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Technical Report: Development and trialing of a procedure for the identification of priority Ridge to Reef sites in the Solomon Islands

Technical Report:
Development and trialing of a procedure for the identification of priority R2R sites in the Solomon Islands

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Abbreviations

GEBCO - Global Bathymetric Chart of Oceans

GEF – Global Environment Facility

GIS – Geographic Information Systems

InVEST – Integrated Valuation of Ecosystem Services and Tradeoffs

IW R2R – International Waters Ridge to Reef

LULC – land use land cover

NASA – National Aeronautics and Space Administration

NDVI – Normalized Difference Vegetation Index

PICT – Pacific Island Countries and Territories

SDR – Sediment Delivery Ratio

SPC – Pacific Community

SRTM – Shuttle Radar Topography Mission

TSS – Total Suspended Solids

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Introduction

The Regional International Waters Ridge to Reef (IW R2R) Project is executed regionally by the Pacific Community (SPC), based in Suva, Fiji. The Regional IW R2R Project is part of the larger 5-year GEF-funded Regional Pacific Ridge to Reef Program being implemented by UNDP, UNE and FAO, and SPC across fourteen Pacific Islands countries: Cook Islands, Federated States of Micronesia, Fiji, Kiribati, Nauru, Niue, Palau, Papua New Guinea, Republic of the Marshall Islands, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu.

In bringing together countries that face similar threats to fresh and coastal water systems, the Regional IW R2R Project aims to test the mainstreaming of ridge-to-reef, climate-resilient approaches to integrated land, water, forest and coastal management in the PICs through strategic planning, capacity building and piloted local actions. The Project is implementing a variety of practical approaches to safeguarding water systems and coastal habitats in the fourteen participating countries with the aim of engaging and supporting national governments and local communities to build the knowledge base to better understand the cause-and-effect relationship of the 'whole-of-island' environmental degradation and develop the skills and systems to better manage these impacts.

Within project activities, there is also a focus on strengthening scientific understanding of the current state of priority coastal areas, and support for the development and endorsement of national and regional strategic action frameworks for ICM/IWRM. The aim of these strategic action frameworks is to meet the regional need for the mainstreaming of the ridge-to-reef approaches in national development planning. One project activity is the development and trialing of a spatial prioritization process to identify priority R2R project sites using a land-sea linkage approach for a case study in the Solomon Islands.

In recent years, the Solomon Islands have undergone extensive deforestation due to urbanization, fire, agricultural expansion, and timber supply to Asian markets (Global Forest Watch 2022, Gibson 2018). An estimated 71.5 kha of humid primary forest and 101.8 kha of tree cover was deforested between the years 2015-2020 based on satellite imagery analysis, resulting in an annual decrease of ~0.52% of primary forest and ~0.61% of all tree cover in the Solomon Islands (GlobalForestWatch 2022). This same dataset suggested that ~90% of deforestation within the Solomon Islands occurred because of agricultural expansion, but other studies have suggested that unsustainable logging has been a driver of forest change within the country. The standard forestry practices within the Solomon Islands involve selective logging for high-value timber with cut-size limitations to produce a sustainable trade, but these practices are difficult to enforce (Katovai et al. 2015), and it is believed that up to seven times the sustainable limit (250,000 m^3yr^{-1}) has been harvested annually in previous years (Hughes et al. 2010). Regardless of the driver of deforestation, most of the forest loss over the last decade has occurred in the Western province, around the capital of Honiara in the Guadalcanal province, and in the Malaita province (Hansen et al. 2013, Gibson 2018).

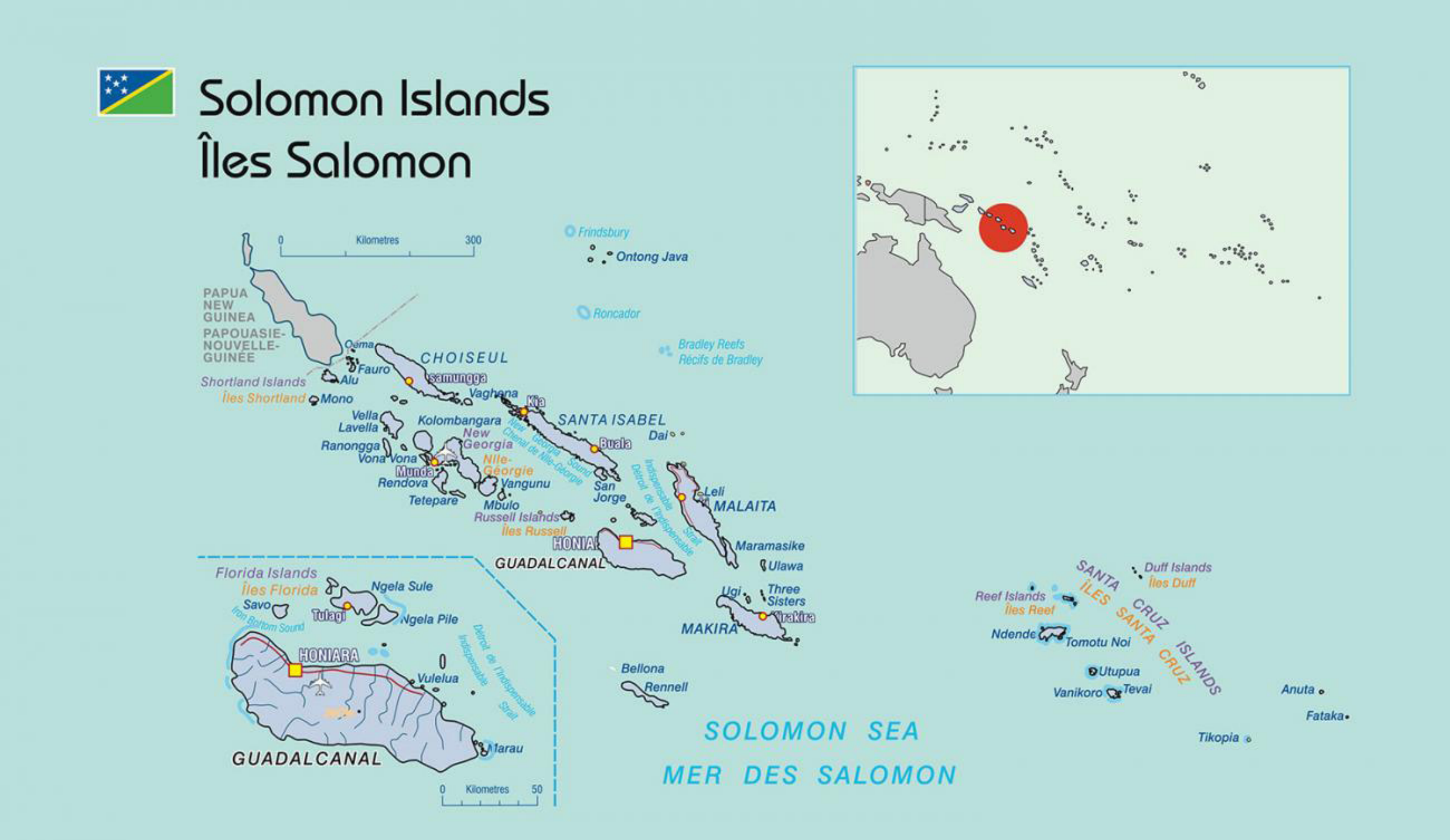
The effects of soil loss and sedimentation from the current land activities on both surface water quality and the marine environment have been studied at local sites but not extensively investigated throughout the Solomon Islands. The Jejevo catchment on Isabel Island was extensively modelled using combinations of land-sea linkage models, and the results suggested that data complex models are often highly successful in modelling to marine environments (Hutley et al. 2020). However, sedimentation data needed to calibrate these models are scarce (Hutley et al. 2020). Additionally, model simulations suggested that increased logging on Kolombangara Island, Solomon Islands nullified the effects of best management practices (Wenger et al. 2018) and the resulting increased sedimentation negatively impacted both corals and grazer fish communities that are often a large component of subsistence fisheries (Wenger et al. 2020). These studies provide powerful tools for assessing land-sea linkage impacts, but data are often limited to produce robust results of these applications at a broader scale.

Mataniko Catchment, located adjacent to the capital of Honiara on the island of Guadalcanal, is a watershed of particular concern as it has been identified as a high flood risk and hazard area, and it provides essential water resources to the capital. The catchment has been identified as a priority site for R2R activities, and data has been collected on water quality and both terrestrial and marine biodiversity (Sobey 2020). In particular, the Mataniko Catchment Integrated Watershed Plan identifies the need for reducing forestry impacts on water quality as well as restoration of the watershed to minimize impacts on the environment. Identification of priority sites for restoration and protection is essential for meeting the goals of the Integrated Watershed Plan and protection of resources, as well as identifying areas to channel funding for projects to improve management decisions.

For this study, we integrated existing frameworks that were developed for the spatial prioritization of R2R sites within Vanuatu (Delevaux and Stamoulis 2018) and the Solomon Islands (Hutley et al. 2020, Wenger et al. 2018, Wenger et al. 2020) with a few modifications implemented for this application. This approach uses a sediment erosion model to estimate sediment export/load at the catchment scale and summarizes the annual soil load at the catchment outlet. Using the catchment outlet as the land-sea linkage, a water quality model is then used to estimate the spatial extent of the sediment plume as it extends into the coastal environment. The area of coral reef habitat that is exposed to the plume in terms of suspended solids is summarized per catchment. The total amount of sediment load, area of high sediment export and coral area impacted under the sediment plume are used to rank and prioritize catchments within the area of interest.

In addition to ranking catchments for prioritization based on current conditions, scenario modeling used to estimate conditions under alternative management practices. Relative changes in catchment rankings can then be used for further prioritization of R2R projects and guide other land management. In this study, we focus on spatial prioritization at two tiers: a broader national approach for all catchments within the Solomon Islands and a localized application for the Mataniko Catchment.

The objectives of this project were to 1) model the impact of current land practices on sediment erosion and export, 2) link the resulting sediment export to the marine environment through a water quality model, 3) provide both local (Mataniko catchment) and national reporting to identify areas of concern under current conditions, and 4) use scenario modelling the effects of reforestation in the Mataniko watershed and a 10-year projection of a business-as-usual deforestation scenario for identification of priority R2R sites across the Solomon Islands. The study also examined an additional objective of modelling the combined effects of reforestation and protected areas scenarios to identify and select priority sites and areas for protection.



Methods

Site Description

The Solomon Islands is an island nation consisting of over 900 islands with a combined land area of 28,400 km^2 and an exclusive economic zone of 1,589,477 km^2. There are nine administrative provinces: Central, Choiseul, Guadalcanal, Isabel, Makira-Ulawa, Malaita, Rennell and Bellona, Temotu, and Western provinces. The nine administrative provinces vary in size and population but all are generally largely forested (Table 1, Figure 1.). Mean annual precipitation is approximately 3,000 mm per year throughout the country, although variation exists across the regions. Elevation and topography range from low-lying coastal areas to steep mountains, with the highest peak occurring at 2,335 m on Mount Makarakomburu on Guadalcanal Island.

Table 1. Nine administrative regions of Solomon Islands and the land use land cover composition (km^2) derived from European Space Agency World Cover 2020 (Zanaga et al. 2020).

