MARINE HEATWAVE IMPACTS ON SEAGRASS IN VANUATU

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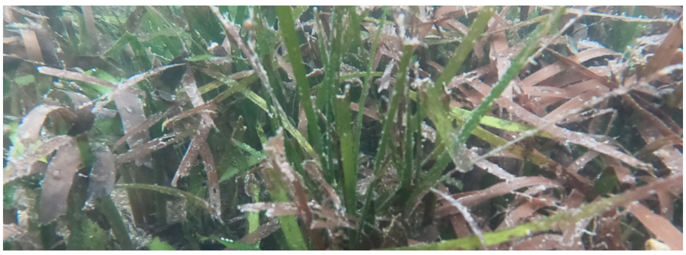
This case study examines the impacts of climate change on marine heatwaves and seagrass in Vanuatu. Guidance around conducting this type of step-by-step assessment is provided in more detail on the Van-KIRAP web portal, along with other climate impact related case studies (also termed infobytes), factsheets, visualisation tools and technical resources. This case study can be used as an example for undertaking similar climate hazard-based impact assessments.

STEP 1 Understand the context and scope

The ocean has warmed since 1970, taking up more than 90 % of the excess heat from global greenhouse gas emissions in the climate system [1]. This is reflected in the average annual duration of marine heatwaves (MHWs) in the Pacific. In the 1980s to 2000s this was 5–16 days, but during the 2010s increased to 8–20+ days [2], with increasing intensity [1]. MHW events are defined as: discrete, prolonged anomalously warm water events which last for five or more days, with temperatures warmer than the 90th percentile relative to climatological values.

As Pacific Island countries rely heavily on coastal and ocean resources, projected increases in future sea surface temperatures (SSTs) and corresponding MHW frequency, intensity, and duration could be detrimental across the Pacific Island region [3, 4]. Tropical seagrass beds are particularly vulnerable to high SSTs. **Here we explore current and future impacts of MHWs on seagrass in Vanuatu.** For information on how this climate hazard-based impact study fits into a broader risk framework, see the Climate risk factsheet.



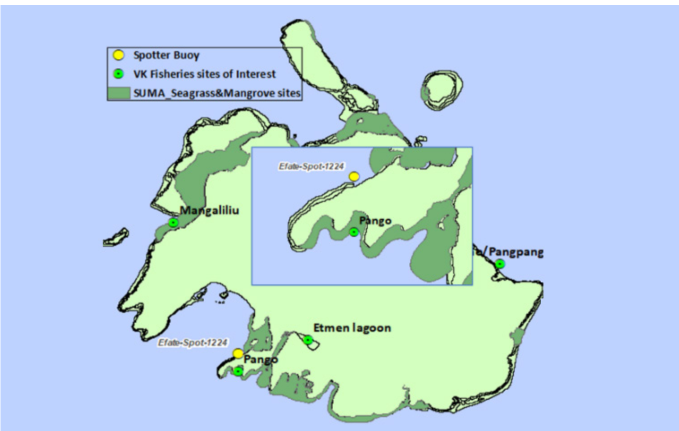


Figure 1 Seagrass (Thalassia hemprichii) found in Pango, Efate. A spotter buoy is located near Pango. Photo credit: Rebecca Gregory

STEP 2 Engage and meet with stakeholders

Van-KIRAP fisheries sector personnel, Vanuatu Meteorology and Geo-hazards Department (VMGD) and CSIRO scientists have met regularly to discuss different aspects of fisheries and related climate change impacts. Key literature was also drawn upon to inform the assessment. Fisheries personnel, supported by key literature, highlighted that through offering protection from predation and provision of food and other natural resources, seagrass beds provide critical habitat, including nursery areas. Seagrass beds also support high biodiversity and aquatic productivity for an extensive range of fish and invertebrates, as well as ecologically significant megafauna such as dugongs and sea turtles [5]. Seagrass beds provide additional ecosystem services such as improvement of water quality for coastal lagoons and other inshore resources [5], including as a natural carbon sink to facilitate greenhouse gas mitigation [6-8].

