



# Regional Guidelines for the Application of Ridge to Reef Spatial Prioritization and Planning Procedures





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Produced and reviewed by GEF Pacific International Waters Ridge to Reef Regional Project,  
Pacific Community (SPC), Suva, Fiji



Suva, Fiji, 2021

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The **Pacific Ridge to Reef (R2R) Programme** is a multi-country, multi-GEF agency programmatic initiative guiding the coordinated investment of US\$90 million in GEF grant funding across multiple focal areas of biodiversity conservation, land degradation, climate change adaptation and mitigation, sustainable land management, sustainable forest management, and international waters in Pacific Small Island Developing States (SIDS).

Operating across 14 Pacific Island countries, the programme aims to deliver tangible and quantifiable local and global environmental benefits by focusing on cross-cutting approaches to water, land and coastal management with linkages across GEF focal areas including: biodiversity, land degradation, international waters, sustainable forest management, climate mitigation and adaptation and capacity development.

The programme is implemented by United Nations Development Programme (UNDP), the United Nations Food & Agriculture Organization (FAO) & the United Nations Environment Programme (UNEP).

Executed regionally by the Pacific Community through the **Regional Ridge to Reef International Waters Project (Regional IW R2R)**, the R2R programme is supported by the Regional Programme Coordination Unit (RPCU) in areas of science-based planning, human capital development, policy and strategic planning, results-based management, and knowledge sharing. The Regional IW R2R Project is one of 15 child projects under the Programme and provides the primary programme coordination vehicle for the 14 other child projects – the national R2R System for Transparent Allocation of Resources (STAR) Projects under the Pacific R2R Programme.

The Regional Project aims to test the mainstreaming of 'ridge-to-reef' (R2R), climate resilient approaches to integrated land, water, forest and coastal management in the Pacific Island countries (PICs) through strategic planning, capacity building and piloted local actions to sustain livelihoods and preserve ecosystem services.

The Regional IW R2R Project has 14 demonstration projects in participating Pacific Islands - 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.

**The GEF** unites 182 countries in partnership with international institutions, non-governmental organizations (NGOs), and the private sector to address global environmental issues while supporting national sustainable development initiatives.

The GEF Pacific R2R programme was developed to provide an opportunity for Pacific small island developing states (SIDS) to develop and implement integrated approaches for the sustainable development of island economies and communities. Partnerships are key to realizing benefits at the local, regional, and global levels.

## GEF Implementing Agencies

**UNDP** is on the ground in 177 countries and territories and partners with people at all levels of society to help build nations that can withstand crisis, and drive and sustain the kind of growth that improves the quality of life for everyone.

**FAO** has 194 member nations working to achieve food security for all, to make sure people have a regular access to enough high-quality food to lead active and healthy lives.

**UNEP** is the leading global environmental authority that sets the environmental agenda and promotes the coherent implementation of the environmental dimension of sustainable development within the United Nations system.

## Executing Agency

**The Pacific Community** is an international development organization with 26 member countries and territories. It is the principal scientific and technical agency proudly supporting development in the Pacific regional since 1947.

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## ABBREVIATIONS

BIOPAMA	Biodiversity and Protected Areas Management
BIORAP	Biological Rapid Assessment
DEM	Digital Elevation Model
DPSIR	Drivers Pressure State Impact Response
EIA	Environmental Impact Assessment
FAME	Fisheries Aquaculture and Maritime Ecosystems
FSM	Federated States of Micronesia
GEF	Global Environment Facility
GSD	GeoScience Division
ICM	Integrated Coastal Management
IDA	Island Diagnostic Analysis
IMC	Inter-ministerial Committee
IW	International Waters
IWRM	Integrated Water Resource Management
KBA	Key Biodiversity Areas
MPA	Marine Protected Area
MYCWP	Multi-year costed workpan
NBSAP	National Biodiversity Strategy and Action Plans
PIC	Pacific Island Countries
PNG	Papua New Guinea
PSC	Program Steering Committee
R2R	Ridge-to-Reef
RapCA	Rapid Assessment of Coastal Priority Areas
RPCU	Regional Programme Coordination Unit
RSC	Regional Steering Committee
RSC	Regional Steering Committee
RSTC	Regional Science and Technical Committee
SAF	Strategic Action Framework
SAP	Strategic Action Plan
SoC	State of the Coast
SoE	State of Environment
SPC	Pacific Community
SPREP	Secretariat of the Pacific Regional Environmental Programme



## EXECUTIVE SUMMARY

Identification and selection of priority coastal areas for conservation and management is commonly guided by information and observations, which may be qualitative or quantitative. This is a common practice in Pacific Island countries where spatial information may be lacking, and poor scientific basis for supporting policy decisions.

The R2R fine-scale spatially explicit decision support framework for conservation actions is adapted, applied and scaled up from previously developed tool for quantifying the effect of nutrient enriched groundwater and sediment stream runoff on coral reefs in Fiji and Hawai'i (Delevaux et al. 2018). The R2R modelling framework now provides for the identification of priority land areas for land-use incl. forest conservation that can maximize downstream benefits – i.e. maps of reef areas at risk, and maps of priority land areas for conservation.

The R2R spatial prioritization and planning guidelines set out in this document complement the existing ones in the “tool-box” where their uses and applications may be already widely documented and accepted as best practice. The guidelines are intended for stakeholders and resource managers to use and apply in work up-scaling R2R investments and land and sea integrated planning of ecosystem goods and services.

## PURPOSE/ INTENT

The guidelines provide a simple, user-friendly and cost-effective rapid assessment procedure and objective approach that support the identification and selection, for the ridge to reef interventions and reforms, of priority targeted coastal areas or sites for conservation actions, upscaling future R2R investments and ICM planning.