Region	Forest Cover	Grassland Cover	Cropland Cover	Urban Cover	Barren Ground	Land Area (ha)
Central	629.3 (86.7%)	32.6 (4.5%)	0.0 (0.0%)	0.9 (0.1%)	8.9 (1.2%)	726.0
Choiseul	3,572.4 (95.3%)	12.7 (0.3%)	0.2 (0.0%)	0.2 (0.0%)	13.4 (0.4%)	3,749.6
Guadalcanal	5,803 (94.8%)	214.8 (3.5%)	4.7 (0.1%)	11.4 (0.2%)	45.0 90.7%)	6,119.1
Isabel	4,426.0 (92.3%)	18.0 (0.4%)	0.3 (0.0%)	0.9 (0.0%)	18.6 (0.4%)	4,793.7
Makira-Ulawa	3,306.6 (98.3%)	16.3 (0.4%)	0.4 (0.0%)	0.6 (0.0%)	11.3 (0.3%)	3,667.8
Malaita	4,502.5 (94.0%)	79.0 (1.7%)	0.2 (0.0%)	3.3 (0.1%)	11.3 (0.2%)	4,791.4
Rennell-Bellona	758.9 (99.0%)	3.0 (0.4%)	0.0 (0.0%)	0.2 (0.0%)	1.7 (0.2%)	766.1
Temotu	942.8 (94.7%)	7.8 (0.8%)	0.0 (0.0%)	0.4 (0.0%)	5.1 (0.5%)	995.6
Western	5,900.0 (95.4%)	55.9 (0.9%)	0.4 (0.0%)	2.3 (0.0%)	27.0 (0.4%)	6,186.5

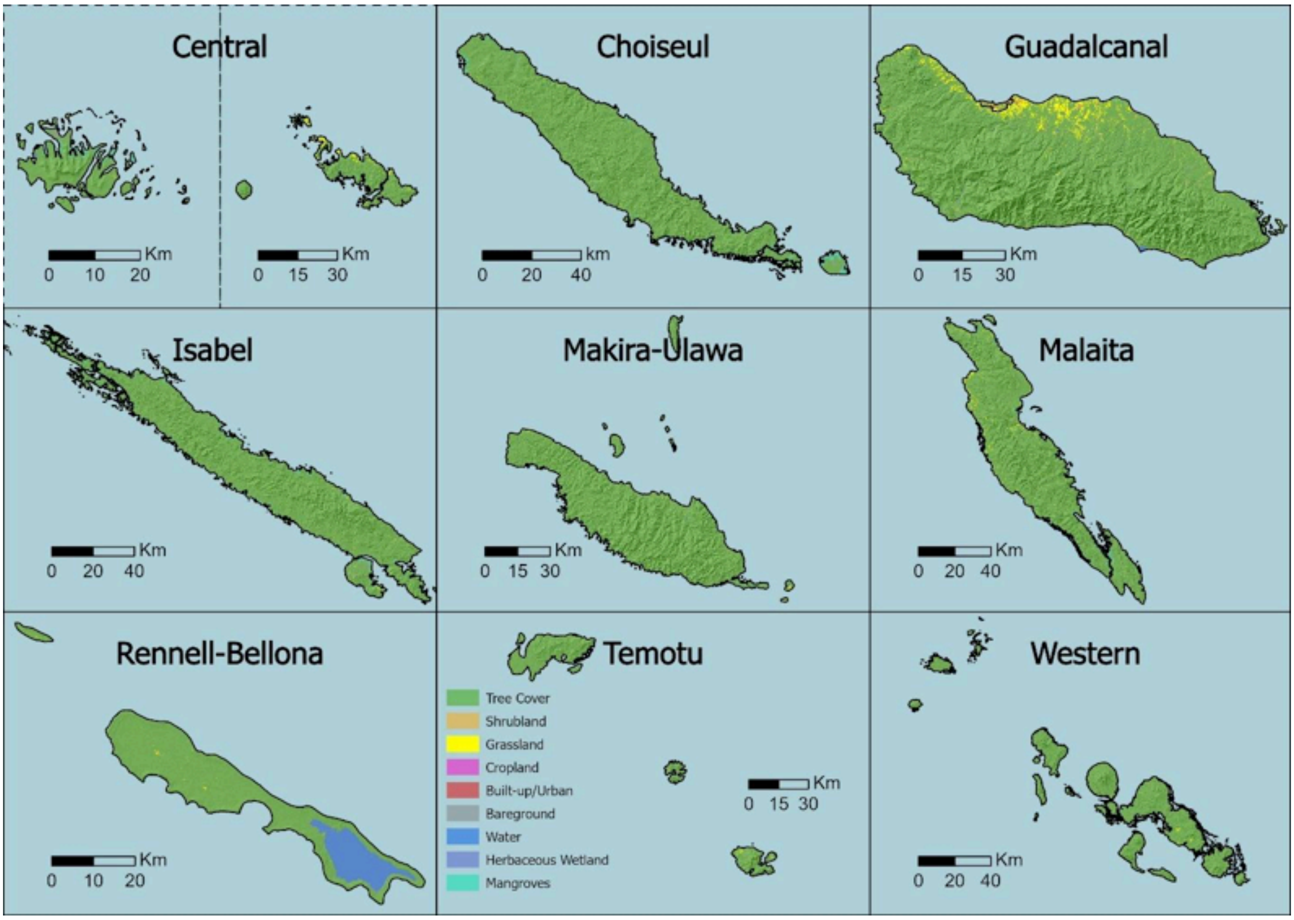


Figure 1. Land use land cover maps of the nine administrative regions in the Solomon Islands derived from European Space Agency World Cover 2020.

The Mataniko watershed and catchment (~5,700 ha) is located on Guadalcanal Island and borders the capital city of Honiara. Mataniko Catchment is densely populated, with approximately 5,114 people per square km (Trundle and McEnvoy 2016). The area is characterized by open grassland areas that have been deforested near Honiara and steep forested areas in the mountainous areas that extend more inland. Soils are largely clay loams, and elevation ranges from low coastal areas to ~750 m in elevation near the mountainous zones (Figure 2).

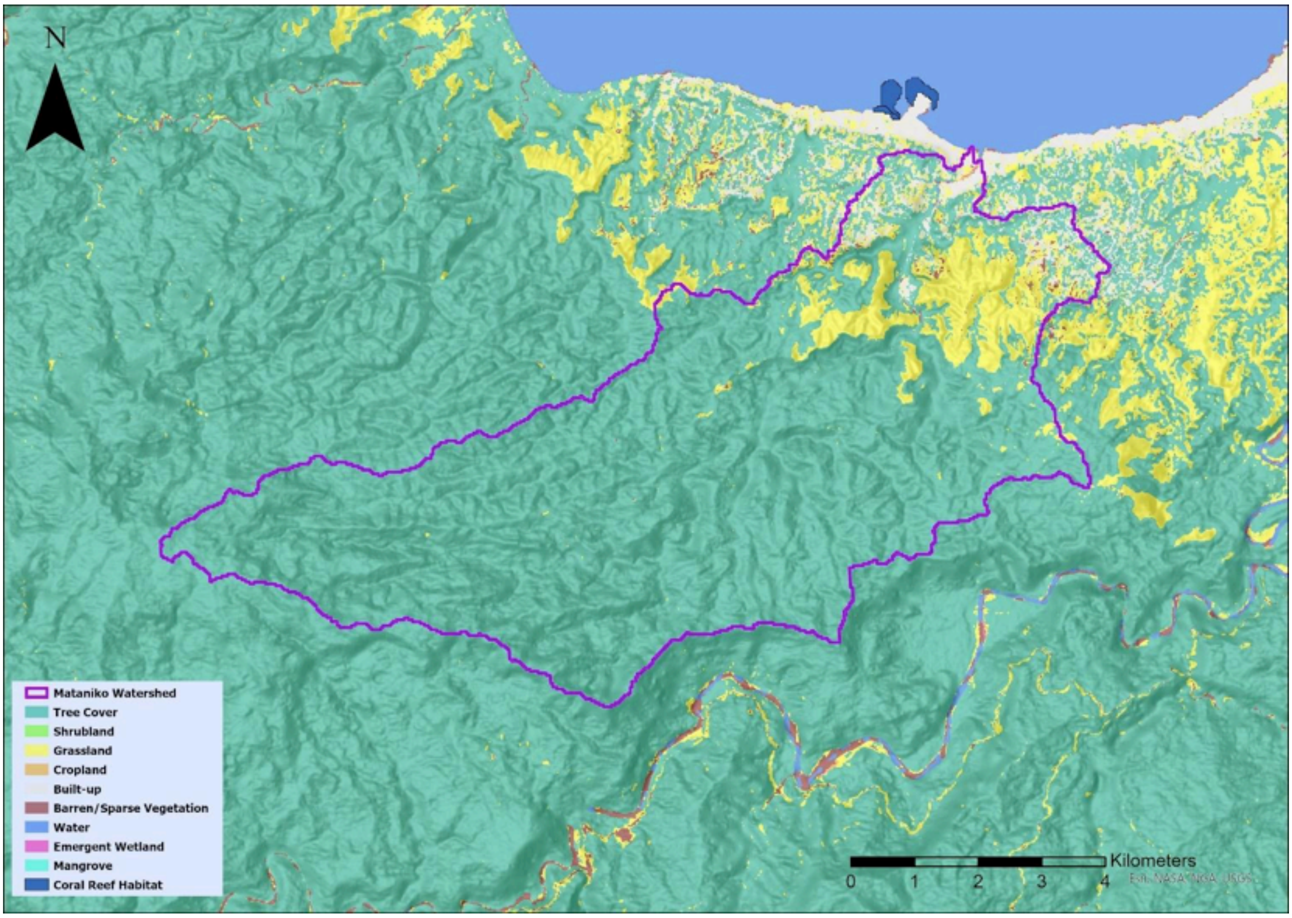


Figure 2. Land use land cover and hillside map of Mataniko Catchment, Solomon Islands, derived from European Space Agency World Cover 2020 and SRTM DEM.

Sedimentation Model – InVEST SDR Model

The Natural Capital Project's Integrated Valuation of Ecosystem Services and Tradeoffs Sediment Delivery Ratio Model (InVEST SDR version 3.9) was used to model annual soil erosion and sediment export for catchments (Sharp et al. 2020, Hamel et al. 2015, Tallis and Polasky 2009). InVEST SDR estimates sediment yield ($t.yr^{-1}$) by combining the revised universal soil loss equation (RUSLE) and a flow path algorithm that uses a connectivity index to account for upslope and downslope conditions (Borselli et al. 2008). A stream layer is derived from a digital elevation model (DEM) using a specified user-flow accumulation threshold and any sediment that flows into the steam network is assumed to be exported to the catchment outlet. It is important to note in the interpretation of model outputs that the model does not consider gully erosion or in-stream processes and therefore any deposition within streams is not considered in the model. InVEST SDR produces outputs at two scales: sediment export and retention per raster cell (set as the resolution of the digital elevation model: see below) and the sum of total sediment exported to streams and therefore exported at the catchment outlet.

InVEST SDR first calculates potential overland soil loss using RUSLE (equation 1) (Renard et al. 1997)

$$A = R \times K \times LS \times C \times P \qquad (1)$$

where A is the annual rate of soil loss ($t.yr^{-1}$), R is a factor for annual rainfall erosivity ($MJ.mm.ha^{-1}.hr^{-1}$), K is a factor for soil erodibility ($t.ha.hrs.MJ^{-1}.ha^{-1}.mm^{-1}$), LS is a factor for slope length and gradient/steepness (unitless), C is a factor for cover-management (unitless), and P is a factor for supporting practices (unitless).

Rainfall erosivity (R) can be calculated from monthly or annual average rainfall data using a variety of methods and equations. For this study, erosivity was calculated from average monthly precipitation data using the Roose equation (1996) with a multiplier of 0.5 that was used in similar studies throughout the region (Wenger et al. 2018, Hutley et al. 2020) (equation 2). Monthly average precipitation was calculated using the WorldClim2 dataset, a global spatial data that contains monthly averages from the years 1970-2020 at 1 km resolution (Fick and Hijmans 2017). The monthly average raster datasets were then averaged to create one monthly average for 1970-2000 using the Raster Math tool in ArcGIS and then multiplied by the factor below to produce an erosivity index based on the Roose equation.

$$R = P_m \text{ x } 0.5 \qquad (2)$$

where R = rainfall erosivity and P_m is the average monthly precipitation from 1970-2000

Soil erodibility (K) represents the susceptibility of soil particles to be dislodged from the soil horizon and can be calculated from a variety of methods using soil texture, percent organic matter, soil particle size, permeability class, and other physical characteristics of soils. Raster datasets for the mean sand, silt, clay, and organic matter concentrations were downloaded for the 0-5 cm soil layer from the ISRIC Soil Grids website (Poggio et al. 2021). Data for each soil component were downloaded as tiles, tiles were then mosaiced to create a country-wide dataset, and the final mosaic was reprojected to WGS 84 UTM 57N coordinate system in ArcGIS.

The raster library in R (v 4.1) was used to calculate soil texture based on the composition of silt, sand, and clay and then produce a raster with soil erodibility values using soil texture and percent organic matter (Stone and Hilborn 2012) (Table 2).

The InVEST SDR model uses a spatial digital elevation model (DEM) to calculate the length slope factors (LS) for the RUSLE equation. Selection of the DEM is critical to model runs as all other inputs are resampled to match the spatial resolution of the DEM. The DEM created from the Shuttle Radar Topographical Mission available from the United States National Aeronautics and Space Administration (NASA) was selected for this application. This dataset is 30-m resolution and typically has any erroneous data, such as pits and voids, already corrected and filled. Data were downloaded as tiles and then mosaiced using ArcGIS software (Mosaic to New Raster tool). The administrative boundaries for each region were buffered by 40 meters and then used to extract the elevation raster for each of the nine administrative boundaries in the Solomon Islands (Central, Choiseul, Guadalcanal, Isabel, Makira-Ulawa, Malaita, Rennell-Bellona, Temotu, and Western) in ArcGIS (Buffer and Extract by Mask tools). Data were then reprojected to WGS 84 UTM 57S for model runs.

Table 2. Soil erodibility values for soil classes based on soil texture and organic matter content.

Soil Texture	Organic Matter Content = 2%	Organic Matter Content < 2%	Organic Matter Content > 2%
Clay	0.029	0.032	0.028
Clay loam	0.04	0.043	0.037
Coarse sandy loam	0.009	0.009	0.009
Fine sand	0.011	0.012	0.008
Fine sandy loam	0.024	0.029	0.022
Heavy clay	0.022	0.025	0.02
Loam	0.04	0.045	0.034
Loamy fine sand	0.014	0.02	0.012
Loamy sand	0.005	0.007	0.005

Soil Texture	Organic Matter Content = 2%	Organic Matter Content < 2%	Organic Matter Content > 2%
Loamy very fine sand	0.051	0.058	0.033
Sand	0.003	0.004	0.001
Sandy clay loam	0.026	0.026	0.026
Sandy loam	0.017	0.018	0.016
Silt loam	0.05	0.054	0.049
Silty clay	0.034	0.036	0.034
Silty clay loam	0.042	0.046	0.04
Very fine sand	0.057	0.061	0.049
Very fine sandy loam	0.046	0.054	0.043

InVEST SDR uses a land use land cover (LULC) raster to map cover management (*C*) and practice (*P*) factors across the area of interest. The LULC dataset used for this analysis was the European Space Agency World Cover 2020 dataset which provides global coverage at 10-m resolution (Zanaga et al. 2020). The LULC dataset is derived from Sentinel-2 satellite imagery, classified using machine learning algorithms, and validated using ground control points throughout the world. For general validation purposes, the consultant overlaid the LULC with Sentinel-2 RGB satellite imagery to verify that the dataset generally matches the satellite imagery it represents.

