2. WHERE ARE THE NEARSHORE RESOURCES LOCATED? *SATELLITE MAPPING OF NEARSHORE HABITATS*

What did we do, and why is this information important?

Bathymetry is the foundation for much ocean science and policy. In the same way that topographic maps represent the three-dimensional features of the terrain on land, bathymetric maps illustrate the terrain that lies underwater. Bathymetric data, which include information about the depths and shapes of underwater terrain, are essential for characterizing marine habitats and have a range of important management applications. Bathymetry is a key element of biological oceanography. The depth and characteristics of the seabed define the habitat for benthic (bottom-dwelling) organisms and are fundamental aspects of marine ecosystems. Nearshore bathymetric data are increasingly important as scientists learn more about the effects of tsunamis, cyclones, and climate change-driven sea level rise on coastal communities and economies.

Bathymetric data for shallow-water areas are critical for assessing the status of coral reef ecosystems located there, as the exchange of nutrients, sediments, and pollutants between the land and ocean must pass through these habitats. It is also an area susceptible to anthropogenic impacts, such as sedimentation, nutrient enrichment, and ship groundings. Perhaps most importantly for the people and coastal communities of Timor-Leste, these nearshore areas provide food and livelihoods (Figure 2). Therefore, these data can be useful in helping protect and manage these fragile resources that support high levels of biodiversity.

Figure 2. A panoramic view of local fishers reef gleaning at low tide on the north coast of Timor-Leste near Manatuto (*top*) and a close-up showing two of the fishers gleaning (*bottom*).

Bathymetric data can be acquired by many techniques, each with varying degrees of accuracy and resolution. Collecting bathymetric data for shallow-water habitats can be challenging—especially in remote locations—as many available options are logistically unfeasible or prohibitively expensive. For such locations, satellite-derived bathymetry, also referred to as estimated depths, has been shown to be an effective technique. NOAA-CREP has developed and refined methods for deriving depth from high-resolution WorldView-2 satellite imagery for shallow-water coral reef habitats (Ehses and Rooney 2015). Along with the satellite-derived depths, NOAA-CREP has also developed new methods of identifying different marine habitats (e.g., sand flats, seagrasses) by interpreting patterns in seafloor terrain from WorldView-2 satellite imagery for the shallow-water habitats.

NOAA-CREP has applied these two methods here to develop baseline maps for the nearshore habitats along the coastline of Timor-Leste.

Where and how did we do it?

Satellite Imagery Acquisition and Analysis

The region of interest for this mapping effort focused on coastal shallow-water habitats (Figure 3). NOAA-CREP contracted with DigitalGlobe (http://www.digitalglobe.com/) for the acquisition of high-resolution WorldView-2 satellite imagery for the coastline of Timor-Leste. The WorldView-2 imagery is composed of 8-multispectral imaging bands, including a coastal band that allows for greater penetration in clear waters, an important consideration in bathymetric mapping of nearshore habitats (DigitalGlobe 2010). The spatial resolution of the WorldView-2 imagery varies from 46–52 cm for panchromatic and from 184–210 cm for multispectral.

We evaluated both archived and newly collected image swaths with DigitalGlobe ensuring the highest quality images available for each of the regions were purchased. Images for the south shore were specifically acquired during the dry season in September and October, assuming the nearshore waters would be less turbid at that time, thereby improving the quality of those images. DigitalGlobe permitted us to decline images for the same area up to three times before making a final selection. Images with minimal cloud cover, water turbidity, and sun glint (the amount of light reflected from the ocean surface) and with a higher solar elevation angle (angle of the sun above the horizon) were selected. DigitalGlobe was unable to fulfill our quality requirements for all regions and therefore provided an excess set of images to peruse. A method referred to as “cloud patching” had to be applied to some areas, especially along the shore of Timor-Leste, using cloud-free portions of an image rather than the whole image for processing.