STEP 3 Explore background information and historic climate data

There is ecological diversity in seagrass habitats across the Western Pacific region, depending on prevailing water quality and clarity, nutrient availability, and exposure to wave action [5]. Seagrass species diversity is typically very rich in Vanuatu [7, 9], with most found in waters shallower than 10 m [5]. Seagrass meadows in the Pango region of Efate Island have recently been assessed noting a domination of *Thalassia hemprichii* seagrass [9] (Figure 1).

In Vanuatu, annual average SST ranges from about 25.5 °C to 28.5 °C from south to north, supporting seagrass habitats (Figure 2; top left). Through the period 1982–2021, SST has been warming in the Pango region (Figure 2; top right), and while the annual number of days experiencing MHWs is around 25 per year on average, the total number and severity of MHW events has been increasing (Figure 2; bottom left). This trend is also evident at an ocean scale across the broader region around Vanuatu (Figure 2; bottom right). In February 2016, during a strong El Niño event, a strong MHW (SST anomaly of 1.75–2.0 °C) resulted in a major fish kill event in the Pango area [10]. For more information on MHW categories and the 2016 MHW and fish kill event, see the MHW explainer.

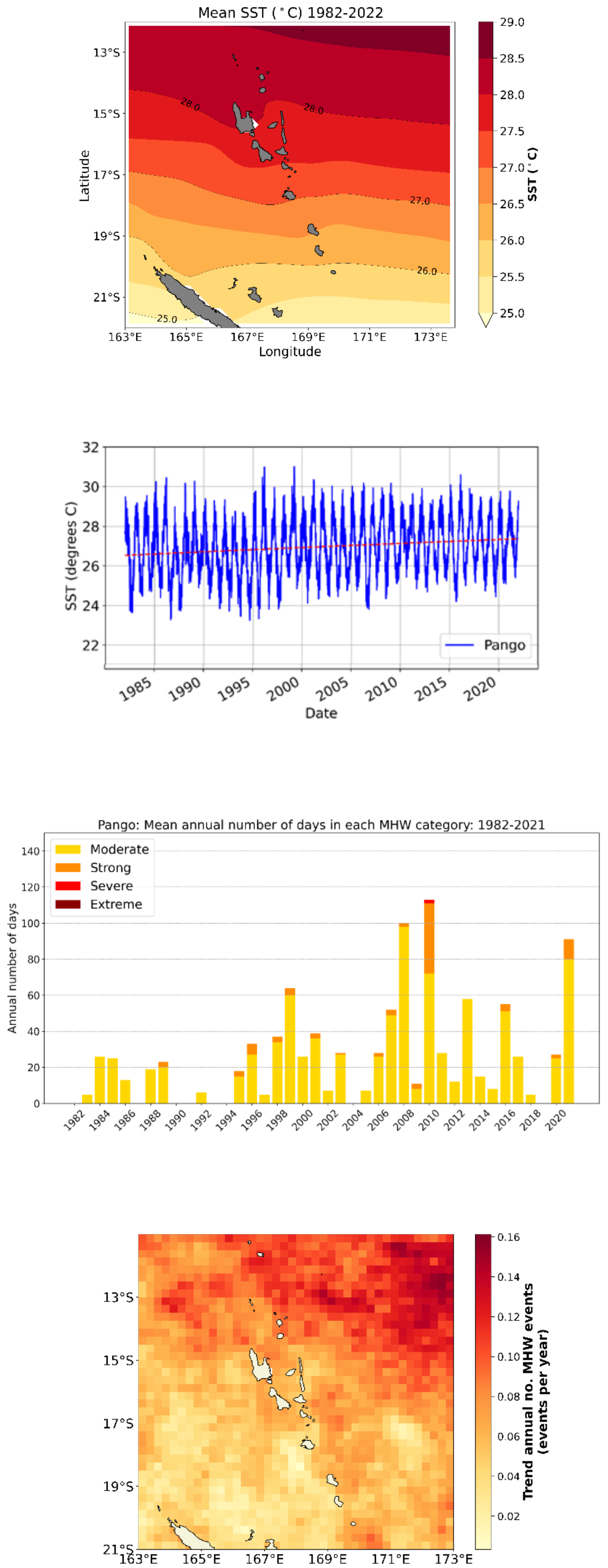


Figure 2 Vanuatu mean SST (°C) (1982–2022) (top left). SST (°C) timeseries from 1982–2021 for Pango region (blue line)(top right). Annual number of days in each MHW category over the period 1982–2021 for Pango region (bottom left). Trend in annual number of MHW events (1982–2019) (bottom right). Events are defined as: discrete, prolonged anomalously warm water event which lasts for five or more days, with temperatures warmer than the 90th percentile relative to climatological values. MHWs are considered as separate events if they are separated from a previous MHW by more than two days. Hobday et al. [10, 11]. Source data: NOAA OISST v2-1 SST [12].

More generally, SST is also strongly influenced by natural climate variability, including large-scale processes such as the El Niño Southern Oscillation (ENSO). SSTs are generally higher during La Niña and lower during El Niño periods in Vanuatu. For information about ENSO influences on SST (see the Climate variability explainer).