A biophysical table is used to link the land use land cover class to both the cover management (*C*) and practice (*P*) factors. The Natural Capital Project provides a database of *C* and *P* factor values from various studies around the world on its website. Unfortunately, *C* and *P* factors for the Solomon Islands and general Pacific Islands region were absent from both the database and scientific literature. Substituting normalized difference vegetation index (NDVI), a measure of vegetation greenness derived from infrared-red- and red-light bandwidths has been proposed as an alternative method for calculating the *C* factor since vegetation cover and NDVI are generally correlated (Parveen and Kumar 2012). Considering that NDVI is also highly correlated with precipitation, the consultant used the average NDVI from the Landsat 8 satellite (Chander et al. 2009) for the years 2019-2020 to match the timeframe of the LULC and best represent vegetation cover throughout both dry and wet seasons.

Google Earth Engine was used to extract the mean annual NDVI for each LULC class specifically found within each of the nine regions (Table 3) and separately for the Mataniko catchment (Table 4). There were cloud and cloud shadow artefacts evident in the annual composites, which skewed the distribution and average value. To prevent these artefacts from skewing mean NDVI values for land cover classes, values of 0.30 and lower were masked from the calculations of mean NDVI. The following formula was used to transform NDVI to *C* factor (Parveen and Kumar 2012) (equation 3)

$$C = e^{(-2*((\mathrm{NDVI})/(1-\mathrm{NDVI})))} \qquad (3)$$

Since *P* factor values were not available for the project sites and general farming practices are unknown, a default value of 1.0 was used for all LULC classes.

Table 3. Cover management (*C*) factor for land use land cover types for nine regions in the Solomon Islands.

LULC Code	LULC	Central	Choiseul	Guadalcanal	Isabel	Makira-Ulawa	Malaita	Rennell-Bellona	Temotu	Western
10	Tree Cover	0.02	0.03	0.05	0.04	0.00	0.02	0.01	0.01	0.06
20	Shrubland	0.07	0.03	0.06	0.07	0.03	0.04	0.03	0.08	0.08
30	Grassland	0.13	0.05	0.06	0.07	0.02	0.03	0.05	0.04	0.11
40	Cropland	0.08	0.09	0.07	0.14	0.06	0.13	0.04	0.12	0.17
50	Built-up	0.20	0.15	0.19	0.19	0.15	0.15	0.18	0.16	0.21
60	Bare/sparse vegetation	0.03	0.03	0.19	0.06	0.03	0.06	0.05	0.03	0.06
80	Water	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
90	Herbaceous Wetland	0.08	0.06	0.07	0.09	0.03	0.09	0.10	0.08	0.08
95	Mangroves	0.06	0.01	0.09	0.04	0.01	0.05	---	0.01	0.04

Table 4. Cover management (*C*) factor for land use land cover types for Mataniko Catchment, Solomon Islands.

LULC Code	LULC	Mataniko
10	Tree Cover	0.02
20	Shrubland	---
30	Grassland	0.13
40	Cropland	0.05
50	Built-up	0.19
60	Bare/sparse vegetation	0.17
80	Water	0.00
90	Herbaceous Wetland	0.01
95	Mangroves	---

The DelinateIt software that comes with the InVEST suite of ecosystem service models was used to derive catchment shapefiles for each of the nine regions in the Solomon Islands (Central, Choiseul, Guadalcanal, Isabel, Makira-Ulawa, Malaita, Rennell-Bellona, Temotu, and Western) using the D-infinity algorithm which allows for multi-dimensional flow across a cell. This software fills pits and voids within the DEM during this processing and applies a plateau algorithm to correct for flat surfaces. DelineateIT can also produce duplicate catchment boundaries if pre-defined pour points are not used in the software. This is largely a result of the algorithm creating and redefining catchments using the D-infinity algorithm. Some artefacts may still be present in the final catchment and will need to be reviewed and deleted as necessary. The consultant removed duplicate catchment boundaries manually before proceeding with the model runs.

Catchments were compared to both stream data downloaded from the OpenStreetMap project and Sentinel-2 RGB satellite imagery. Watershed boundaries seem to match mapped streams, although there is some small error between the 30-meter resolution data and actual stream paths. DelineateIT also produces pour points for each catchment that represent the outlet and land-sea linkage between the sediment models, and the water quality model discussed later. The DelineateIT software can produce multiple smaller catchments because of the D-infinity algorithm and due to this artefact, only catchments greater than 50.0 ha in the area were included in the analysis.

A default value of 1,000 cells was used as a preliminary threshold flow accumulation value for determining stream layers. The resulting stream raster datasets were validated by visually comparing the stream raster and RGB Sentinel-2 satellite imagery. A stream layer from the Open Street Map project was also used to extract the mean and 80th percentile values from the flow accumulation raster, although this method did not provide any relevant information since there was some misalignment with the stream layer and 30-meter DEM-derived layers. A final threshold accumulation value of 1,000 was used for model runs since the resulting stream rasters were indicative of the waterways seen in the satellite imagery.

The InVEST SDR model takes the theoretical sediment load calculated from the RUSLE and models sediment transport as a function of flow path through the landscape. Transport is largely defined by the Borselli k and IC_0 parameters. Due to lack of suspended solids data collected from outlets during field studies to validate the resulting export predicted from the model runs, default values for these parameters as suggested in the InVEST User's Guide were used. If field data were available, the model parameters could be altered to ensure sediment export output at the catchment matched the sediment data recorded at field sites/stream gauges. These parameters are typically adjusted after initial model runs by comparing outputs to the sedimentation data collected at stream gauges or outlets. The parameters are then readjusted, new models are run, the output compared to the stream gauge data until the two datasets converge. Sedimentation data for the Solomon Islands was not available to calibrate these values so the following default values were used.

Borselli k Parameter: 2

Borselli IC_0 Parameter: 0.5

Max SDR Value: 0.8

Max L Value: 150

Water Quality Model

A water quality model was used to estimate the impact of land practices on the marine environment by linking the modelled sediment export to coral reef habitat and fish populations. A Sediment Extent Model (SEM) was used to model sediment plumes based on an ocean surface current velocities and direction, a soil particle settling rate, and ocean depth derived from bathymetry data (Rude et al. 2016, Hutley et al. 2020). Ocean current velocities and direction were derived from the Hybrid Coordinate Ocean Model (HYCOM) to create an accumulated cost distance raster that represents the amount of time (seconds) it takes sediment to travel across each raster grid cell. A settling rate is used to estimate how fast the suspended sediment load from each catchment falls out of solution and is deposited on the ocean floor (or subsequent coral area). Sediment deposition on any overlapping coral areas within each catchment's sediment plume can be used to identify catchments with the highest potential to smoother coral populations. Conversely, total suspended sediment (TSS) represents the amount of sediment still within the water column and not deposited on the ocean floor. TSS can be used as a metric to estimate potential impacts to fisheries, coral polyps as they filter the water column, and other marine features.

Sediment deposition is calculated at each raster cell by dividing the product of the annual sediment export per catchment, accumulated time cost, the revised settling rate by the depth of the water column at the given cell (equation 4):

$S_i = (S_p \times C_i \times R_i) / (-1 \times D_i)$ (4)

where S_i = grid cell value of accumulated sediment ($t.yr^{-1}$)

S_p = annual sediment load per catchment ($t.yr^{-1}$)

C_i = grid cell value of accumulated travel time (sec)

R_i = grid cell settling rate ($m.sec^{-1}$)

D_i = depth at grid cell (m)

Total suspended solids (TSS) traveling through the water column within each grid cell can be calculated by substituting the reciprocal of the settling rate (equation 5):

$S_i = (S_p \times C_i \times (1-R_i)) / (-1 \times D_i)$ (5)

where S_i = grid cell value of accumulated sediment ($t.yr^{-1}$)

S_p = annual sediment load per catchment ($t.yr^{-1}$)

C_i = grid cell value of accumulated travel time (sec)

R_i = grid cell settling rate ($m.sec^{-1}$)

D_i = depth at grid cell (m)

The SEM differs slightly from the approach used in Vanuatu (Delevaux and Stamouli, 2020) as the SEM is based on the settling rate of the soil particles typically found in the study area, and the latter used a quantile-derived decay function. Additionally, Delevaux and Stamoulis (2020) constrained the sediment plume to a maximum distance of 3 km to estimate impacts on the nearshore environment and the approach in this study removes the 3 km barrier to allow sediment plumes to flow until all suspended sediment is deposited on the ocean floor. This methodology is based on a recent coastal sediment model study conducted in the Solomon Islands (Hutley et al. 2020) that used a settling rate of 0.0005 m sec-1 in depths greater than 10-m (equation 6) and a depth-adjusted factor to account for nearshore processes that prevent sediment from settling in depths less than 10-m (equation 7). The revised settling rate is outlined below:

$R_i = 0.00005$ (for depths greater than 10 m) (6)

and

$R_i = 0.00005/(10^{(adj)})$ (for depths under 10 m) (7)

where R_i = grid cell settling rate ($m.sec^{-1}$)

$adj = 0.5^{(0.1*(-1*\,depth)-1)}$

D_i = depth at grid cell (m)

Google Earth Engine was used to download the mean east-west (*u*) and north-south (*v*) velocity vector components of the HYCOM ocean surface currents (at zero meters depth) ($m.sec^{-1}$) for the Solomon Islands from the years 2011-2020. The 2011-2020 timeframe was selected to provide a long-term trend that was representative of both El Nino and La Nina events. The data were resampled to 60-m resolution, converted to points, and Inverse-Distance Weighting interpolation (variable distance with 30 points) was used to approximate nearshore data gaps. The resulting datasets were then masked so that the landmass of the Solomon Islands was excluded from the ocean current data.

A cost raster that represents the accumulated time it takes to cross a grid cell based on ocean current velocity and direction was created using the Path Distance tool in ArcGIS (Rude et al. 2016, Delevaux et al. 2020). The tool requires a source point for each of the watersheds (output of DelineateIT), a cost raster (seconds), a horizontal raster (degrees), and a horizontal factor. The source points for each catchment are available as an output from the DelineateIT tool and satellite imagery was used to adjust the location of the pour points to stream outfalls to best represent the catchment outlets in reality. The cost raster is calculated by dividing the width of the cell (60-m in this instance) by the square root of the sum of the squares of both *u* and *v* vectors (equation 8)

$$Seconds = \text{cell size} / (\sqrt{(u^2 + v^2)}) \qquad (8)$$

The horizontal raster defines the direction of current flow across each cell within a raster and the ocean surface current direction was calculated from the *u* and *v* vectors. This equation was slightly modified from Delevaux and Stamoulis (2020) so that the revised equation gives direction in degrees (0-359.9) (equation 9), which is the format required for the horizontal raster input for the Path Distance.

$$Degree = (|\text{ATan2}(u,v) * 180\pi - 180|) \qquad (9)$$

As with previous applications, there is no other information to suggest the flow of the sediment into the ocean differs from moving forward as it settles. Therefore, this study used a forward horizontal factor variable in the Path Distance tool settings.

Bathymetry data were downloaded from the Global Bathymetric Chart of Oceans (GEBCO 2021, www.gebco.net/data_and_products/gridded_bathymetry_data) and converted to 60-meter resolution for analysis. Depth for data gaps from nearshore locations was interpolated by converting the raster data to points and using Inverse Distance Weighting interpolation (variable distance with 30 points) in ArcGIS. Interpolated data were then reclipped to a 5-kilometer buffer of each of the nine regions.

Spatial Prioritization Model Criteria

Identification of High Sediment Export Areas and Catchments on Land

A threshold of 11 t.ha^{-1}.yr^{-1} of sediment export within each pixel was used to determine areas of sustainable or unsustainable soil erosion within the landscape. This threshold was used by a previous study in the Solomon Islands (Wenger et al. 2018) for assessing land use impacts on soil erosion and is based on the maximum rate of soil erosion that can still allow economic sustainability of crop production (Renard et al. 1997). Wenger et al. (2018) concluded that this threshold lies towards the lower end of the estimated 0.2 - 93.0 t. ha^{-1}. yr^{-1} of soil generation, assuming bedrock weathering of basaltic lava between 0.008 - 3.43 mm.yr^{-1} (Dosseto et al. 2012, Louvat and Allègre 1997) and bulk densities of 2.7 g.cm^{-3} for basalt and 1.5 g.cm^{-3} for soil (Louvat and Allègre 1997). Cell values between 0.0 - 11.0 t.ha^{-1}.yr^{-1} (0.0 - 1.0 t.pixel^{-1}) were considered low priority areas of sediment export, 11.0 - 22.0 t.ha^{-1}.yr^{-1} ^{1} (1.0 - 2.0 t.pixel^{-1}) were considered mid priority areas, and areas with over double the sustainable rate of soil loss (> 22.0 t.ha^{-1}.yr^{-1}) ^{1} (> 2.0 t.pixel^{-1}) were considered high-priority areas for intervention or restorations. The total area for high-priority sediment export areas was calculated for each catchment, and catchments were ranked on the combined area of high-priority sediment export cells as a percentage of the total area within the catchment.