## RATIONALE

Science and evidence-based approaches to natural resource management and planning are one of the (13) principles of Ridge to Reef. The development of spatial prioritization and planning procedures promote such approaches, which are particularly useful and relevant in high islands where the dynamics of ecosystems from ridge to reef are relatively complex and, in most cases, not readily well known or documented. The implementation of this approach in GIS allows managers to visualize the potential outcomes of management interventions. This type of approach has the potential to engender collaborative stewardship among agencies, communities, and other stakeholders and inform ecosystem-based, land-sea integrated planning in Pacific Island nations. The R2R fine-scale spatially explicit decision support framework for conservation actions is adapted, applied and scaled up from previously developed tool for quantifying the effect of nutrient-enriched groundwater and sediment stream runoff on coral reefs in Fiji and Hawai'i (Delevaux et al. 2018).

## SCOPE

The scope for the useful application of the guidelines would cover a wide range of multiple sectors resource management and planning, stretching from the mountain top or source on land to the reef and seas beyond. Within this stretch of land-seascapes, which includes land, water, forest and coastal areas, are produced numerous ecological systems goods and services. The R2R concept promotes ecosystem-based management approaches, which effectively links to the holistic conservation and sustainable use of natural resources across sectors.

Operationally the guidelines are relevant to the work of scientists and managers, who support and implement multi-sectoral natural resource management planning. In addition, the guidelines are equally important and relevant to inform policy discussion and decision making at the higher political level.



## BACKGROUND

There are numerous ways of supporting and informing policy discussion aimed at identifying and selecting priority coastal areas for effective protection and management. The selection of priority coastal areas to focus such efforts is usually guided by information and observations, which may be qualitative or quantitative. Given limited resources for conservation, accessible, easy-to-use conservation planning tools that are appropriate for islands context are critically needed, especially those that incorporate ridge-to-reef or land-sea connectivity and consider human wellbeing. Ridge to reef modelling framework adapts and implements a fine-scale spatially explicit (~30 x 30 m) linked land-sea decision support framework. The modelling tool used existing and global open-access geospatial datasets and literature to identify where terrestrial conservation initiatives may have the greatest impact on marine conservation. Coupled with scenario planning, the modelling framework provides for the identification of priority land areas for land-use incl. forest conservation that can maximize downstream benefits – i.e. maps of reef areas at risk, and maps of priority land areas for conservation.

In this vein, and in response to one of the GEF International Waters (IW) R2R project targets and deliverables, the R2R spatial prioritization planning procedures were developed to assist in the identification and selection of priority coastal sites in future R2R interventions and participatory planning. The development of spatial prioritization procedures is modelled and implemented at two scales: -

- National scale approach -Adapt and apply a spatially explicit framework with scenario planning to identify national priority areas that benefit land and sea; and
- Local-scale approach - Downscale this application of the planning procedures to test the effect of proposed local R2R management actions in one or several watersheds within or connected to a demonstration site.

The land-sea modelling focuses on watershed catchments sediment runoff and export from the source to the shoreline and impacts on adjacent ecosystems and coral reefs habitats based on different land-use change scenarios – e.g. deforestation and logging practice codes. The details on the national and local scale approaches are further explained in the sections below. Generally, model results are only as good as the model inputs or data put into the models. Therefore, access to geospatial data is extremely important in land-sea modelling and the application of R2R spatial prioritization and planning procedures. While public domain data and information are easily accessible, the non-public domain data require consents and approvals, recognising that the process of accessing such information can be lengthy and challenging.

It is important that existing processes and requirements are closely followed to access, collect, collate and store the information in databases for processing and analyses. Sometimes, the information and GIS/ geospatial datasets are housed in regional and international organisations and can only be released on consent of countries, entities or individuals who own the data. Where there is no information or the data available is simply inadequate, it can be difficult to proceed with the application of R2R spatial prioritization and planning procedures. In this case, priority areas or sites can be selected based on observations and qualitative assessments. This generally does not demonstrate priority sites selection that is supported by best use of a science- and evidence-based approach. Alternatively, and most appropriate in local scale approach, field work can be planned to collect baseline data on selected indicators. Other useful results from survey work and inventories would help generate maps, establish the current state of resources and habitats and other valuable uses of primary data.

The R2R conceptual framework on spatial prioritization and planning procedures provide clear and easy to follow sets of guidelines to identify and select priority coastal areas and sites for the conservation and sustainable use of ecosystem goods and services. This is implemented through the following steps for tracing land-sea linkages are follows: -

- Model the sediment export and plume under present conditions and each deforestation scenario;
- Identify coral reef areas exposed to significant change in sediment for each scenario compared to present; and
- Identify the watersheds supplying the most sediment (>40%) to those coral reef areas.

In summary, the regional guidelines on R2R spatial prioritization procedures would assist stakeholders who may be engaged directly or indirectly in managing natural resources across a land and sea continuum. This research and modelling work explore the ridge-to-reef concept that integrates natural and human systems, and land and ocean realms, to improve our understanding of island systems and support conservation and sustainable use resource and development planning. The R2R prioritization and modelling procedures were trialled in Vanuatu. The results and model outputs provide the platform for developing regional guidelines for the implementation of the R2R spatial prioritization procedures, and specific case studies in its application in Vanuatu and other Pacific Islands.

## STEPWISE APPLICATION OF THE R2R SPATIAL PRIORITIZATION PROCEDURES

A clear and stepwise model application of the national- and local- scale approach or method will be developed and appended to these guidelines. This is a useful template for interested persons to practice and learn how to use the R2R spatial prioritization and planning procedures. The following steps provide guidance when undertaking spatial prioritization work to identify and select priority future coastal areas or sites for protection.

