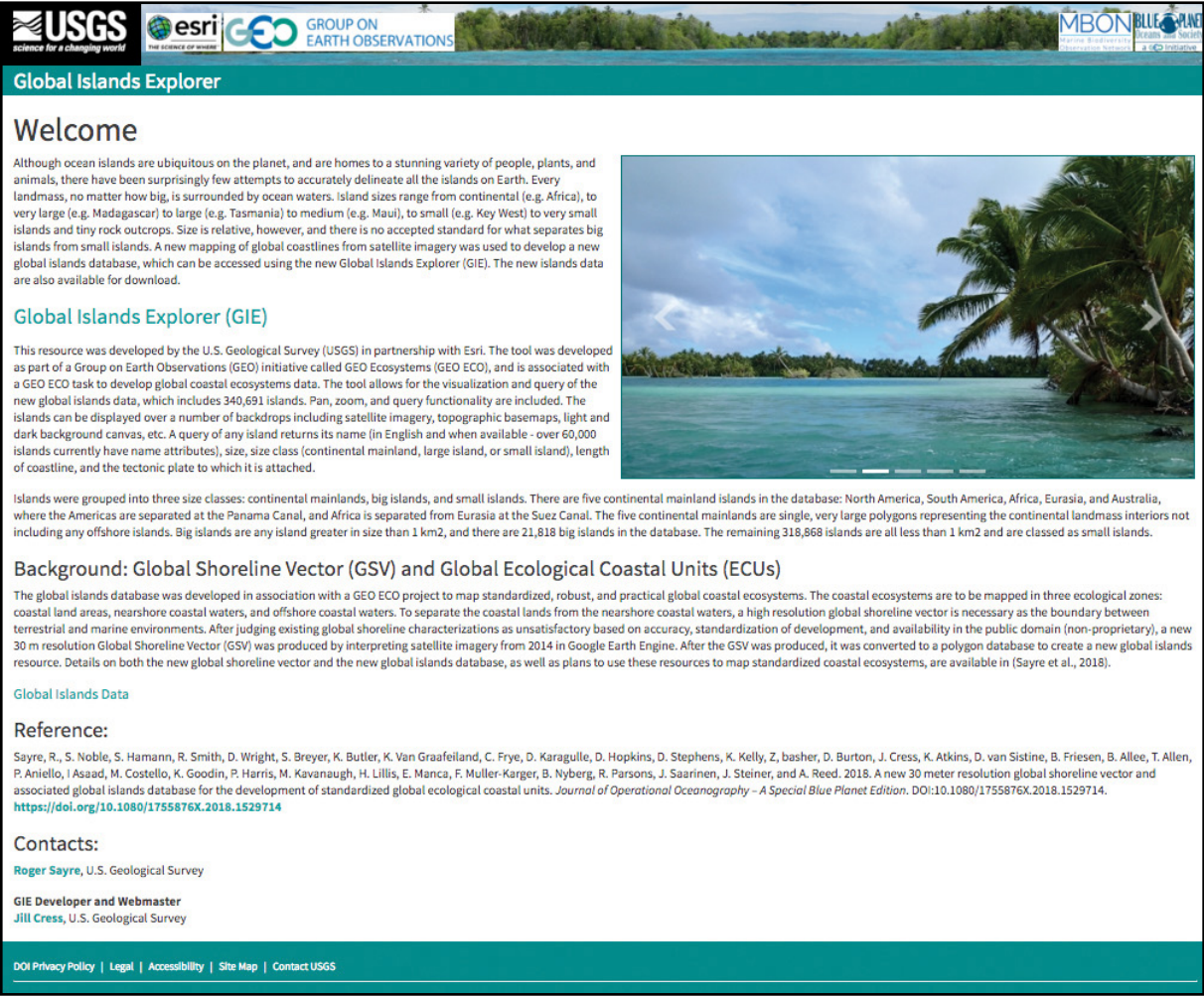
beyond simple exploration to include limited analysis (e.g. feature counts, buffering, etc.) Currently, pan, zoom and query functions are included, as is a text-based exploration tool allowing users to explore any geography of interest by typing in the name of an island or region. The island data are served as raster image services, but are available for download in their original vector polygon format. The welcome page for the GIE is presented in Figure 12.

Accessing the Data

The global islands data and the GIE tool are open data resources available without a login requirement from the Esri Living Atlas (<http://livingatlas.arcgis.com>) and elsewhere in the ArcGIS Online content. The islands data are therefore easily integrated with hundreds of other datasets representing the most current, detailed, authoritative, and curated GIS-ready global islands data available. This integration is easily accomplished without the need for

downloading, preparing, and reconciling disparate datasets by the user. The islands data are also available in the public domain at the U.S. Geological Survey’s Global Ecosystems webpage and resources (<https://rmgsc.cr.usgs.gov/outgoing/ecosystems/Global/>). While the data are available in ArcGIS formats, they are also accessible as polygon features in an Open Geospatial Consortium (OGC) Geo Package, or similar, format.

Figure 12. The welcome page of the Global Island Explorer tool.



Conclusion

In a first-of-its kind effort, spatial data on the locations and shapes of the islands of the Earth were extracted from satellite imagery in a standardized and replicable process. A new global islands datalayer was produced which is more current, comprehensive, and accurate than existing global island data products. The new islands data are available as polygons for use in GIS technologies, and for other non-specialist audiences the data are easily accessed and

explored using a new web-based Global Island Explorer tool. The data are intended to be useful in assessments of island biodiversity, ecological processes, and ecosystem accounting, and could also be useful for resource management and planning at multiple scales. Maps describing the island distributions at global, continental, regional, national and subnational scales are presented herein. Access to the data is open.

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