Impacts on Marine Habitats

Global coral reef data was downloaded from the UN Environment World Conservation Monitoring Centre Global Dataset of Warm Water Coral Reef Data v.4 (UNEP-WCMC, WorldFish Centre, WRI, TNC. 2021), which is a compilation of the data including the Millennium Coral Mapping Project (Spalding 2001, IMaRS-USF 2005, IMaRS-USF, IRD 2005). Areas of overlapping coral habitat and sediment plumes for each watershed were calculated as a measure of impact on the marine environment. The estimated TSS per grid cell calculated in equation 5 was converted to kg/m^3 using 1.5 g/cm^3 as density volcanic soils (Louvat and Allègre 1997) to adjust tons to kg/m^3 per grid cell and dividing the product by 3,600m^2 (the area of the 60-m cell used for the SEM model). Catchments were ranked by totalling each catchment's TSS that overlapped with coral areas and then ranking these into three classes.

Final Prioritization Ranking

Natural Breaks were used to rank all national catchments into 3 groups to represent low, medium, and high priority for three criteria: total sediment export, percentage of high export areas to total catchment area, and the sum of TSS on the coral impacted under the catchment's modelled sediment plume. The natural breaks classification technique minimizes the average deviation within each derived class and maximizes the inter-class deviation of class means (Jenks 1957). Total sediment export was used to identify areas with the most potential total soil loss and therefore contribute the most sediment to the marine environment. The percentage sediment export was used to identify catchments that have a disproportionate amount of high levels of soil loss and therefore used to identify areas that may benefit the most from restoration or intervention. TSS for coral areas under the plume was used to identify catchments with the highest connectivity and impact on coral resources.

Scenario Design

To demonstrate the flexibility of this procedure for spatial prioritization of R2R sites over a temporal scale, scenarios were created at both the local and national scale by: 1) changing any grassland areas in the Mataniko Catchment that had high sediment export (> 22.0 $t.ha^{-1}.yr^{-1}$ or > 2.0 $t.pixel^{-1}.yr^{-1}$) to forest LULC to simulate a reforestation project aimed at decreasing sedimentation to the outlet, 2) a 10-year projection of continued forestry practices (business-as-usual) across all of the watersheds within the Solomon Islands, and 3) a scenario that uses the 10-year deforestation projection on Guadalcanal Island but simulates increased protected area designations by increasing a buffer around streams from 50-m to 100-m.

For the Mataniko Catchment, all pixels with high sediment export (>2.0 $t.pixel^{-1}.yr^{-1}$) that have a LULC of grassland were selected and converted to forest LULC (a total of 46.0 ha). The scenario simulates an R2R project where high export areas are targeted for reforestation and is based on the recommendations and goals of the Mataniko Catchment Integrated Management Plan. The InVEST SDR model was rerun using the reforested LULC, and the resulting total sediment export and percentage of high sediment export areas were compared to the baseline scenario.

A 10-year business-as-usual scenario that assumed an annual conversion of 0.52% of forest cover to grassland was created to estimate impacts under a 10-year extension of the current deforestation regime and to identify potential catchments of future concern. The rate of conversion for the primary forest was selected as the annual deforestation rate rather than the annual rate for total tree cover loss (0.61% yr-1) due to the uncertainty of whether logging or agricultural conversion is the primary driver of deforestation. The Revised Solomon Islands Code of Logging Practice (2002) limits logging within 1) 200-m of villages, 2) 30-m from gardens and farms, 3) 30-meters from Tambu areas, 4) 100-meters from oceans, lagoons, and lakes, 5) any areas above 400-m in elevation, 6) areas of ecological of scientific importance (protected areas, wetlands, swamps, outer reef islands, etc.), 7) landslip areas, 8) 50-m of streams that are greater than 10-m wide and 25-m from streams less than 10-m wide, 9) 50-m of log ponds and 40-m of roadways, 10) 10-m of gullies or smaller drainage areas, and 11) slopes that are greater than 30 degrees. While exceptions to these rules can be granted based on the discretion of the government, the code was used as a hard rule for determining where deforestation can occur. Specifically, the scenario that was created expanded deforestation outwards from existing grassland to forest land cover in a buffering effect but restricted deforestation to elevations under 400-m, slopes under 30 degrees, outside of 100-m buffer of oceans and lakes, > 30-m from cropland LULC, > 200-m from urban/built-up LULC, and > 50-m from the stream layers generated by the InVEST SDR tool. These areas were used to mask the expansion of grassland into the forest, and the SDR model was rerun with the adjusted LULC to evaluate changes in sediment export among islands and watersheds.

An alternative island-scale scenario was created for Guadalcanal that uses the 10-year business-as-usual deforestation scenario described above but extends the protective buffer around stream areas from 50-m to 100-m. This 10-year deforestation with increased protection scenario simulates either a potential change in the forest code to expand stream buffers or a regulation that designates all areas within 100-m of the stream network as protected areas. Model results from the current baseline, 10-year business as usual, and 10-year increased protection scenario were compared to examine deforestation impacts under various levels of stream buffer protection for Guadalcanal Island.

Results

Area of Sediment Plume and Impacted Coral Using the HYCOM Ocean Current Methods

The total area and average area per catchment estimated under sediment plume varied results across the regions. Total plume areas were estimated to be the largest in extent around the Western, Isabel, and Malaita regions, while Rennell-Bellona, Isabel, Guadalcanal, and Western had the largest average plume area per catchment (Table 5). Western, Malaita and Isabel regions had the highest amount of potential coral area under sediment plumes, and Malaita, Isabel, and Choiseul had the highest average potential coral area under plume per catchment (Table 5, Figure 3).

Table 5. Total area of sediment plume (ha), mean area of sediment plume per catchment (ha), the total area of the coral area under plume (ha), and mean area of coral reef under plume per catchment (ha) for the nine regions in the Solomon Islands.

Region	Number of Catchments	Total Plume (ha)	Average Plume (ha)	Total Area of Impacted Coral (ha)	Average Area of Impacted Coral (ha)
Central	172	438,228.00	2,294.40	30,620.20	178
Choiseul	331	766,422.70	2,208.70	86,624.50	261.7
Guadalcanal	270	775,505.50	2,793.90	32,187.50	119.2
Isabel	473	1,423,282.70	2,753.00	130,878.50	276.7
Makira-Ulawa	300	779,718.20	2,348.50	46,623.00	155.4
Malaita	454	1,176,742.40	2,536.10	160,554.20	353.6
Rennell-Bellona	4	10,257.50	3,419.20	648.2	162.1
Temotu	213	428,162.00	1,869.70	40,492.80	190.1
Western	886	2,335,609.80	2,544.20	167,981.90	189.6

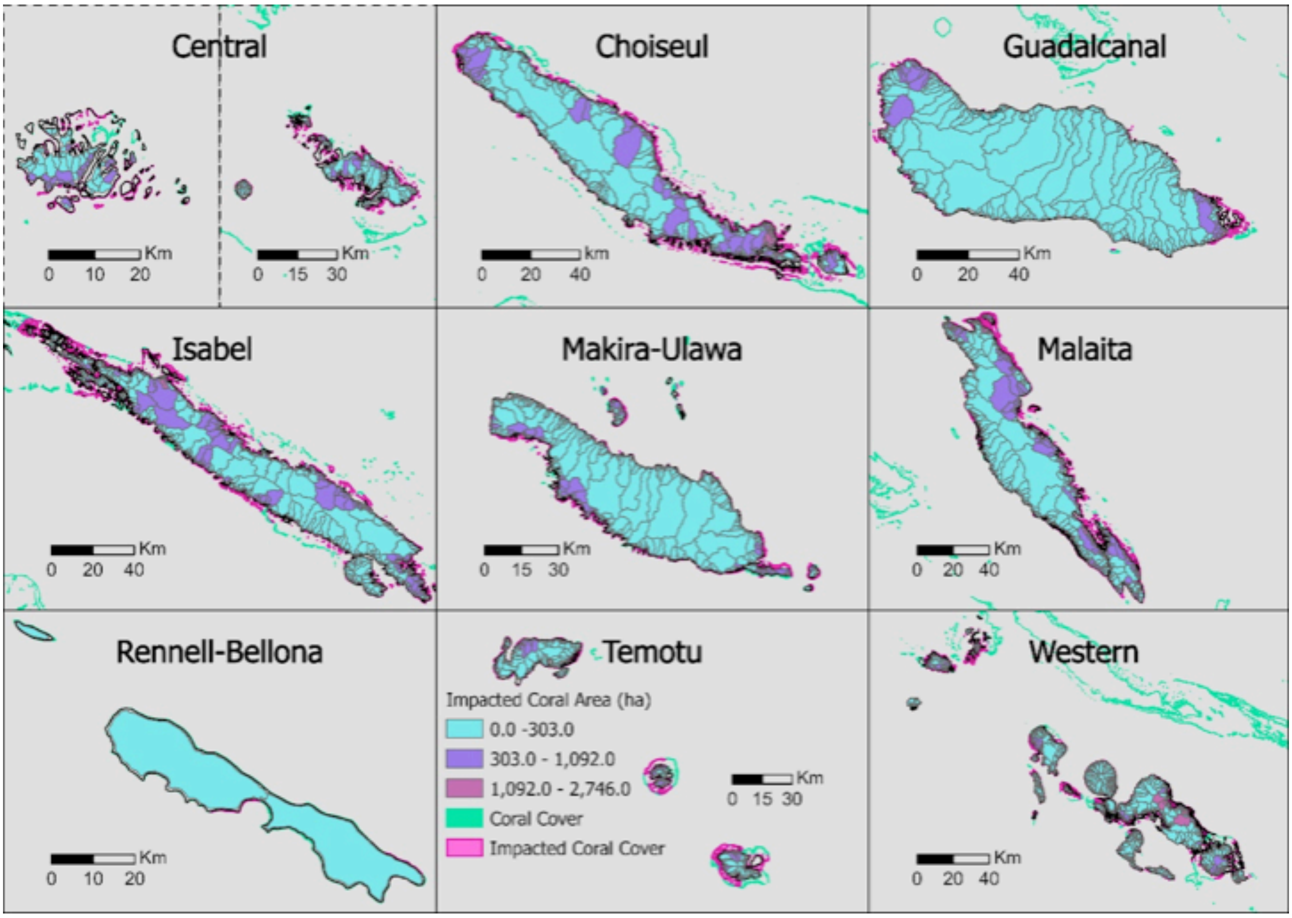


Figure 3. Ranking of catchments based on the potential impacted coral area (ha) under sediment plume for nine regions in the Solomon Islands under the baseline scenario using the mean values for HYCOM data from 2011-2020.

National Scale Prioritization

Baseline/Current Conditions:

A total of 3,104 catchments were modelled for the nine regions in the Solomon Islands. At the regional scale; Guadalcanal, Western, and Isabel regions had the highest levels of estimated sediment export and average export per catchment and Isabel, Malaita, Temotu, and Choiseul had the largest amounts of coral reef area under potential exposure to sediment plumes (Table 6).

Prioritization ranking for catchments shows a similar pattern that is outlined above for the island-scale summary metrics. Guadalcanal, Western, and Isabel regions had a higher concentration of high and medium priority ranks of total sediment export (Figure 4) and a percentage of high export areas (Figure 5). Guadalcanal, Isabel, Choiseul, Malaita, and Western regions had the highest number of medium and high-ranking TSS for impacted coral area catchments (Figure 6).

Table 6. Summary of annual sediment export (t.yr-1), average annual sediment export per catchment (t.yr-1), the total area of high sediment export (ha), and average area of high export per catchment (ha) for nine regions in the Solomon Islands.