Altogether, 104 high-resolution unprocessed WorldView-2 satellite images, collected between January 2010 and August 2014, were acquired for Timor-Leste (Appendix B). Each image provided by DigitalGlobe was roughly clipped to the region of interest boundaries; areas outside the region of interest were masked out (Figure 3). Complete image coverage was achieved for the coastlines of Oecusse, Atauro Island, and the north and south shores of Timor-Leste. Overall challenges in acquiring WorldView-2 imagery of sufficient quality included cloud cover, sun angle and glint, waves and whitewater, and particularly, nearshore turbidity caused by run-off of terrestrial sediments during heavy rains.

After evaluating the quality of each image, 68 were deemed suitable for potentially deriving depths or for benthic habitat classification (Figure 3). The remaining images were either unsuitable due to high turbidity, cloud cover, etc., or they overlapped with higher quality images; therefore, further processing of these images was not required.

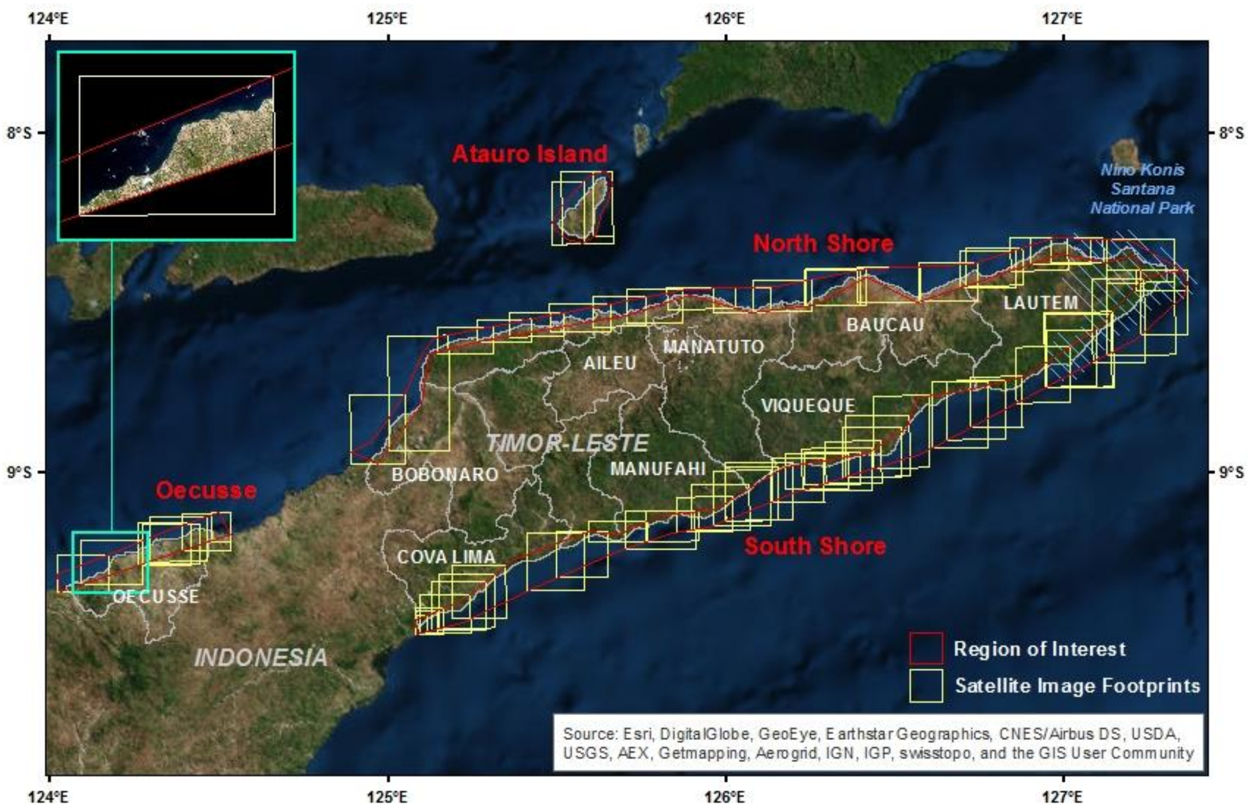

Figure 3. Map showing the region of interest outlined in red around Timor-Leste of which 68 WorldView-2 satellite images were acquired and georeferenced (yellow boxes). Inset shows an example of the extent for one satellite image that was clipped to the region of interest.