Tropical seagrass species around the world show varying tolerances to increased temperatures [13, 14], with thermal tolerance not well studied in seagrass in the Pacific [15]. Tropical species tend to have higher optimal temperature tolerances than temperate species, with optimal growth occurring in the range 23–32 °C [16], depending on the species. Some species survive at temperatures as high as 32 °C, while others begin to show shoot mortality above 26 °C [16]. Where water temperature rises to 35–40 °C, photosynthesis declines due to the breakdown of photosynthetic enzymes resulting in reduced growth [5] or death with extended extreme MHWs [17, 18] and related subsequent ecosystem change [19, 20]. Recent monitoring indicates a general seagrass decline in the Western Pacific [21].

STEP 4 Collect information about future climate scenarios

Applications of climate projections for the coming decades are influenced by inherent uncertainty in future global greenhouse gas emissions ranging from very low (SSP126) to very high (SSP585), regional climate responses simulated by climate models for each emissions scenario, and natural climate variability (see also Step 5) (see Emissions pathways factsheet, Climate models factsheet and Climate variability explainer).

Over the 21st century the ocean is projected to further warm, and compared to the 1995–2004 period, projected increases are around 0.7 °C by 2050 under low emissions, or up to around 1.1 °C under high emissions (Figure 3). Correspondingly, MHW and extreme El Niño and La Niña events are projected to become more frequent [22, 23].

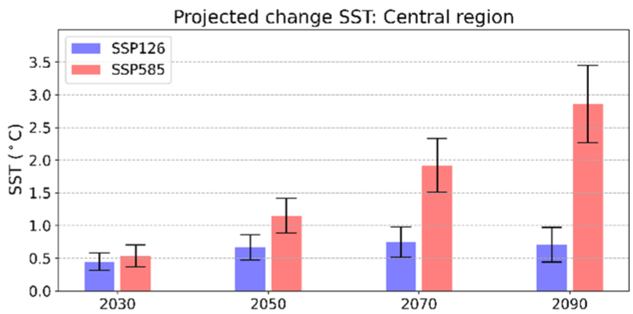


Figure 3 Projected SST (°C) change for Vanuatu Central region, including Pango, for 20-year periods centred on 2030, 2050, 2070, and 2090 relative to 1995–2004. (Data source: 18 CMIP6 models under low (SSP126; purple) and high (SSP585; pink) emission scenarios). (See GHG emissions factsheet). Bars indicate standard deviation.

Projected MHWs out to the end of the century have been calculated for a lower-warming climate model and a higher-warming climate model, under low and high emissions scenarios, to capture the projected range of change (Figure 4). Across all sites, the typical number of MHWs is around 25 days per year (1982–2021) (Figure 4). Under the low emissions scenario (SSP126), this increases to about 80–150 days per year by 2050 (Figure 4). Under the high emissions scenario (SSP585), this increases to about 170–310 days per year by 2050, with many days in the "Strong" and "Severe" MHW categories (Figure 4). By 2090, larger increases in MHWs are projected, more so in the north. For a low emissions scenario, the number of MHW days is 110–190, with a substantial increase in "Strong" events. For a high emissions scenario, the number of MHW days is 320–360, with a big increase in "Severe" and "Extreme" events (Figure 4).