Region	Area (Hectares)	Number of Catchments	Total Sediment Export	Average Sediment Export	Total High Export Area (Hectares)	Average High Export Area
Central	40,281	172	35,656.7	207.3	101.4	0.6
Choiseul	303,015	331	974,305.0	2,943.5	6,727.6	20.3
Guadalcanal	521,415	270	7,775,229.5	28,797.1	89,425.9	331.2
Isabel	371,165	473	1,942,269.4	4,106.3	16,399.0	34.7
Makira-Ulawa	295,045	300	98,620.8	328.7	53.7	0.2
Malaita	388,610	454	1,423,314.3	3,135.1	10,698.2	23.6
Rennell-Bellona	74,503	4	1,159.1	289.8	0.0	0.0
Temotu	67,588	213	96,593.5	453.5	457.9	2.1
Western	468,145	886	3,946,552.5	4,454.3	42,534.2	48.0

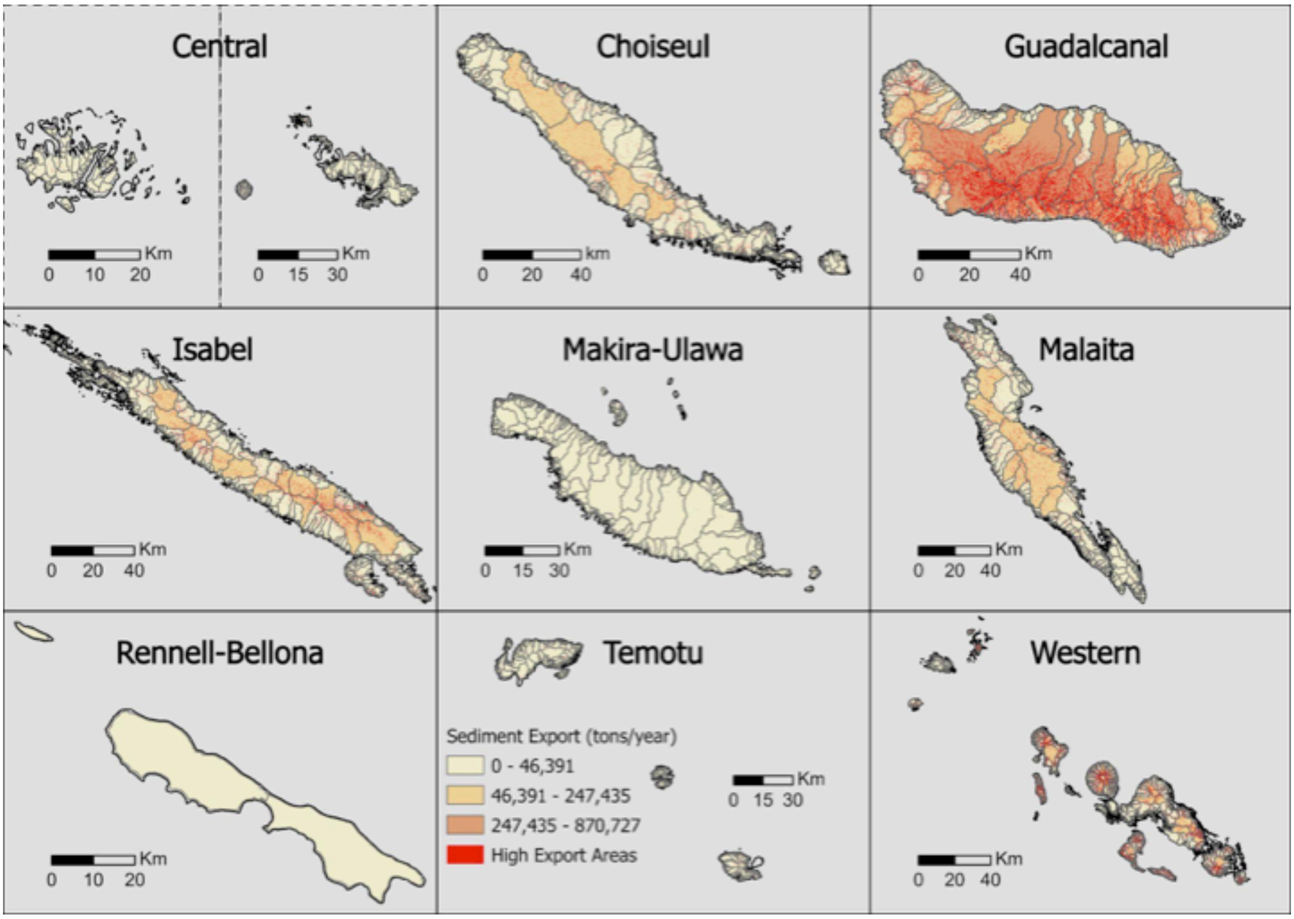


Figure 4. Ranking of catchments based on sediment export at the catchment outlet for nine regions in the Solomon Islands under the baseline scenario.

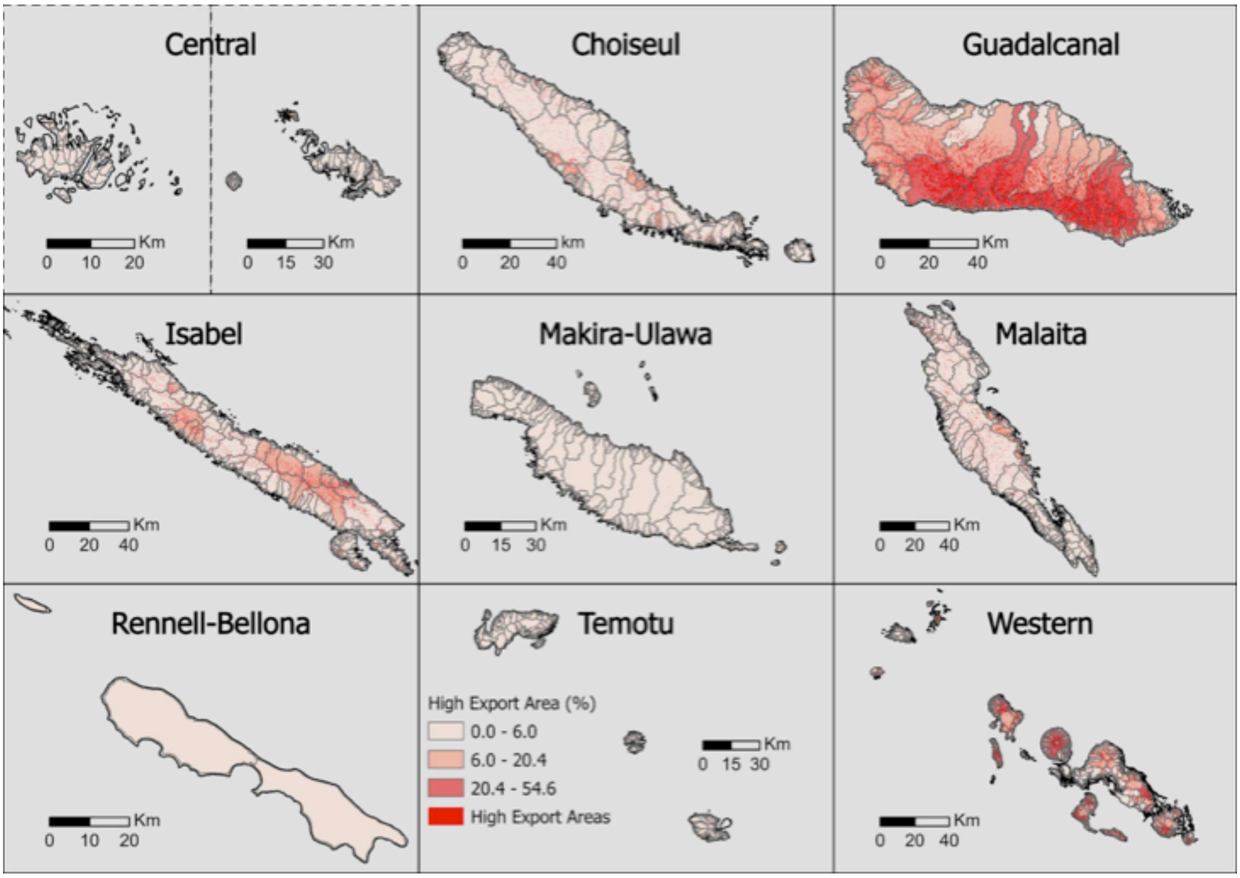


Figure 5. Ranking of catchments based on areas of high sediment export (> 22.0 t.ha^{-1}.yr^{-1} or > 2.0 t.pixel^{-1}.yr^{-1}) for nine regions in the Solomon Islands under the baseline scenario.

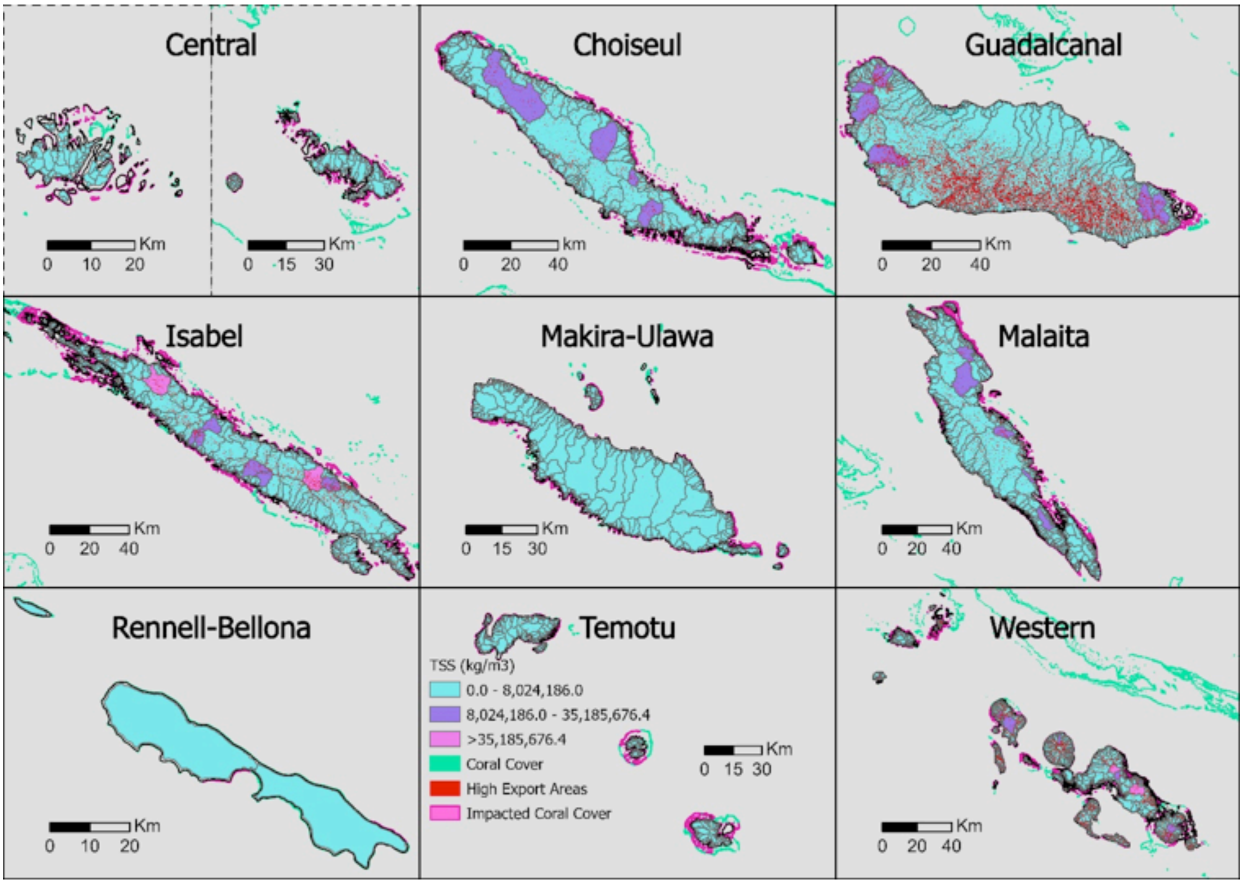


Figure 6. Ranking of catchments based on the total amount of TSS within areas of coral habitat for nine regions in the Solomon Islands under the baseline scenario.

10-year Business-as-usual Deforestation Scenario

Under the deforestation scenario, all regions experienced increases in sediment export, with the Western, Guadalcanal, and Isabel regions having the greatest change in sediment export compared to the baseline scenario (Table 7). Proportionally, the Central region experienced the largest change in deforestation and the greatest increase in both sediment export and areas of high sediment export compared to the baseline scenario (52% increase in sediment export and 576% increase in high sediment export areas). There were relatively no changes between the ranking of catchments amongst regions for the baseline and deforestation scenarios (Figures 7 and 8).

Table 7. Summary table of total sediment export, average sediment export per catchment, total high sediment export area, and average high sediment export area per catchment under the 10-year deforestation model, as well as change in percent forest conversion and sediment export between the baseline and 10-year deforestation scenarios.