The typical geolocation accuracy of a standard WorldView-2 product is in the range of 4–5 m. Depth estimations are sensitive to high geographic accuracy because *in-situ* depth values (i.e., ground-truth data) correspond to specific coordinates. Therefore, our goal was improving the accuracy of the raw images' geographic location by associating them to a georeferenced basemap. At the time, the only known available large-scale basemap covering Timor-Leste was an ESRI ArcGIS online map (http://www.esri.com/data/basemaps). This was used to georeference the 68 raw satellite images.

Prior to extracting estimates of depth based on coastal, blue, green, and yellow bands in the georeferenced satellite image, radiometric corrections were applied using DigitalGlobe's established processing procedures. Depth soundings, collected during NOAA-CREP's field operations in Timor-Leste in October 2012 and June 2013, were then used to validate or ground truth the estimated depths derived from the satellite imagery (Figure 4). Next, benthic habitats were classified into one of 12 different habitat classes. Areas that could not be classified, primarily due to the depth limitations of satellite imagery, were labeled as unknown. See Appendix C for details on the processes to derive estimated depths and classify benthic features from WorldView-2 satellite imagery and available ground-truth data.

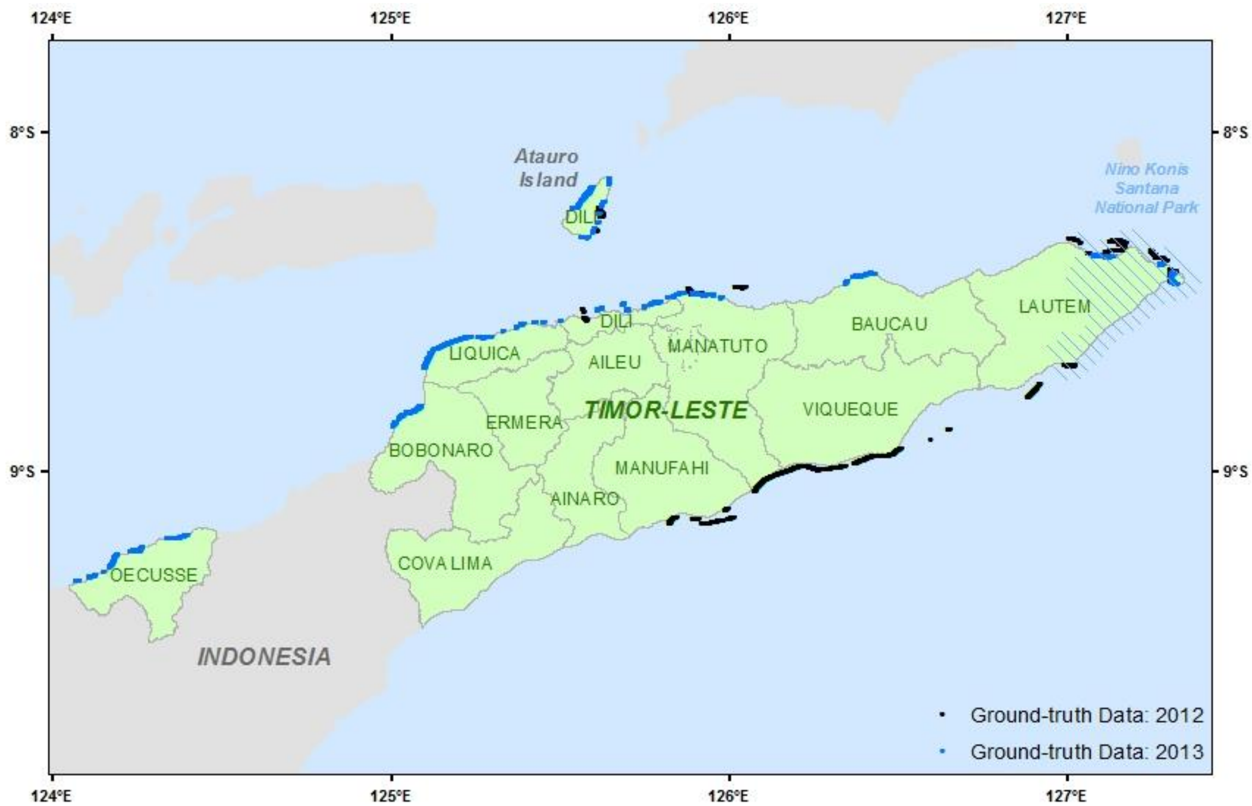

Figure 4. Depth soundings collected during NOAA-CREP surveys in 2012 (black) and 2013 (blue) used to validate the estimated depths derived from the satellite imagery.

What did we accomplish?

Bathymetry

We generated satellite-derived bathymetry in shallow waters, from the shoreline to approximately 15-m depths, for Atauro Island, Oecusse, and most of the north shore of Timor-Leste with relatively small gaps (Figure 5). These gaps mainly occur in areas of surf, breaking waves, and intensive glint. Insufficient depth soundings which would support effective groundtruthing and prolonged periods of high turbidity (i.e., low visibility) caused by extensive rain and sediment runoff prevented the calculation of reliable estimated depths for the entire south coast. In total, we derived estimated depths over a ~120.0 km^2 area surrounding Atauro Island (15.1 km^2), Oecusse (19.3 km^2), and the north shore of Timor-Leste (85.6 km^2; Table 1).