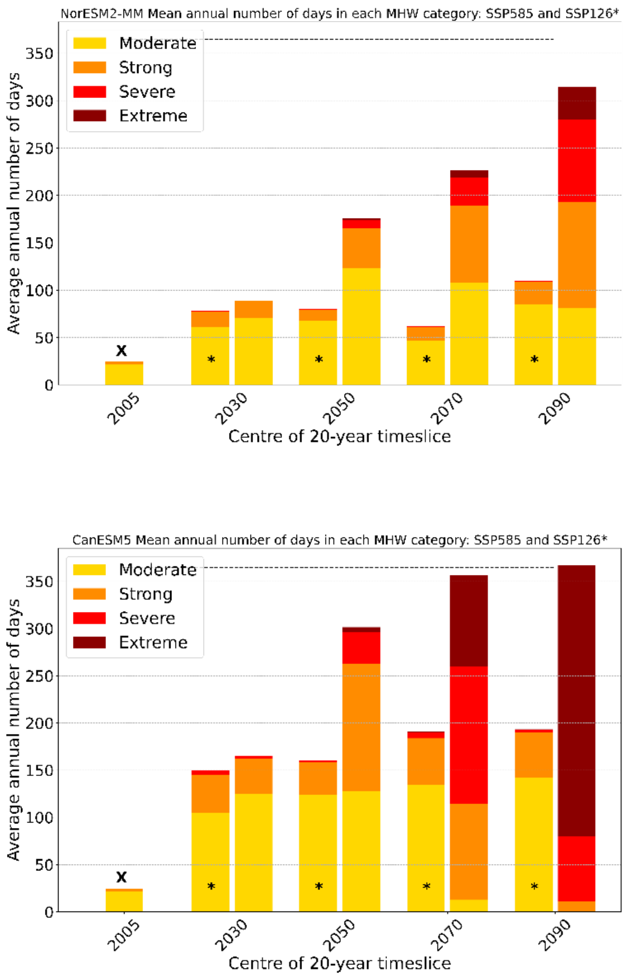


Figure 4 Projected average annual number of MHW days for an area-averaged domain encompassing Pango for the 1982–2021 period based on observations (x ;NOAA OISST v2-1 SST [12]), and the 'best-case' (NorESM2-MM; left panel) and 'worst-case' model (CanESM5; right panel) under SSP126 (*) and SSP585, based on CMIP6 modelling (see Climate projections for use in impact assessments factsheet). Averages for 20-year periods centred on 2030, 2050, 2070, and 2090, are plotted for each of four categories (moderate, strong, severe, and extreme MHW [10]; see Marine heatwave factsheet for category definition).

While different seagrass species show different thermal tolerances, they are all likely to be sensitive to projected increases in SST [7]. Stress may result from short-term 'spikes' in maximum temperature over periods of hours, with increasing duration of events above 40 °C likely to affect the ecological function of tropical seagrass meadows [18]. Stress may also result from longer (multi-day and multi-week) MHW exposures [24] where seagrass beds are already growing at their maximum temperature tolerance [5].

STEP 5 Analyse climate-related impacts

Under the high emissions scenario, by the end of the century, the Pango region could experience almost year-round MHW conditions, with more than two-thirds of the year in the "Extreme" category (worst-case model). In contrast, the impact of following the low emissions RCP2.6 trajectory is clearly evident, with MHW days projected to be mostly less than 200 days per year on average even by 2100, and with the majority of those remaining in the "Moderate" category with "Extreme" MHW conditions remaining a rare event (Figure 4). Both scenarios represent a significant increase in potential impacts on seagrass beds in Vanuatu from future MHWs compared with current/historical trends (Figure 2), with the worst-case being potentially catastrophic at a local to national scale.

Seagrasses are already being impacted due to coastal development [9]. With increasing intensity, frequency and duration of MHWs over Vanuatu, the resilience of seagrass meadows is further compromised, underlining the need to implement conservation and restoration strategies and reduce greenhouse gas emissions [7].