Region	Forest Conversion (%)	Total Sediment Export	Average Sediment Export	Total High Export Area (ha)	Average High Export Area (ha)	Change in Sediment Export
Central	-11.4	54,055.3	314.3	686.3	4.0	18,398.6
Choiseul	-3.7	996,851.13	3,011.63	6,764.12	20.4	22,546.1
Guadalcanal	-7.6	7,839,433.15	29,034.94	90,182.0	334.0	64,203.7
Isabel	-3.6	1,993,949.10	4,215.54	17,054.2	36.0	51,679.7
Makira-Ulawa	-2.8	103,885.79	346.29	962.14	3.2	5,265.0
Malaita	-7.5	1,437,858.70	3,167.09	10,884.0	30.0	14,544.4
Rennell-Bellona	-2.0	1,221.80	407.00	0.00	0.0	62.7
Temotu	-5.0	107,403.68	504.24	603.45	2.8	10,810.2
Western	-4.9	4,064,349.00	4,587.30	44,227.6	50.0	117,796.5

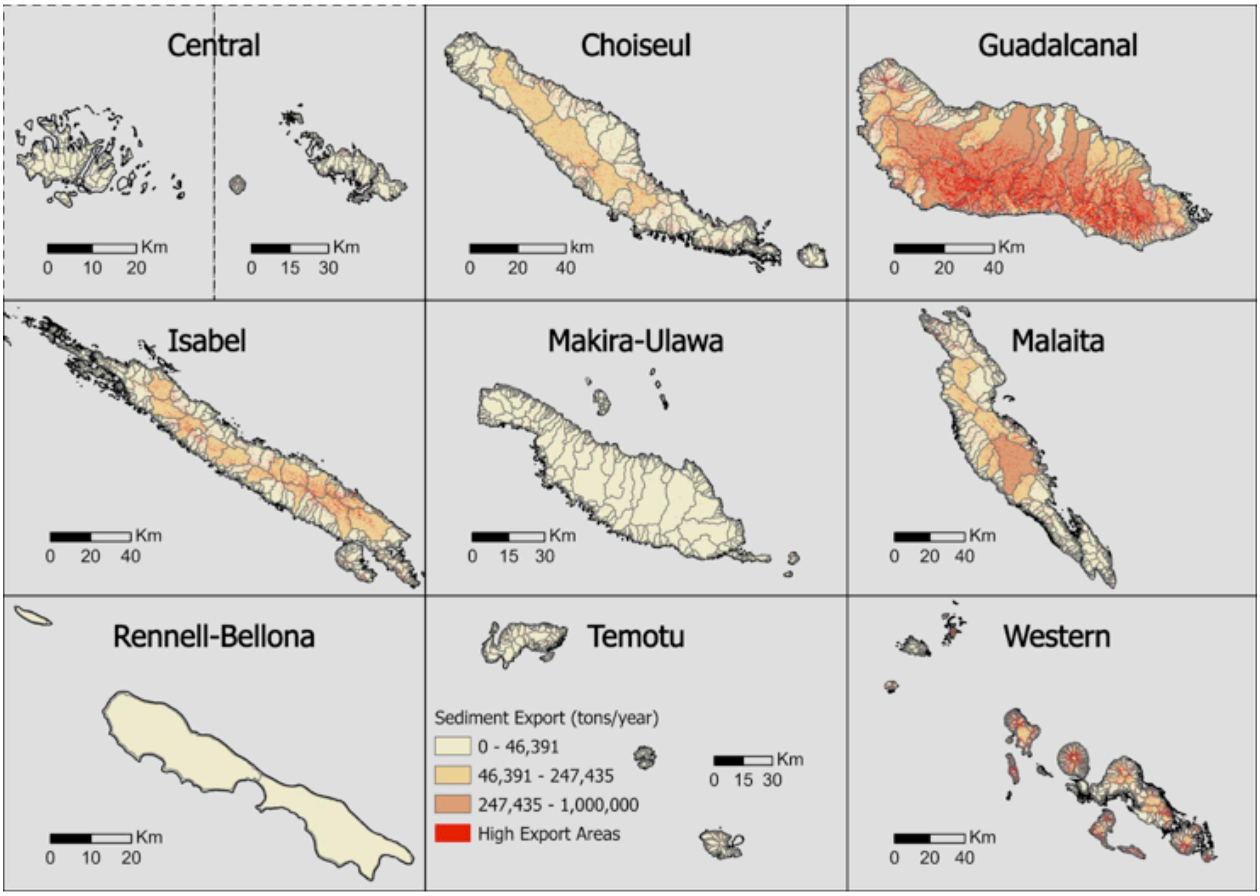


Figure 7. Ranking of catchments based on sediment export at the catchment outlet for nine regions in the Solomon Islands under the 10-year deforestation projection scenario.

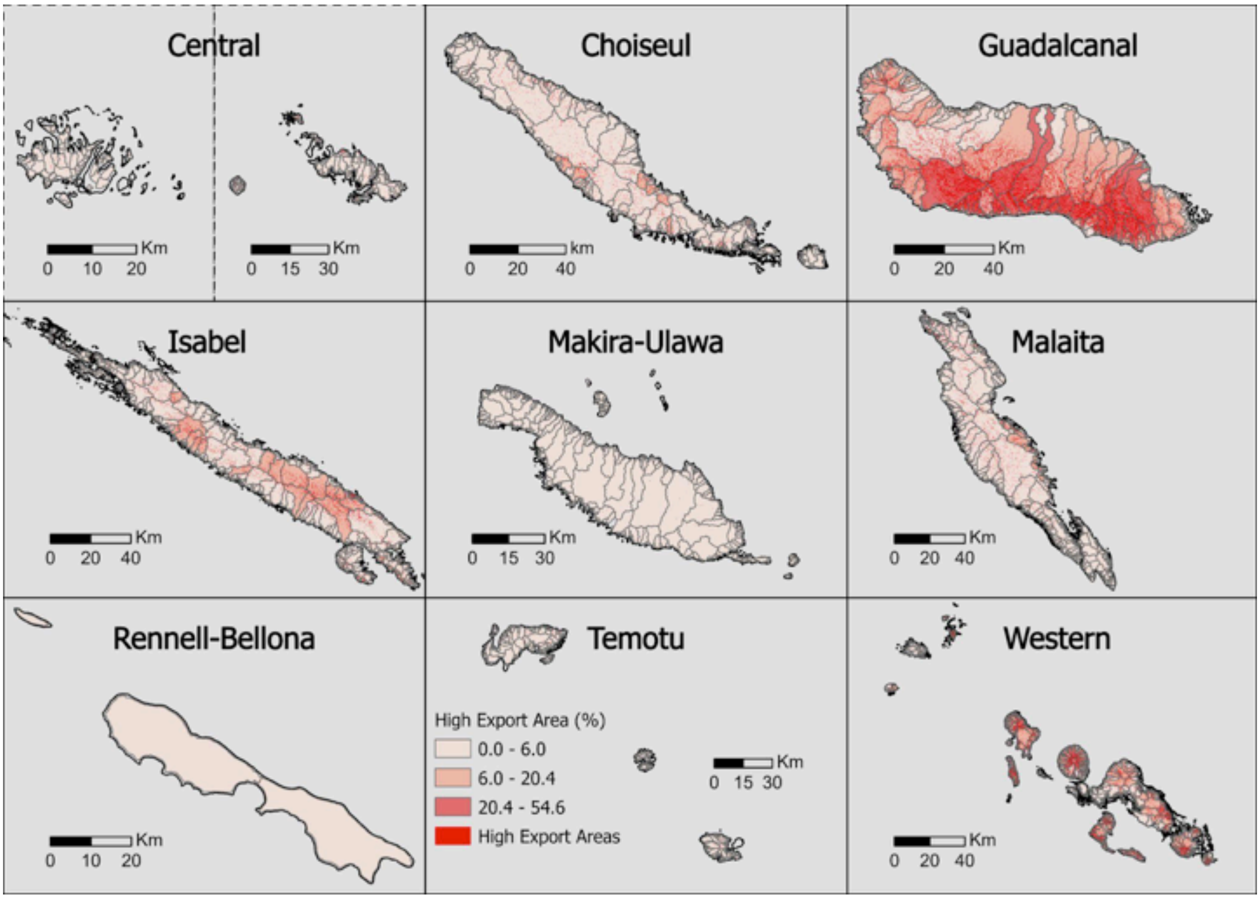


Figure 8. Ranking of catchments based on areas of high sediment export (> 22.0 $t.ha^{-1}.yr^{-1}$ or > 2.0 $t.pixel^{-1}.yr^{-1}$) for nine regions in the Solomon Islands under the 10-year deforestation projection scenario.

Island Scale Prioritization Under Different Management Scenarios – Guadalcanal

Deforestation scenarios for the Guadalcanal Island region resulted in a 7.3%-7.6% decrease in forest cover and less than 1% increase in both total sediment export and total area of high sediment export area (Table 8). Changing the buffer length around streams from 50-m to 100-m showed little change between sedimentation at the outlet and areas of high sediment export.

Table 8. Summary table of total sediment export, average sediment export per catchment, total high sediment export area, and average high sediment export area per catchment under the 10-year deforestation model, as well as change in percent forest conversion and sediment export between the baseline and 10-year deforestation scenarios.

Scenario	% Change in Forest Cover	Total Sediment Export	% Change in Total Sediment Export	Total High Sediment Export Area	% Change in High Sediment Export Area
Baseline	--	7,775,229.5	--	89,426.0	--
Deforestation	-7.6%	7,839,433.2	0.83%	90,182.0	0.85%
Deforestation 100-m Buffers	-7.3%	7,829,904.0	0.70%	90,058.9	0.71%

Local Scale Prioritization – Mataniko Catchment

Under the baseline conditions, there was an estimated annual soil export of 16,495 $t.yr^{-1}$ within the Mataniko catchment and 3.0 ha of the coral area impacted by the sediment plume. The mean per pixel value of sediment export was 1.47 $t.\ ha^{-1}$ with a standard deviation of 3.9 $t.\ ha^{-1}$. Areas of high sediment export were located on pixels with steep slopes and within the cleared grassland area outside of Honiara (Figure 9). The total area of cells with sediment export greater than or equal to 22 t.yr-1 that were identified for the reforestation scenario was 46.0 ha. The estimated annual soil export to the outlet was 14,995 $t.yr^{-1}$ under the reforestation scenario, which resulted in a 9.1% decrease in soil loss compared to the baseline scenario (Figure 10).

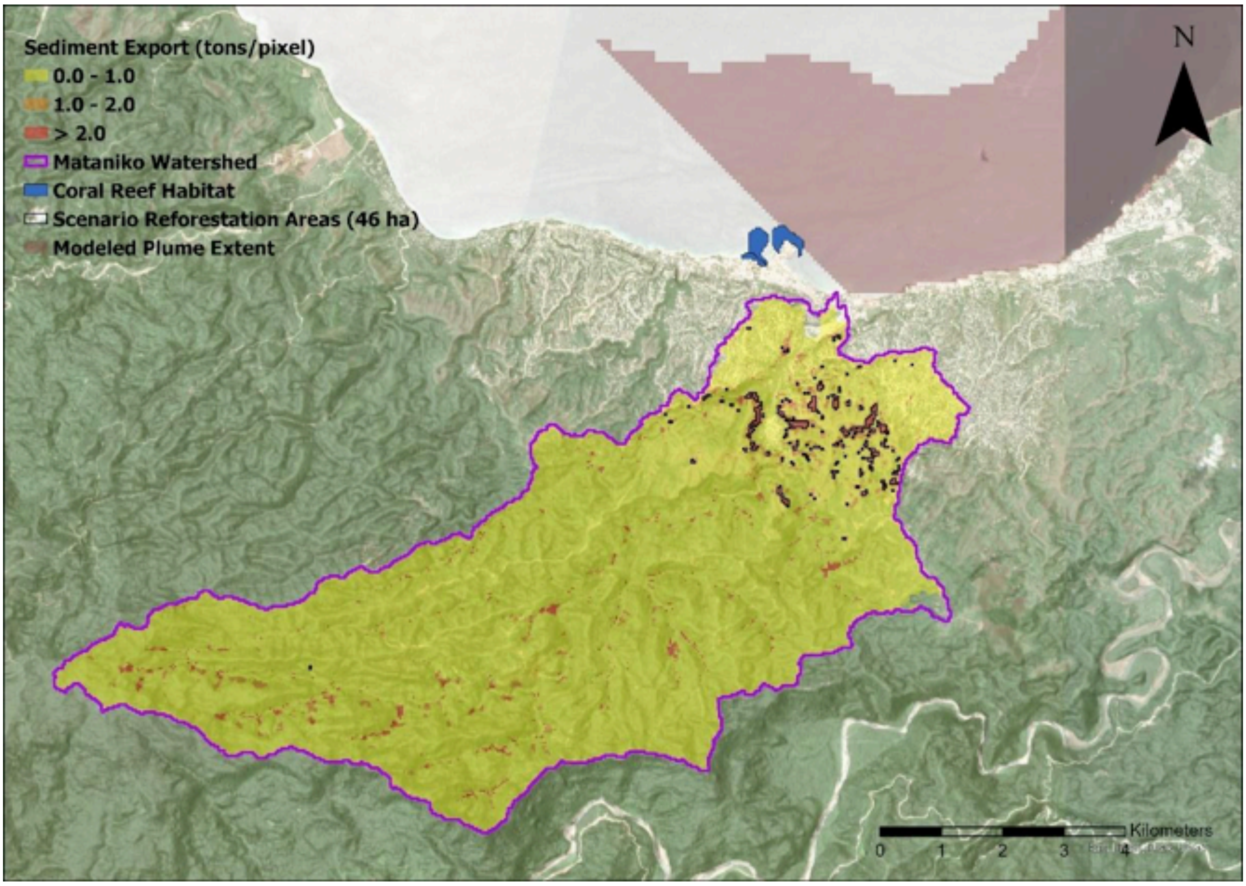


Figure 9. Baseline scenario of the Mataniko Catchment, Guadalcanal Island with sediment export per pixel classified as low, medium and high sediment export areas, modelled plume extent, nearby coral reef areas, and high sediment export areas identified for the reforestation scenario.