- i. Participatory planning processes – consult widely and work with the project host agency to prepare an implementation plan and mobilize team and resources. Carry out a literature review and collect national spatial data.
- ii. Develop potential future land-use or marine-use change scenarios locally relevant to the PICs, agree on quantifiable criteria such as resilience indicators (e.g. clean water or fisheries supply) for the identification of priority R2R sites, and reflect the importance of sites from the range of biological, environmental, cultural and socioeconomic conditions at the national level.
- iii. Identify relevant data gaps important for analyses and inputs into land-sea models – this includes low resolutions spatial data such as terrestrial biodiversity and land-use data, hydrology/ water quality data, bathymetry, resources and habitats,
- iv. If there are spatial data gaps in certain areas important for modelling work, then prepare to carry out field work and collect primary data. This includes consulting widely within and out of the country to solicit and access relevant information and advice.
- v. Notably, one can use existing and global open access geospatial datasets and literature to identify where terrestrial conservation initiatives may have the greatest impact on marine conservation.

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<sup>1</sup> Scenario design can be done in collaboration with the decision makers to understand better and select resilience indicators. For example, for Vanuatu trials, the focus was on deforestation because it is one of the major threats to terrestrial ecosystems and known to also impact marine ecosystems, and related ecosystem goods and services (biodiversity, water, fisheries).

- vi. For purposes of field work to ground truth and collect additional primary data, develop and agree on sampling protocols or designs for field work to collect primary data not already available. Coordinate logistical arrangements including teams of people involved and their roles.
- vii. Carry out field work closely adhering to sampling design and following deadlines and details set out in the implementation plan.
- viii. Data processing and analyses – this includes transcribing raw data, cleaning, collating and entering data into dbase, extraction and formatting data for model inputs, calibrating of models, and conducting of spatial analysis on model outputs.
- ix. If required, prepare to do further additional survey work to optimise calibration of marine and terrestrial models. The exercise should be participatory to promote capacity building.
- x. Prepare technical reports that include clearly the methods employed, model outputs, maps depicting priority areas and sites, and packaged models. The narratives should clearly explain the model outputs and use that to inform advice and recommendations on priority areas or sites to protect (watersheds, forests, coral reefs, etc.).
- xi. Present and discuss methods and outputs with other actors or peer review and refinement, taking into consideration the needs and usefulness of end products.
- xii. Use existing data to define criteria and identify national level priority sites or target areas. This can be done through diagnostic analysis stakeholder workshops or simply reporting back to communities in targeted demonstration project sites.
- xiii. Use the results to support future upscaling R2R investments and national planning for ICM. The information obtained through land-sea modelling should highlight those priority areas most critical to protect.

## NATIONAL-SCALE R2R SPATIAL MODELLING FRAMEWORK

The national scale approach R2R spatial modelling framework for selecting priority sites covers the whole country and it will use all available spatial data and information useful for land-sea modelling. In the Pacific region, numerous studies and research have been undertaken on various ecosystems goods and services including land, water, forest, coastal and marine areas. This includes the initial land-sea modelling work that was done in Fiji and Hawaii (Delevaux et al. 2018).

This modelling tool was adapted, applied, and scaled up to inform conservation actions at the sub-watershed scale across the entire archipelago of Vanuatu. This has been the process for preparing of the R2R spatial prioritization procedures and modelling framework which was trialled in Vanuatu. Notwithstanding, there remain gaps requiring further research to better understand ecological systems and biological diversity of species and their interactions. That said, the guidelines needed to progress national-scale approach to model land-sea connectivity and is primarily centred on diffusing sediment into the marine environment, using a plume model in GIS coupled with marine geography datasets. The potential marine impact from sediment export is estimated by linking to source watersheds, in order to identify the priority conservation areas that mutually benefit the land and sea.

The national-scale approach provides for a number of analyses and modelling work that generate the following results: -

- i. Present land use/cover (LUC) – forest, grass/ shrub-land, human LUC (e.g., agriculture, human settlement, plantation)
- ii. Low and high deforestation scenario – convert forest to human LUC where deforestation trends have been observed (e.g., low elevation, gentle slopes)
- iii. Present sediment export – ton/yr or ton/km<sup>2</sup>/yr
- iv. Change in sediment export - ton/yr or ton/km<sup>2</sup>/yr
- v. Marine impact assessment– habitat area (km<sup>2</sup>), coral cover (%), fish biomass (kg or tons)
- vi. Prioritize watersheds – rank based on potential impact of sediment runoff on coral reefs
- vii. Prioritize forest areas – erosion prone areas in priority watersheds
- viii. Social and economic drivers in the prioritization – e.g. watershed(s) providing essential ecosystem goods and services (e.g., drinking water) to nearby cities and towns

There are three (3) modelling outcomes and results: -

- i. Identification of coral reef areas that can be vulnerable to sediment runoff;
- ii. Identification of priority forest conservation areas on the land that can have the greatest impact on marine conservation in Vanuatu; and
- iii. Development of a decision support tool to identify synergies and trade-offs in habitat conservation across terrestrial and marine ecosystems at an archipelago scale that can also be applied elsewhere.

Generally, the key outcomes provide maps-depicting priority watersheds linked to coral reefs through sediment run-off, and coral reefs at risk as well as relative potential impact (low, medium, high). Another important result identified forest areas that most prone to erosion, and thereby contributing the most to coral reef impacts through sedimentation. Similarly, it is important to account for the social and economic factors in the prioritization of sites, particularly those with vital roles in supporting the surrounding environment and the well-being of the population residing in the broader area.