Overall, increased SST will be one of the most important environmental stressors on seagrass habitats as clearly shown by the massive seagrass losses (1310 km^2 between 2002 and 2016, including a 36 % loss in 2010/2011) recorded after highly elevated seawater temperatures in Shark Bay, Australia [18, 24].

STEP 6

Evaluate other climate and non-climate factors

It is important to note that only SST and MHW conditions are assessed under future climate change scenarios in Step 5. Other climate and non-climate factors causing potential impacts are listed below that may also influence the sustainability of seagrass habitats. Further analysis around these may be prudent.

Climate factors affecting seagrass	
Sea level rise	Rising sea levels may lead to landward seagrass migration [7].
Tropical cyclones	In addition to increasing sediment loads and nutrient levels, cyclones and storms increase the power of waves affecting coastal habitats. Wave surge strips leaves from seagrasses and often uproots the subsurface rhizomes, also resulting in reductions in light caused by greater turbidity [5]. Cyclones will occur less often but a greater proportion of the cyclones that do occur will be severe [25-27].
Extreme rainfall	Extreme rainfall events can cause prolonged periods of low salinity, light deprivation and increased silt and contaminant load (via terrestrial runoff), resulting in major loss of seagrasses [28]. The intensity and frequency of extreme rainfall is expected to increase in future [25].
El Niño Southern Oscillation (ENSO)	ENSO is a large-scale driver of natural climate variability in the Pacific, affecting SST and sea level [2, 13]. ENSO also affects tropical cyclone frequency [29]. The combination of ENSO and climate change means that seagrass may be more exposed to higher temperatures during very low tides [12]. La Niña and El Niño extremes are projected to increase in future [22, 23].
Non-climate factors	
Land-use planning and development	Unsustainable catchment management and coastal development may increase sediment and pollutants washed into coastal waters, leading to a decline in seagrass productivity [7]. Seagrass beds are very sensitive to low light levels [30] with interactions between elevated temperatures and reduced light levels resulting in greater potential impacts [5].

STEP 7 Plan future adaptation

Adaptation can be incremental or transformative, with enablers and barriers, synergies and trade-offs, pathways and limits, costs and benefits. The process usually starts with consideration of adaptation options. A list of adaptation options that could be considered, tested, and verified in the community to improve resilience includes:

- The National Ocean Policy aims to build marine ecosystem resilience to climate change including rising ocean temperatures, acidity and sea level rise, and one of the policy actions is to strengthen risk assessments and their use in planning.
- The Dugong and Seagrass Conservation Project aims to enhance the conservation of dugongs and their associated seagrass ecosystems in eight countries in the Indo-Pacific region, including Vanuatu [31].
- Long-term seagrass monitoring has been established in Vanuatu as part of the Seagrass-Watch, global seagrass assessment and monitoring program. Establishing a network of monitoring sites in Vanuatu provides valuable information on trends in the health of seagrass meadows and provides a tool for decision-makers in adopting protective measures. Working with both scientists and local stakeholders, this approach is designed to draw attention to anthropogenic impacts on seagrass meadows which degrade coastal ecosystems and decrease their yield of natural resources [30].
- Seagrass species can adapt to global climate change to some degree if well managed and protected [14]. Exploration of the priorities, costs and expertise would inform the feasibility of protection and restoration options.
- Ongoing support for seagrass related research and monitoring is required [21, 32], including mapping, pollution, water quality, human health, carbon mitigation, coastal protection, traditional knowledge and coastal fisheries.
- Inclusion of seagrass as a provider of ecosystem services and a contributor to the social, economic and cultural integrity of Pacific peoples would elevate the importance of seagrass in management strategies.

STEP 8 Communicate findings

Communicating the assessment findings to key sector stakeholders is the final step of the climate hazard-based impact assessment. Multiple communication formats, co-designed and co-produced with target users in mind are more likely to support action and decision-making. The contents of this infobyte, together with other related resources shown below, can be disseminated and shared with key stakeholders to help them plan for and adapt to the changing climate.

Van-KIRAP Web Portal

Case Studies

Fact Sheets

Guidance Material

Videos

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