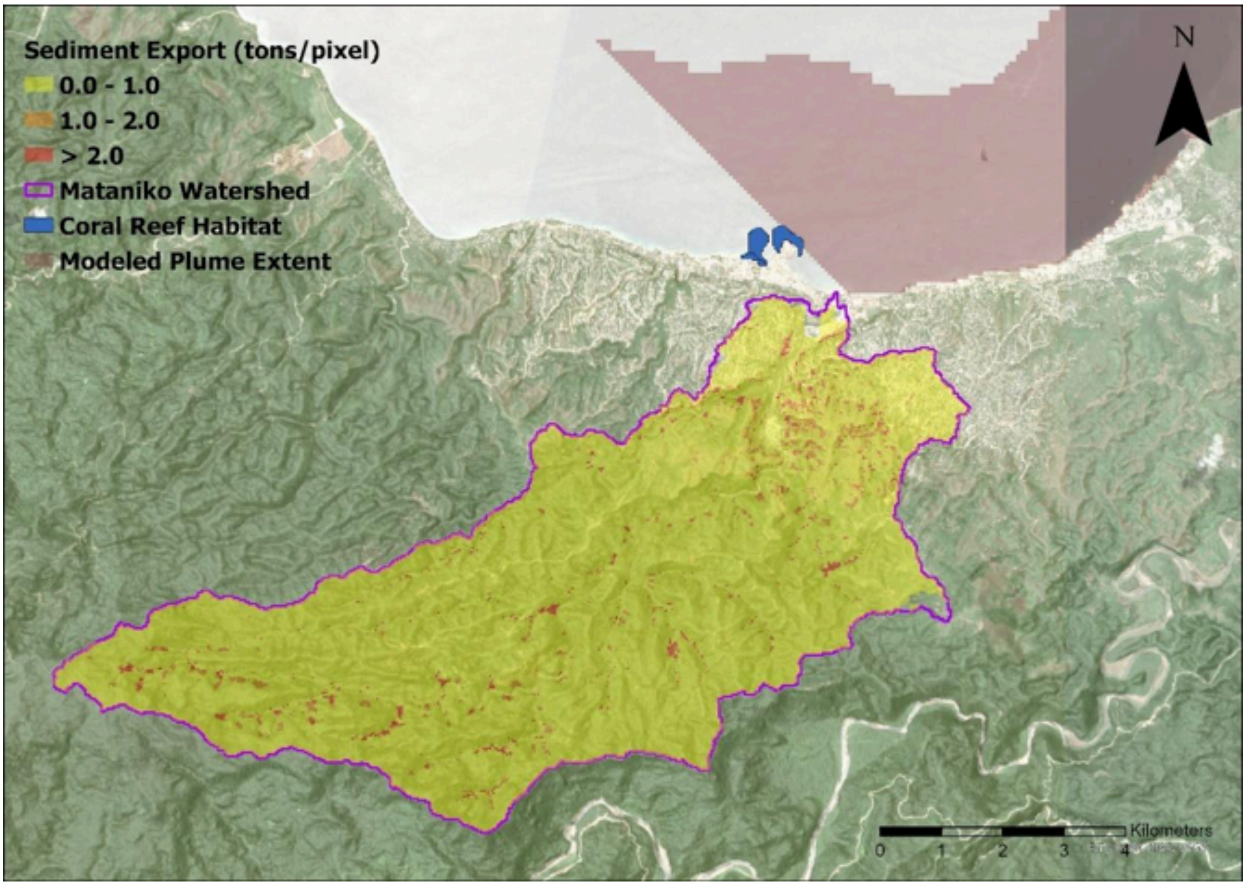


Figure 10. Reforestation scenario of the Mataniko Catchment, Guadalcanal Island, with sediment export per pixel classified as low, medium and high sediment export areas, modelled plume extent, and nearby coral reef areas.

Conclusion and recommendations

The land-sea linkage framework used in this study outlines a multi-tier hierarchical approach for identifying and prioritizing R2R sites and projects. National reporting could be used as an initial identifier of problematic catchments for which R2R data collection could be focused. Once sedimentation and other supporting data are collected at sites, these data can then be used to calibrate and validate model results. With calibrated models, intra-catchment assessments that identify areas of high sediment export or connectivity can be identified, and scenario modelling can be used to measure the relative success of the intervention, protection, or restoration projects. While this framework has focused specifically on coral reef impacts, the ranking of catchments based on total sediment export and total suspended solids could be used as a priority ranking system for other impacts on the marine environment, such as degradation to fisheries (Wenger et al. 2020) or recreational areas.

Lack of calibration data for both the sedimentation and water quality model likely limits the interpretation of absolute values derived from this study. In this case study, results from the InVEST SDR model likely overpredict sediment export at the catchment outlet and the averaged ocean current data likely exaggerates the footprint of the sediment plume since extreme weather events may skew the mean values. While input data were reviewed to ensure it was reasonable and accurate, there are a few parameters that can only be optimized using calibration data collected during field studies to further refine these models. In particular, InVEST SDR can be sensitive to the C factor for estimating sediment erosion and to the Borselli parameters that define sediment transport to the streams. The difference between C factors calculated for the Guadalcanal region and those calculated specifically for the Mataniko Catchment (Tables 3 and 4) is an example of how scale derived C factors influence the magnitude of sediment export.

The C factors derived from NDVI for the Guadalcanal region were higher than those derived specifically for the Mataniko Catchment, and the estimated sediment export at the catchment (with all other factors held constant) using the regional values was nearly double than the modelled export using C factors derived from the Mataniko catchment scale. In particular, the regionally derived C factor for the tree cover LULC in Guadalcanal was over double the value derived specifically for Mataniko Catchment and given this likely explains the higher export since the majority of Guadalcanal and Mataniko are forested based on the LULC data. Despite the difficulty of interpreting the absolute results due to lack of calibration, the relative ranking of catchments can still be used for inter-and intra-regional comparisons as a preliminary assessment of where to prioritize more detailed data collection for calibrated model runs.

At the national scale, baseline conditions indicate that Guadalcanal, Western, and Isabel regions have the highest sedimentation rates in the Solomon Islands. The Guadalcanal and Western regions have some of the steepest slopes within the Solomon Islands, and regardless of the LULC present at high slope areas, steep slopes result in higher sediment export areas due to the slope-length factor of the RUSLE equation in the InVEST SDR model. This is particularly evident in the southern portion of Guadalcanal, where there the majority of the high sediment export areas are located along steep slopes ($\bar{x}$ =30.2%, σ=11.2%) that border streams and on the steep volcanic slopes of the Western province ($\bar{x}$ =20.6%, σ=10.5%).

Additionally, the Guadalcanal, Western, and Isabel regions have the highest derived C factor for the tree cover LULC. The higher C factor, in combination with the steep slopes, will result in increased sediment export as the SDR model is sensitive to the C factor parameter, as stated above.

The Isabel, Malaita, and Western regions have the highest amount of coral area under plumes and are, therefore, the regions with the highest connectivity to potential coral reef impacts. The Choiseul, Malaita, and Guadalcanal regions had catchments with the highest amount of TSS impacting coral reef areas, and Isabel and Western regions had catchments with moderate levels. The medium and high-ranking catchments may be considered for closer examination and detailed analysis at the catchment scale to determine prioritization for R2R projects. Even though Guadalcanal had several catchments with the highest ranks for sediment export at the outlet, these specific catchments had limited connectivity to coral areas and, therefore, lower ranks for TSS in coral areas. However, our specific prioritization process only ranked catchments in the TSS area in regard to coral reef impacts, and high sediment export catchments may still have a high impact on other marine resources such as fisheries.

The choice of the settling rate needs to be carefully considered for estimating sediment plumes, as soil particle size greatly affects the settling rate. Using Stoke's Law, settling rates can differ from minutes for coarse sand, hours for silt, and days for clay particles. This study used a specific settling rate that was selected in previous studies for the Solomon Islands, and future replication of this procedure in other countries should involve researching some preliminary soil data to assist in choosing an appropriate settling rate. Depth becomes another factor to consider as sediment settles through the water column since sediment may still be transported when surface plumes are no longer apparent at the ocean surface. While the HYCOM and GEBCO datasets are widely available, the coarse scale of the ocean current velocities and bathymetry data may lead to exaggerated plume extents, and locally collected current and bathymetric data should be used if available.

The 10-year deforestation scenario resulted in increased sedimentation export for all regions and a relatively similar ranking of catchments between the baseline and deforestation scenarios. The region with the largest change in sediment export and high sediment areas as a result of deforestation was the Central region. The Central Region is also one of the regions with the smallest landmass and the highest rate of forest conversion in this scenario. The scenario also simulated expanded deforestation from grassland areas and catchments that are already cleared and therefore, already ranked high for export, which is likely also the same catchments that had expanded deforestation. In reality, deforestation due to logging will differ from the simulated scenario, but the scenario process and results may be used to help identify which regions may be more susceptible to increased soil erosion and impacts on the marine environment. While deforestation scenarios did not change the overall relative inter-and intra-regional of catchments, there was still an evident, yet varying, increase in sedimentation export even when logging was restricted to the Solomon Islands Forest Code regulations and guidelines.

Despite the caveats identified above regarding the potentially inflated *C* factors for Guadalcanal, both the deforestation and deforestation with increased 100-m stream buffer scenarios developed for the Guadalcanal Island-level example showed little change in total sediment export and high sediment export areas when compared to the baseline scenario. Deforestation scenarios resulted in less than a 1% increase in both sedimentation export at the catchment and total area of high sediment export while representing over 7% deforestation across Guadalcanal. The method for extending deforestation from existing grassland LULC may not be indicative of forestry practices in reality; however, deforestation was confined to low slopes under 400-m elevations with varying buffers from streams and other features based on the current Solomon Islands forestry code. Confining deforestation to the low slope-low elevation conditions decreases the effect of the slope-length factor within the SDR model, which likely explains the relatively small increase in sedimentation with respect to the baseline. Preventing deforestation along the stream buffers likely also contributes to lower rates of sedimentation in the SDR model since these areas generally have the highest upslope contributions and are adjacent to the streams and rivers, so any sediment export from these cells is assumed to flow to the outlet. However, the overall total sediment export and downstream impacts in Guadalcanal are still substantial in magnitude and represent the highest export in the Solomon Islands. While these scenarios show that deforestation impacts are likely minimal when the forestry code is followed, site-level efforts to stabilize the steep slopes that are contributing to the estimated output are probably warranted.

Local-scale reporting for the Mataniko catchment demonstrates the flexibility in this framework to identify site-level interventions for future applications throughout the region. The reforestation of the high-export grassland areas demonstrated a considerable (10%) reduction in sedimentation at the outlet. As with all models, caution needs to be taken in terms of interpreting results without validation. The Natural Capital Project cautions against interpreting InVEST SDR results at the pixel level scale since there may be spatial errors associated with the varying multiple-scale input variables, each themselves representing varying degrees of uncertainty. However, using the approach that targets areas of high sediment export in the manner presented in this study tends to identify larger areas that may reduce the noise associated with pixel-level interpretation.

Data availability in Pacific Island countries can be sparse and the technical capacity needed to reproduce some of the input data required for these models may be limited (Martin and Williams 2021). Additionally, many Pacific Island countries are limited by the availability of hardware, GIS software, and the technical expertise to preprocess data, run models, and interpret the results. The approach outlined in this study utilizes open-source software such as Google Earth Engine, InVEST SDR model, and QGIS to access, manipulate, and model globally available data at various scales. The InVEST SDR model is well documented by the Natural Capital Project, with support provided in the form of a user guide, user forums, and videos on model usage and interpretation of the results. Both the preprocessing of input data for models, construction and application of the plume model, and summarization of ranking across regions and catchments require intermediate knowledge of spatial analysis and GIS functions. To assist in replicability, this report includes detailed procedures for some of these processes in the methodology and supplemental material (please see Annexes).

While increasing national GIS capacity and support is one method to boost the replicability of R2R spatial prioritization across PICTs, specific datasets could also be pre-processed and made available to these countries to facilitate the modelling process. For example, the R code used to calculate soil erodibility values could be used to generate country-level soil erodibility data and then could be hosted on SPC's R2R GeoNode or Digital Pacific repository as a resource for countries. Additional datasets that are derived from Google Earth Engine could also be processed for each country and hosted on either the GeoNode or Digital Pacific. However, these datasets should still be validated using some expertise to prevent erroneous model results and interpretation, and therefore, funding, if available, should also be directed at collecting validation and calibration data in addition to making these datasets available to partner countries.