## LOCAL-SCALE R2R MODELLING FRAMEWORK

Like national-scale approach above, the local scale approach uses similar downscaled procedures and guidelines applied to demonstration sites of interests. For instance, trial work of the procedures in Vanuatu was done in the Tagabe catchment within the Mele Bay R2R system. The IW R2R project demonstration sites in all project countries are operating at the local-scale or subnational level. Again, the science- and evidence-based approach is the starting point guideline to ensure adequate data and information is available to enable land-sea modelling. If the primary and secondary data and indicators are not adequate, then field work is needed to collect baseline and primary data.

The sediment and plume models are developed for a localised area and the model results of projected land-use changes are then linked to potential marine impacts. The InVEST SDR is coupled with a GIS-based plume model to derive the sediment export per watershed and generate sediment plume maps.

Next, the following list provides the tasks and details related to processing of information, analyses and modelling, which in turn help generate maps of selected priority areas under different terrestrial and marine management scenarios. The scenario analysis involves predicting the distribution of coral reef benthic and fish indicators under present conditions and each scenario. It also calculates

the coral reef indicators change for each scenario compared to present. The modelling procedure is set out below: -

- i. Design scenarios representative of management actions
- ii. Watershed analysis and plume maps are used to characterise sediment inputs to the marine environment under present and proposed management conditions;
- iii. Model the effects of sediment runoff and marine habitat on benthic indicators and associated fish indicators<sup>2</sup> and map their distribution;
- iv. Model calibration on present conditions – may involve collection of additional datasets on habitats and resources to better calibrate the models. For example, coral reef models are calibrated using empirical data collected from additional surveys on “X<sup>3</sup>” number of random coral reef sites using an equal random-stratified survey design based on depth and distance to stream mouth (see notes on strata below).

a. Benthic models = sediment<sup>4</sup> (mediated by humans) + habitat

b. Fish models = sediment + fishing (mediated by humans) + habitat  
+ benthic indicators

**Notes:** strata used (i) shallow (1-5 m), moderate (5-12 m), deep (12-21 m);  
and (ii) near (0-1.5 km), medium (1.5-3 km), far (3-4.5 km)

- v. Number of watersheds in or adjacent to the demonstration site, linking to coastal/marine environment – enclosed or semi-enclosed bay, open sea areas
- vi. Characteristics of the demonstration site – drinking water, dependency on coastal/marine resources, population indices (urbanization and trends)
- vii. <sup>56</sup> Governance – watershed management plan, marine management plan linking to challenges and actions (protect drinking water, restore forest and nearshore fisheries, improved livelihoods)
- viii. Demarcated ecosystems – update land cover map by digitizing recent satellite imagery; watersheds, land-modelling boundaries, marine-modelling boundaries, coral reef areas; 7 modelling boundaries are set prior calibrating the models;
- ix. Management scenarios – after calibrating the models on present conditions, then run management scenarios and look at what changed – e.g. management (forest restoration, urbanization); marine management (fishing pressure, marine closure)

The local-scale approach results: -

- i. Calibrated coral reef models defining the relationships (positive, negative, concave or convex) between:
  - a. the benthic indicators (hard coral, macro-algae, turf algae), and the environmental benthic drivers (terrestrial, marine)

<sup>2</sup> For example, herbivore fishes are selected as indicators of coral reef resilience to climate change bleaching impact and targeted fish because it is a proxy for ecosystem goods and services

<sup>3</sup> At least 30 sites required for any statistical analysis – 58 sites were selected for trialling work in Tagabe, Vanuatu

<sup>4</sup> The scenarios affect this variable which can be mediated by management actions, the same applies for fishing pressure

<sup>5</sup> Trial work in Vanuatu selected 4-watersheds discharging into Mele Bay because they all contribute to the sediment plume affecting coral reefs, and can be controlled with appropriate R2R management approaches, and document or test changes in Tagabe over time. Management scenarios inform scenario design which is first done in the process

<sup>6</sup> In Vanuatu trials, modelling boundaries were done for 4-watersheds of Mele Bay because they all contribute to the sediment budget downstream

- b. the fish indicators (total biomass, herbivore biomass, targeted biomass), and the environmental fish drivers (terrestrial, marine, and human)
- ii. maps depicting sediment impacted coastal/ marine areas (extent impact % or g/m<sup>2</sup> of benthic and fish indicators) under different scenarios
- iii. maps depicting the impact of current fishing pressure and management scenarios such as marine closures on fish/ benthic indicators.
- iv. maps depicting the impact of management scenarios such as forest restoration on:
  - a. native forest (ha) and subsequent levels of sediment export (ton/yr) and range of impacts to the adjacent coastal/ marine areas
  - b. change in habitat quality (ha) due to increase/ decrease/ no change in macroalgae, subsequent impact of fish biomass (ton), and “X” tons when coupled with marine closure
- v. Maps depicting the impact of urbanization scenario relative to human land-use trends (ha) and therefore further influence of sediment export (ton/yr); as well, corresponding change in habitat quality (ha), fish biomass (tons), and when coupled with marine closure (tons)
- vi. Benefits of the R2R approach are broad ranging and potentially more useful than other sector- or ecosystem-focused approach because it promotes:
  - a. Restoring native forest and land use best-practice
  - b. Reducing volume of sediment export and increasing the retention of soils on land
  - c. Restoring or protecting marine habitats and fish biomass

## SPATIAL PRIORITIZATION BENEFITS AND IMPLICATIONS

The R2R spatial prioritization and planning procedures will benefit future R2R investments and planning. It exerts confidence for donors and partners that science- and evidence-based principles were the basis for identifying and selecting priority sites for protection. The steps for spatial prioritization on land are as follows:-

- i. Characterize the potential marine impact using selected indicators<sup>7</sup> which may change on case by case basis, recognising linking indicators to what are being measured;
- ii. Prioritize watersheds by potential marine impact; and
- iii. Identify land areas exposed to significant change in sediment export under each scenario compared to present.