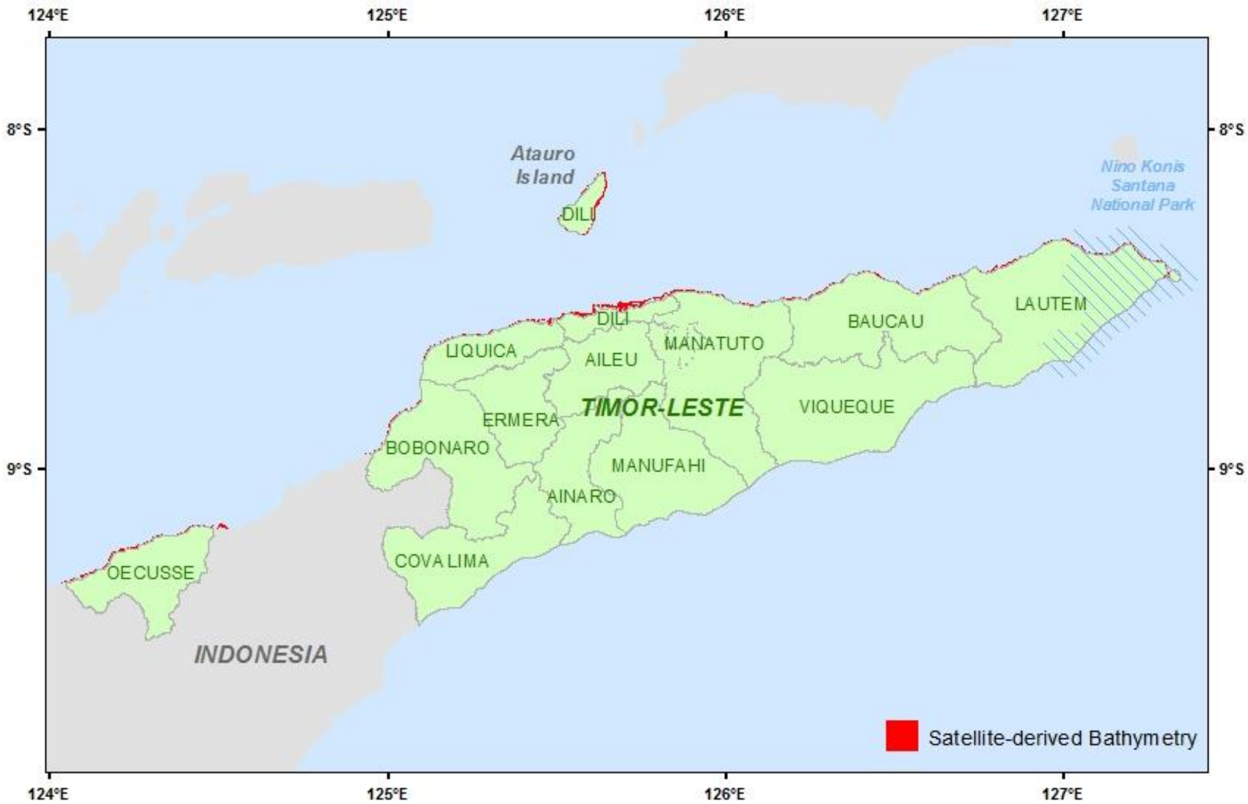

Figure 5. The extent of the satellite-derived bathymetry prepared for Timor-Leste is shown in red.

Table 1. Summary of the satellite-derived bathymetry and habitat classification efforts. 'Derived Bathymetry' and 'Benthic Habitat' is the area mapped by region (km^2). 'Unknown' is the area that could not be classified and is therefore excluded from the 'Benthic Habitat' area. The remaining columns in light green show the benthic habitat characterized for each region (km^2) that are included in the 'Benthic Habitat' area.

Region	Derived Bathymetry (km^2)	Benthic Habitat (km^2)	Hard Substrate (km^2)	Soft Substrate (km^2)	Seagrass (km^2)	Mangrove (km^2)	Macroalgae (km^2)	Intertidal (km^2)	Emergent Rocks (km^2)	Lagoon (km^2)	Unknown (km^2)
Atauro Island	15.1	13.1	7.1	3.6	2.4	0.1	–	–	–	–	7.7
Oecusse	19.3	12.6	3.8	6.8	2.0	< 0.1	–	–	–	–	16.8
North Shore	85.6	76.9	35.1	16.3	10.5	2.7	6.2	3.3	0.5	2.3	249.1
South Shore	–	32.7	14.3	15.3	3.0	0.1	–	–	–	–	120.0
Total	**120.0**	**135.3**	**60.3**	**41.9**	**17.9**	**2.9**	**6.2**	**3.3**	**0.5**	**2.3**	**393.6**

Benthic Habitat

Benthic habitat area by region is less than the satellite-derived bathymetry coverage in the three regions where both were derived; Atauro, Oecusse, and North Shore. This is due to the depth limitations of the satellite imagery and the lack of available validation data for the habitat classifications (Table 1). Like the estimated depth calculations, the quality of benthic habitat classifications is highly dependent on the quality of the images; good visibility is essential. Therefore, the largest gaps in the benthic habitat dataset are along the southern coast of Timor-Leste (Figure 6). Further, the lack of sufficient *in-situ* habitat data across the entire region was problematic. In lieu of having sufficient validation data, local knowledge and visual interpretations of the benthos were used to aid in the benthic habitat characterization. Despite these challenges, we can provide a partial benthic habitat dataset for the shallow (0–20 m) coastal seafloor around Timor-Leste. The resulting dataset summarized 12 characterized habitat classes into 8 habitat types, including: 1) hard substrate, 2) soft substrate, 3) seagrass, 4) mangrove, 5) macroalgae, 6) intertidal, 7) emergent rocks, and 8) lagoon. In total, benthic habitat data covering 135.3 km^2 of nearshore habitats in Timor-Leste (excluding unknown areas) were developed around Atauro Island (13.1 km^2), along the coast of Oecusse (12.6 km^2), and along the north and south shores (76.9 km^2 and 32.7 km^2, respectively; Table 1). We were not able to assess the quality of the benthic habitat classifications due to the lack of ground-truth data.