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Annexes/Attachments

Annex A: R and Python Code for Calculating Soil Erodibility using ISRIC Soil Grids Data

R CODE

```
## Import libraries
library(raster)

## Initialize local variables for output folder
output_folder = “D://SPC/Solomon_Islands_SDR/Soils_Mean0-5cm/”

## Set variables for rasters from ISRIC SOils Grid
pre_clay = raster(“D://SPC/Solomon_Islands_SDR/Soils_Mean0-5cm/Mean0-5cm/Clay.tif”)
pre_organic = raster(“D://SPC/Solomon_Islands_SDR/Soils_Mean0-5cm/Mean0-5cm/Soil_Organic_Carbon.tif”)
pre_sand = raster(“D://SPC/Solomon_Islands_SDR/Soils_Mean0-5cm/Mean0-5cm/Sand.tif”)
pre_silt = raster(“D://SPC/Solomon_Islands_SDR/Soils_Mean0-5cm/Mean0-5cm/Silt.tif”)

## Set variable for output raster and NoData values
dataset_out_uri = os.path.join(output_folder, “erodibility_SLB_ISRICSoilGrids250m_250m.tif”)
nodata_out = -9999

## Adjust ISRIC Soil Data components to output percentages
unit_clay = pre_clay/10.0
unit_organic2 = pre_organic/100.0
unit_silt = pre_silt/10.0
unit_sand = pre_sand/10.0

## Create a raster stack to run vector analysis on soil components
r <- stack(unit_clay, unit_organic2, unit_silt, unit_sand)
```

```
## Create function for calculating soil texture class based on percent clay, sand, silt and return erodibility

rc <- function(unit_clay, unit_organic2, unit_silt, unit_sand) {



  ifelse(unit_silt <= 10 & unit_clay <= 15 & (unit_silt + 1.5*unit_clay) < 15 & unit_sand > 85 & unit_organic2 == 2.0, .02*0.1317,  #Sand

          ifelse(unit_silt <= 10 & unit_clay <= 15 & (unit_silt + 1.5*unit_clay) < 15 & unit_sand > 85 & unit_organic2 < 2.0, 0.03*0.1317,

          ifelse(unit_silt <= 10 & unit_clay <= 15 & (unit_silt + 1.5*unit_clay) < 15 & unit_sand > 85 & unit_organic2 > 2.0, 0.01*0.1317,

       ifelse((((unit_silt + 1.5*unit_clay) >= 15) & ((unit_silt + 2*unit_clay) < 30)) & (unit_organic2 == 2.0), 0.04 * 0.1317, #Loamy Sand

        ifelse((((unit_silt + 1.5*unit_clay) >= 15) & ((unit_silt + 2*unit_clay) < 30)) & (unit_organic2 < 2.0), 0.05 * 0.1317,

        ifelse((((unit_silt + 1.5*unit_clay) >= 15) & ((unit_silt + 2*unit_clay) < 30)) & (unit_organic2 > 2.0), 0.04 * 0.1317,

       ifelse(((7 <= unit_clay) & (unit_clay < 20) & (unit_sand > 52) & ((unit_silt + 2*unit_clay) >= 30)) & (unit_organic2 == 2.0), 0.13 * 0.1317, #Sandy Loam

          ifelse(((7 <= unit_clay) & (unit_clay < 20) & (unit_sand > 52) & ((unit_silt + 2*unit_clay) >= 30)) & (unit_organic2 < 2.0), 0.14 * 0.1317,

          ifelse(((7 <= unit_clay) & (unit_clay < 20) & (unit_sand > 52) & ((unit_silt + 2*unit_clay) >= 30)) & (unit_organic2 > 2.0), 0.12 * 0.1317,

        ifelse(((unit_clay < 7) & (unit_silt < 50) & ((unit_silt+2*unit_clay)>=30)) & (unit_organic2 == 2.0),  0.13 * 0.1317, #Sandy Loam 2

        ifelse(((unit_clay < 7) & (unit_silt < 50) & ((unit_silt+2*unit_clay)>=30)) & (unit_organic2 < 2.0), 0.14 * 0.1317,

        ifelse(((unit_clay < 7) & (unit_silt < 50) & ((unit_silt+2*unit_clay)>=30)) & (unit_organic2 > 2.0), 0.12 * 0.1317,

         ifelse(((unit_clay >= 7) & (unit_clay < 27) & (unit_silt >= 28) & (unit_silt < 50) & (unit_sand <= 52)) & (unit_organic2 == 2.0), 0.3 * 0.1317, #Loam

         ifelse(((unit_clay >= 7) & (unit_clay < 27) & (unit_silt >= 28) & (unit_silt < 50) & (unit_sand <= 52)) & (unit_organic2 < 2.0) ,0.34 * 0.1317,

         ifelse(((unit_clay >= 7) & (unit_clay < 27) & (unit_silt >= 28) & (unit_silt < 50) & (unit_sand <= 52)) & (unit_organic2 > 2.0) ,0.26 * 0.1317,

        ifelse(((unit_silt >= 50) & (unit_clay >= 12) & (unit_clay < 27)) & (unit_organic2 == 2.0), 0.38 * 0.1317, #Silt Loam

       ifelse(((unit_silt >= 50) & (unit_clay >= 12) & (unit_clay < 27)) & (unit_organic2 < 2.0), 0.41 * 0.1317,

       ifelse(((unit_silt >= 50) & (unit_clay >= 12) & (unit_clay < 27)) & (unit_organic2 > 2.0), 0.37 * 0.1317,
```

```
        ifelse((unit_silt >= 50) & (unit_silt < 80) & (unit_clay < 12) & (unit_organic2 == 2.0), 0.38 * 0.1317, #Silt Loam2

        ifelse((unit_silt >= 50) & (unit_silt < 80) & (unit_clay < 12) & (unit_organic2 < 2.0), 0.41 * 0.1317,

        ifelse((unit_silt >= 50) & (unit_silt < 80) & (unit_clay < 12) & (unit_organic2 > 2.0), 0.37 * 0.1317,

        ifelse((unit_silt >= 80) & (unit_clay < 12) & (unit_organic2 == 2.0), 0.38 * 0.1317, #Silt

        ifelse((unit_silt >= 80) & (unit_clay < 12) & (unit_organic2 < 2.0), 0.41 * 0.1317,

        ifelse((unit_silt >= 80) & (unit_clay < 12) & (unit_organic2 > 2.0), 0.37 * 0.1317,

       ifelse((unit_clay >= 20) & (unit_clay < 35) & (unit_silt < 28) & (unit_sand > 45), 0.2 * 0.1317, #Sandy Clay Loam

        ifelse((((unit_clay >= 27) & (unit_clay < 40)) & ((unit_sand > 20) & (unit_sand <= 45))) & (unit_organic2 == 2.0), 0.3 * 0.1317, #Clay Loam

        ifelse((((unit_clay >= 27) & (unit_clay < 40)) & ((unit_sand > 20) & (unit_sand <= 45))) & (unit_organic2 < 2.0), 0.33 * 0.1317,

        ifelse((((unit_clay >= 27) & (unit_clay < 40)) & ((unit_sand > 20) & (unit_sand <= 45))) & (unit_organic2 > 2.0), 0.28 * 0.1317,

        ifelse((unit_clay >= 27) & (unit_clay < 40) & (unit_sand  <= 20) & (unit_organic2 == 2.0), 0.32 * 0.1317, #Silty Clay Loam

        ifelse((unit_clay >= 27) & (unit_clay < 40) & (unit_sand  <= 20) & (unit_organic2 < 2.0), 0.35 * 0.1317,

        ifelse((unit_clay >= 27) & (unit_clay < 40) & (unit_sand  <= 20) & (unit_organic2 > 2.0), 0.30 * 0.1317,

        ifelse((unit_clay >= 35) & (unit_sand > 45), 0.2 * 0.1317, #Sandy Clay

        ifelse((unit_clay >= 40) & (unit_silt >= 40) & (unit_organic2 == 2.0), 0.38 * 0.1317, #Silty Loam

        ifelse((unit_clay >= 40) & (unit_silt >= 40) & (unit_organic2 < 2.0), 0.41 * 0.1317,

        ifelse((unit_clay >= 40) & (unit_silt >= 40) & (unit_organic2 > 2.0), 0.37 * 0.1317,

       ifelse((((unit_clay >= 40) & (unit_sand <= 45) & (unit_silt < 40)) & (unit_organic2 == 2.0)), 0.22 * 0.1317, #Clay

        ifelse((((unit_clay >= 40) & (unit_sand <= 45) & (unit_silt < 40)) & (unit_organic2 < 2.0)), 0.24 * 0.1317,

        ifelse((((unit_clay >= 40) & (unit_sand <= 45) & (unit_silt < 40)) & (unit_organic2 > 2.0)), 0.21 * 0.1317, 0))))))))))))))))))))))))))))))))))))))

}

## Run vecotr analysis using overlay and custom function

r.erod <- overlay(r, fun=rc)

## Write soil erodibility raster to file

writeRaster(r.erod, filename=”D://SPC/Solomon_Islands_SDR/Soils_Mean0-5cm/Mean0-5cm/Erod_SLB_SoilTextureOrganic.tif”, format=”GTiff”, overwrite=TRUE)
```

Annex B: Google Earth Engine Code for Deriving C Factor from LandSat-8 NDVI

The user will need to set up a Google Earth Engine account and upload a shapefile containing the dissolved LULC of the island/region of interest as an asset.

```
// Set the variable pointing to the LULC asset – pathway will depend on the user account and name of the file

var area = ee.FeatureCollection(<pathway/LULC asset>);




// Set the start and end dates for analysis

var startdate = ‘2019-01-01’;

var enddate = ‘2020-12-31’;


// Select the NDVI band form the LandSat 8 ImageCollection and filter by the specified dates and LULC asset boundary

var NDVI = ee.ImageCollection(‘LANDSAT/LC08/C01/T1_ANNUAL_NDVI’)

  .filterBounds(area)

  .filterDate(startdate,enddate);


// Rename the images in the dataset by an index

var rename_band = function(img){

  return img.select([0], [img.id()]);

};


// Stack all the images into a single image

var stacked_image = NDVI.map(rename_band).toBands();


// Mask data with values that may be erroneous (in this case any NDVI value greater than 0.30 is returned (any value lower than 0.30 is ocndiered a cloud or shadow effect

var NDVI_masked = stacked_image.updateMask(stacked_image.gt(0.30))


//Return the mean NDVI values for the target dates at a resolution of 30-meters
```

```
var  MeansOfFeatures = ee.Image(NDVI_masked).reduceRegions({collection: area, reducer: ee.Reducer.mean(), scale: 30});



// Return the mean NDVI values for each of the LULC classes in the asset class

var featureCollection = MeansOfFeatures.map(function(feat){

  var nullfeat = ee.Feature(null)

  return nullfeat.copyProperties(feat)

})



// Export the featureCollection (table) as a CSV file to your Google Drive account.  User will need to change the description and folder settings below

Export.table.toDrive({

  collection: featureCollection,

  description: ‘Choiseul_LULC_NDVI_2019-2020’,

  folder: ‘SLB’,

  fileFormat: ‘CSV’
```

Annex C: Google Earth Engine Code for Downloading HYCOM Ocean Current Velocity Vector Components

The user will need to set up a Google Earth Engine account and upload a 5-km buffer (or greater depending on country application) of the island/region of interest as an asset

Google Earth Engine Code for downloading east-west (*u*) velocity vector of HYCOM Dataset

```
//
var area = ee.FeatureCollection(<asset file defined above>);


// Set the start and end dates
var startdate = ‘2011-01-01’;
var enddate = ‘2020-12-31’;
// Select the HYCOM dataset at the 0-m depth band to get the u component of the ocean surface, filter by dates, and clip the image by the area of interest
var HYCOMu = ee.ImageCollection(‘HYCOM/sea_water_velocity’)
          .filterDate(startdate,enddate)
          .select(‘velocity_u_0’)
          .map(function(image){return image.clip(area)});


// Return the mean value of all images in the ImageCollection form the specified dates and area
var MeanHYCOMu = HYCOMu.reduce(ee.Reducer.mean())
// Export the image (in this case to a Google Drive associated with the user) – it is really useful to set the output image resolution and coordinate system here to limit further post-processing of the data.  User will need to change the description and folder settings below.
Export.image.toDrive({
 image: MeanHYCOMu,
 description: ‘HYCOM_u_0’,
 scale: 60,
 region: area,
 folder: ‘SLB_Velocity’,
 fileFormat: ‘GeoTIFF’,
 formatOptions: {
  cloudOptimized: true
 }
```

```
});
```

Google Earth Engine Code for downloading north-south (*v*) velocity vector of HYCOM Dataset

```
var area = ee.FeatureCollection(<asset file defined above>);


// Set the start and end dates

var startdate = ‘2011-01-01’;

var enddate = ‘2020-12-31’;


// Select the HYCOM dataset at the 0-m depth band to get the u component of the ocean surface, filter by dates, and clip the image by the area of interest

var HYCOMv = ee.ImageCollection(‘HYCOM/sea_water_velocity’)

                .filterDate(startdate,enddate)

                .select(‘velocity_v_0’)

                .map(function(image){return image.clip(area)});

// Return the mean value of all images in the ImageCollection form the specified dates and area

var MeanHYCOMv = HYCOMv.reduce(ee.Reducer.mean())


// Export the image (in this case to a Google Drive associated with the user) – it is really useful to set the output image resolution and coordinate system here to limit further post-processing of the data.  User will need to change the description and folder settings below

Export.image.toDrive({

  image: MeanHYCOMv,

  description: ‘HYCOM_v_0’,

  scale: 60,

  region: area,

  folder: ‘SLB_Velocity’,

  fileFormat: ‘GeoTIFF’,

  formatOptions: {

    cloudOptimized: true

  }

});
```

Annex D: Steps for Calculating Sediment Extent Model Using QGIS and ArcGIS