The successful application of the spatial prioritization procedures requires collaborative management between the government agencies and communities because it provides information to foster a dialogue between decision-makers and communities to cabinet. It can also be applied as part of an interactive decision-making process. Moreover, the spatial prioritization procedures support and inform policy development and decision making. On the one hand the procedures assist in the identification and prioritization of conservation areas at the national scale that can benefit both terrestrial and marine environments. It also supports local scale and communities’ decision-making by testing policy actions and estimating potential outcomes and benefits for improved ecosystem goods and services and improved livelihoods prior implementation.

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<sup>4</sup> For instance, health of habitat and healthy stocks or resources can use indicators such as coral % cover and fish biomass from empirical data. Other indicators are also relevant for measuring health of biodiversity, governance, socio-economic and traditions, improved livelihoods.

## KEY CHALLENGES

### Data and data gaps

Integrated land-sea planning requires the ability to trace where land-based pollutants come from and where they are likely to cause an impact once they enter the marine environment. The R2R modelling framework adapted, applied and scaled up a linked land-sea decision support tool previously developed for Fiji and Hawaii (Delevaux et al. 2018), to quantify, track, and map the impact of land-use change on coral reefs at the sub-watershed scale. Notwithstanding, there remains the challenge of spatial data gaps and improved understanding of the land-sea connectivity. The following points are important tasks of the R2R modelling framework where data is identified, collected and reviewed recognising the limitation of the procedures relative to the adequacy and quality of data inputs into land-sea modelling.

- i. The soils, rainfall, bathymetry, and current data used in modelling are derived from global datasets, freely available, making this approach useful for regions with limited resources.
- ii. Field data used to conduct the marine impact assessment was collected by SPC and the monitoring programs of local government agencies.
- iii. Terrestrial and marine habitat maps were provided by SPC GEM.
- iv. The modelling framework relies on two freely available software packages (i.e., InVEST SDR, and R) and the proprietary software ArcGIS (also available with open access QGIS) (ESRI 2011, Team 2014, 2015, Hamel et al. 2015).
- v. This tool is coupled with scenario planning to inform local conservation actions and identify priority areas on land that can foster coral reef resilience.

## DECISION SUPPORT TOOL IN DATA-POOR REGION

Firstly, prioritize working on the resolution of the input foundational layers, including the soils (~ 900 x 900), bathymetry (~ 500 x 500), and currents (9 x 9 km), are coarse resolution for some of the islands.

- i. Because soil and rainfall maps are coarser resolution than the DEM input, at which SDR operates, it may obscure small scale processes and spatial nuances which can occur in small watersheds and narrow reef systems often found in tropical island environments.
- ii. Note bathymetry and current maps were interpolated nearshore to fill in the gaps along the shoreline, which may create erroneous values. This may impact the dispersion of the TSS plumes in some regions.
- iii. For instance, the coastal plume models could over- or under- estimate the TSS proxy values because we could not account for the effect of fine-scale marine topography or tidal-driven transport on sediment dispersal and settling rates due to the lack of data.
- iv. Future work should investigate how these modelled plumes of TSS compare to local knowledge from coastal communities, satellite imagery, and/or in-situ data as those become available. Also, future research should focus on generating more refined bathymetry data using satellite imagery, which can help refine the plume dispersion models and provide input layers for species distribution modelling.
- v. However spatial planning requires information to prioritize efforts on that ground and these global datasets are freely available for data poor regions; and spatial prioritization requires spatial consistency in the datasets used, otherwise conservation actions tend to focus efforts in data rich places. The global data inputs used in this analysis provide consistent coverage of the entire country.

Secondly, the decision support tool relies on static modelling. While sediment models accounted for the connectivity across the landscape, the marine models are not dynamic and do not explicitly model the response of coral indicators to TSS change. However, it can give an estimate of the directionality of change when coupled with scenarios. The scenario approach is a simple way to circumvent dynamic modelling which is data intensive and hard to calibrate in data poor regions but can still demonstrate changes.

This framework can give an idea of where and what may degrade or recover but it is not a dynamic model where it is possible to see impacts through measuring indicators. In the trial work in Vanuatu, the following were executed: -

- i. Undertake an overlay analysis assuming a potential adverse impact where significant changes in TSS occurred over a coral reef habitat.
- ii. Empirical research has shown that coral reefs chronically exposed to high turbidity can be less vulnerable to sediment impacts. In that case, it is possible that we overestimated the impact of increased TSS on the reefs located near the source of the sediment plume and under-estimated the impact offshore.
- iii. Characterised the potential impact of TSS on coral reefs in terms of coral cover area (km<sup>2</sup>) and fish biomass (kg).

## SUGGESTED APPROACH

The guidelines provide the following suggestions and approach towards curbing some of the above challenges, but also to achieve the goal of identifying and selecting priority sites for future R2R planning.