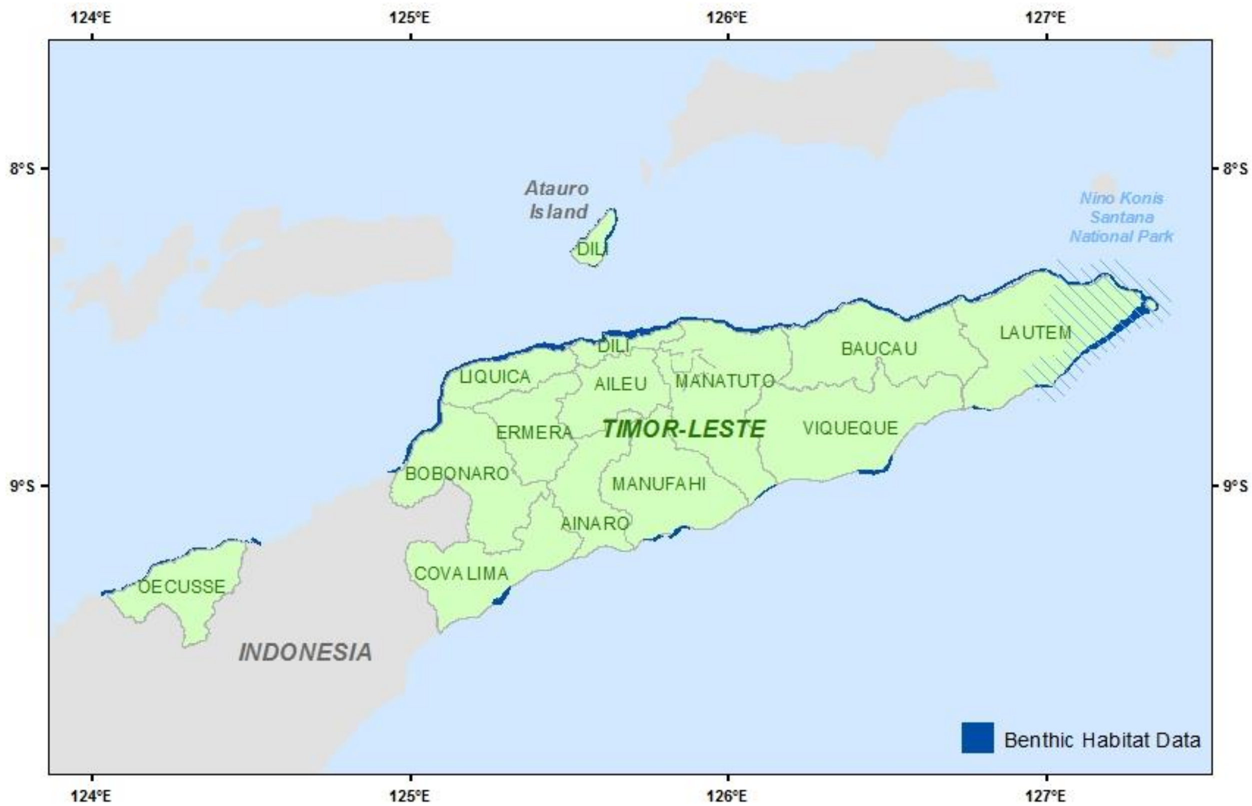

Figure 6. The extent of the benthic habitat dataset prepared for Timor-Leste is shown in blue.

Detailed Maps

A "Map Book" containing a collection of detailed bathymetry and benthic habitat maps for the entire coastline of Timor-Leste has been developed (Appendix D). The maps include additional information allowing for wider utilization, including the location of the NOAA-CREP baseline reef assessment and climate survey sites, satellite imagery for the land area, water features, district boundaries, and place names. High-resolution maps are also provided to better characterize each of the climate survey sites (Appendix E).

Poster Presentation

The process of this satellite mapping work for Timor-Leste was presented in a poster at the 13th International Coral Reef Symposium held in Honolulu, Hawaii in June 2016. See Appendix F for a reduced-size copy of the poster titled *WorldView-2 Satellite Mapping of the Nearshore Ecosystems around Timor-Leste: Goals, Challenges and Accomplishments*.