- i. First inform the modelling tool using data layers representing current conditions so that the results represent the effect of current land-use on sediment runoff once it enters the marine environment;
- ii. Apply land-use scenarios to quantify the potential impact of TSS on reefs under increasing levels of development and deforestation.
- iii. Undertake scenario analysis to identify priority land areas within a large number of priority watersheds (around 50% if the country has several hundred watersheds), where forest conservation can reduce TSS risk to downstream coral reefs
- iv. For restricted bays and related marine areas adjacent to the mouth of the river, reef areas located directly downstream from the watersheds experience deforestation. Therefore, the model outputs would show the connections for the watersheds contributing the largest change in TSS.
- v. Determine where soils are more likely to erode under land-use change can inform where conservation actions on land or sustainable land-use practices can provide benefits downstream.
- vi. Determine the direct and indirect impacts of sedimentation and turbidity on benthic habitat at local scales, or if known, downstream from all watersheds.
- vii. (vii) Land-use planning requires coordinating across difference agencies, such as government or non-government agencies or institutions responsible for fisheries and the environment.
- viii. Identify where coral reefs are vulnerable to local human impacts can inform area-based management actions and spatial prioritization to minimize risks (i.e. probability of disturbance) – determine risk levels by areas.
  - Low risk conservation approach protects nearshore reefs that are not susceptible to sediment impacts;

- High risk conservation approach protects reefs which are more vulnerable to sediment runoff that may support high coral cover and fish biomass – important fishing grounds for nearby villages.

## CONCLUSION

The regional guidelines on the application of the R2R spatial prioritization and planning procedures aimed to assist stakeholders identify and select priority sites for future R2R planning and conservation actions. These guidelines recognise the limitation of the procedures relative to the adequacy and quality of data inputs into land-sea modelling. Further research and trials would certainly improve the application of the procedures.

Moreover, the procedures and modelling framework can evaluate the effect of land-use change, sediment runoff, coral reef habitat, and associated fish communities. The packaged land-sea model outputs and maps provide scientific evidence supporting potential trade-offs and synergies that may result from modelling land and sea connectivity under different land-use scenarios. Next steps would be to build a suite of land-use management scenarios within the priority areas identified, and then evaluate trade-offs to help identify optimal management solutions. By adopting a ridge-to-reef conservation planning process, protected areas can be designed for multiple benefits that include improvements in biodiversity, safe and uncontaminated aquifers, underground and surface water, and reef fisheries. These findings can also help inform priorities for future conservation leases or other payment for ecosystem service schemes by: (1) identifying relevant communities, (2) facilitating communication using maps as visuals, and (3) locating where forest conservation or restoration actions can benefit coral reefs and improve fisheries livelihoods.

## REFERENCES

- Delevaux, J.M.S. & Stamoulis, K.A. (2020). Identification of priority sites for future upscaling ridge-to-reef investments in Vanuatu. Unpub. Report prepared for the Ridge to Reef Programme, Suva, Fiji SPC, 48 pp.
- Delevaux, J.M.S. & Stamoulis, K.A. (2020). Assessment of ridge-to-reef management actions in Tagabe watershed and Mele Bay, Vanuatu. Unpub. Report prepared for the Ridge to Reef Programme, Suva, Fiji SPC, 63 pp.
- Delevaux, J. M. S., Jupiter, S. D., Stamoulis, K. A., Bremer, L. L., Wenger, A. S., Dacks, R, Garrod, P., Falinski, K. A., & Ticktin, T. (2018). Scenario planning with linked land-sea models inform where forest conservation actions will promote coral reef resilience. *Scientific Reports* 8:12465.
- ESRI. 2011. ArcGIS Desktop: Release 10.4. Environmental Systems Research Institute, Redlands, CA.
- Hamel, P., R. Chaplin-Kramer, S. Sim, & C. Mueller. (2015). A new approach to modelling the sediment retention service (InVEST 3.0): case study of the Cape Fear catchment, North Carolina, USA. *Science of the Total Environment* 524:166–177.
- Team, Q. D. (2015). QGIS geographic information system. Open Source Geospatial Foundation Project, Versão 2.
- Team, R. C. (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing.

## ATTACHMENT 1:

### MAPS-DEPICTING OUTCOMES OF THE R2R SPATIAL MODELLING FRAMEWORK

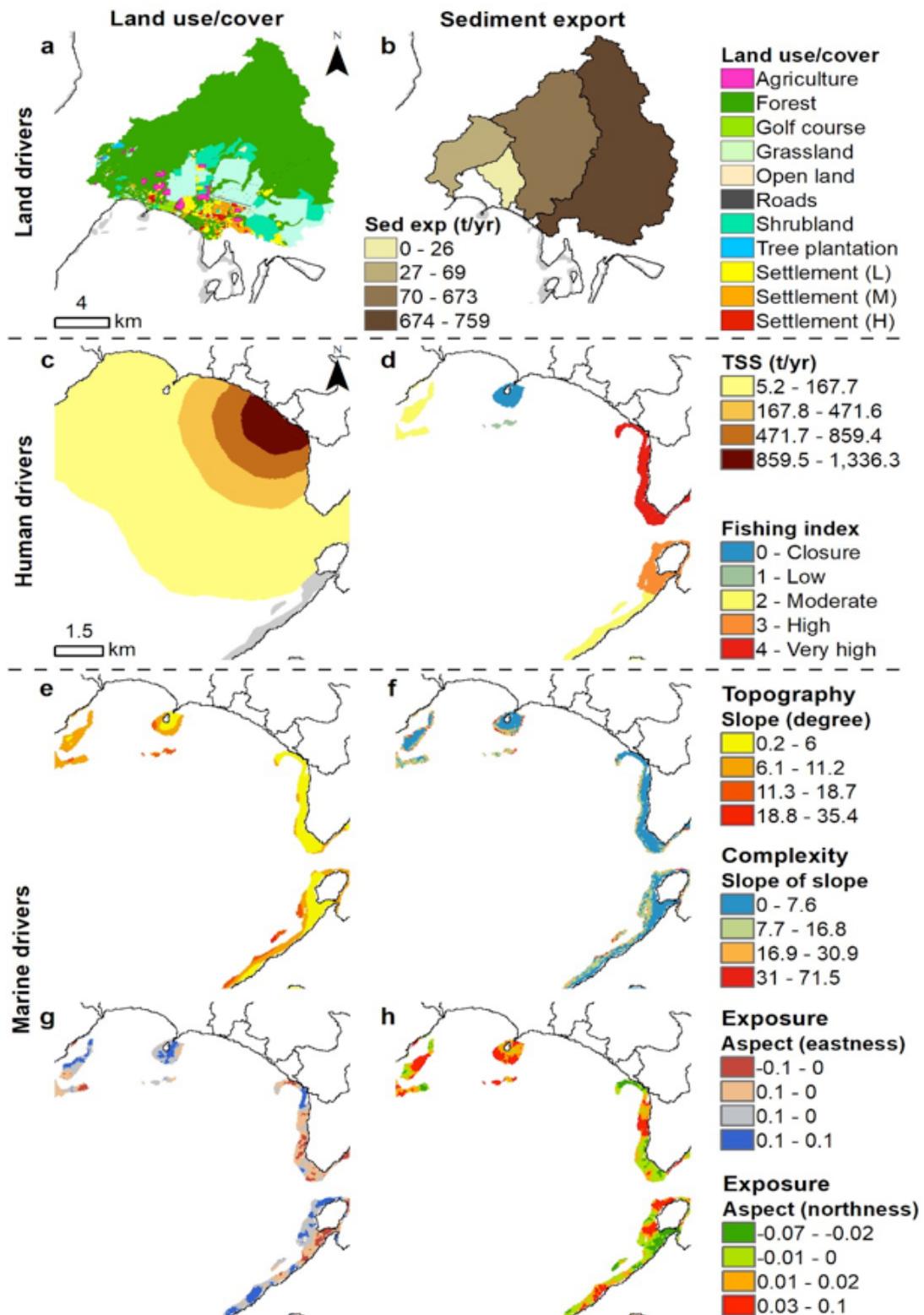


Fig 3. Present ridge to reef drivers

(a) Present land use/cover, (b) InVEST SDR results - sediment export (t/yr) summarized by watershed. The human drivers are represented by (c) modeled TSS plumes (t/yr) and (d) fishing pressure index. The marine drivers include (e) habitat topography (f) complexity, and exposure to wind and currents (g) eastness and (h) northness.

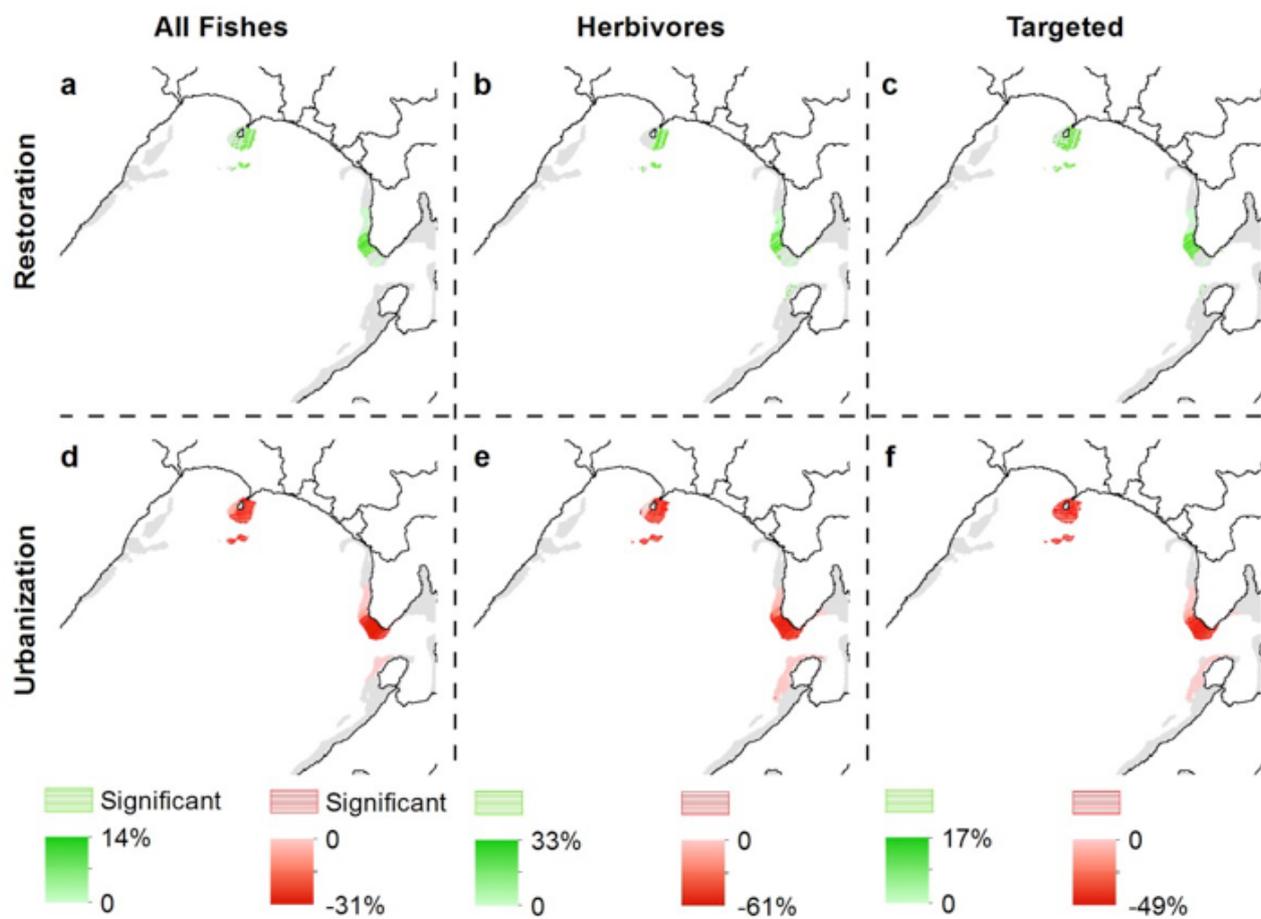


Fig 8. Maps of fish indicators change per land-use change scenarios: total biomass, herbivore biomass, and targeted biomass. Relative change in fish indicator biomass (% change) is shown under the: (a-c) restoration, and (d-f) urbanization scenarios.

## ATTACHMENT 2:

### LAND-SEA MODELLING FRAMEWORK METHOD

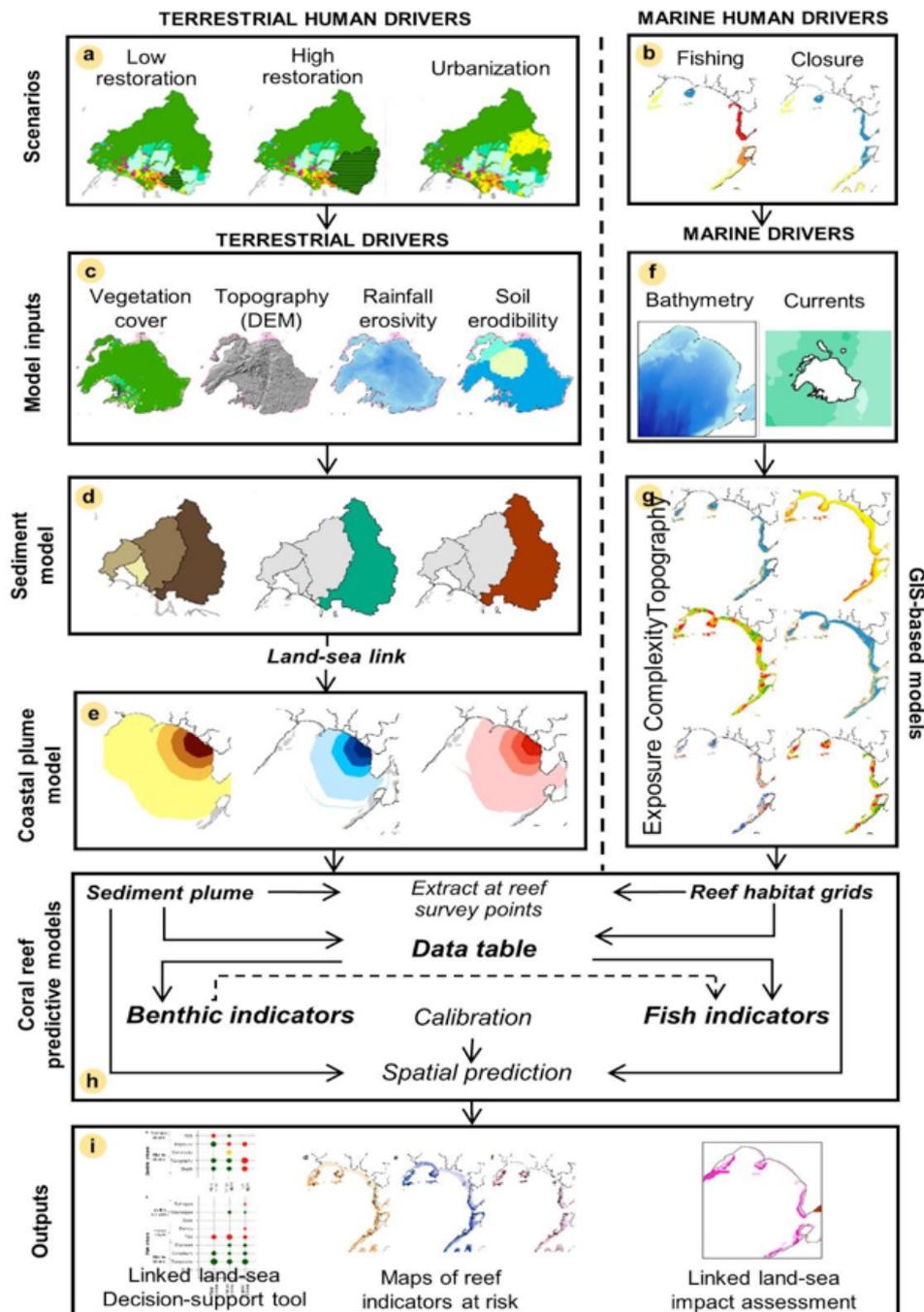


Fig 1. Ridge-to-reef modeling framework.

(a) Land-use change scenarios were coupled with the linked land-sea decision support tool.

(b) Marine management scenario.

(c) Land cover, topography, rainfall, and soil erodibility data were inputs in

(d) the InVEST Sediment Delivery Ratio (SDR) model to quantify sediment export (t/yr).

Sediment export values were assigned to (e) pourpoints at the shoreline and combined with (f) bathymetry and current maps into a coastal discharge model using a GIS distance-based dispersion models to generate sediment plume maps (t/yr). Bathymetry and the habitat map were combined with (g) GIS-based models to derive the marine driver grid data (i.e., habitat topography, geography, exposure, and complexity). (h) The coral reef predictive models were calibrated on coral reef survey data. (i) Outputs were: (1) a linked land-sea decision-support tool, (2) maps of benthic (% cover) and fish (g/m<sup>2</sup>) indicators, and (3) a linked land-sea impact assessment.





