Past and projected future impacts of coral bleaching on the reefs of Vanuatu

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This report contains maps and histograms that describe the past and projected future impacts of thermal stress and resultant coral bleaching on the reefs of Vanuatu. The report includes maps of Vanuatu for a range of variables that describe the thermal history (1985-2017) and projected future exposure to thermal stress. Data for the histograms that accompany each map have been provided as a separate Excel file. All maps within this report have also been provided as individual super high-resolution image files for use in presentations and other reports. The images found within this report should always be cited as Heron et al. 2016 and van Hooidonk et al. 2016. Methods for the generation and visualization of these data can be found within these open access papers, available at the hyperlinks below.

Cover photograph: Branching coral and damselfish near Million Dollar Point and the Coolidge, Espiritu Santo, Vanuatu. Photo Credit: Jeffrey Maynard.

This report is available for download from the SPREP website: http://www.sprep.org

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Executive Summary:

Coastal fish and reef-associated fish are vital ecosystem goods and services, particularly food, that coral reefs provide to island communities in the Pacific. Coral reefs also attract tourists and are therefore also an important sources of tourism income for Pacific island communities and national economies. However, reef habitats are degrading worldwide due to increasing frequency of temperature-induced coral bleaching events and severe tropical storms. As the climate changes, coral and reef fish communities will also change. Coral reef degradation due to thermal bleaching and severe storms will reduce fisheries productivity and can result in declines in food security and income. The objective of this study was to examine past (1985–2017) and projected future (2018–2100) impacts of thermal bleaching to the coral reefs of Vanuatu. Relative refugia are identified – these are locations that have experienced bleaching stress less frequently in the past and that are projected to have lower (later) exposure to bleaching stress in the future. These relative refugia are more likely to provide ecosystem goods and services to the fisheries and tourism sectors than locations severely degraded due to coral bleaching.

There is high spatial variation in the frequency of exposure to severe thermal stress in Vanuatu over the last 30 years, and the projected future exposure to severe thermal stress over the next 80 years. Many of the reef locations in Vanuatu have historically been refugia from thermal stress that causes coral bleaching. Reef locations that represent historical refugia are Tanna, southern Efate, Ambrym, north Pentecost and west Maewo islands. These historical refugia were less frequently exposed to severe thermal stress in the past 30 years and had relatively low rates of change in warm season temperatures and relatively high warm season variability – especially around Epi, west Pentecost and west Maewo islands. Climate model projections for Vanuatu suggest that some of these historical refugia are also temporary refugia from future severe thermal stress. That is, they are projected to experience annual severe bleaching seven or more years later than the average for Vanuatu of 2040. This is particularly true for the reefs of Tanna, Epi and west Maewo islands.

Coral reefs with lower past and projected future exposure to thermal stress may have lower relative vulnerability to climate change. Coral reefs with lower relative vulnerability to climate change are more likely to continue to provide ecosystem goods and services as the climate changes. ***Coral reefs with low climate vulnerability are conservation and management priorities.*** Reducing threats from human activities at locations with low climate vulnerability can give these reefs the best chance of remaining healthy and continuing to provide goods and services (e.g. food, income) for communities.

Results Summary:

Reef Area

Exclusive Economic Zone (EEZ) area (km^2)	668,220
Land area (km^2)	11,880
Land as percentage of EEZ	1.7%

Vanuatu has >1200 km^2 of coral reef that support coastal species and communities. Mangroves cover 25 km^2 (Bell et al. 2011). Vanuatu has 601 reef pixels[1] that were analysed for this study.

Average projected timing of annual severe bleaching (ASB) under RCP8.5[2]

2042 (global average is 2043).

Earliest and latest average projected timing of ASB under RCP8.5

Earliest – coral reefs around Espirutu Santo, Malekula, Epi, and Gaua (2031–2034)
Latest – coral reefs around Malekula, Ambae, Maewo, Epi, and Tanna (2048–2052).

Relative climate losers and winners

Espiritu Santo has the greatest number of reef pixels projected to experience ASB before 2038 (relative climate losers) with 20 pixels, which represents ~3.3% of reef area in Vanuatu.

Maewo has the greatest number of reef pixels projected to experience ASB after 2045 (relative climate winners) with 16 pixels, representing 2.7% of reef pixels in Vanuatu.

Best refugia for future thermal stress

Later bleaching reefs (those projected to experience ASB after 2045) are located in the Banks Group (around Ureparapara, Vanua Lava, Kwakéa, and Gaua), northern Maewo, southeastern Espiritu Santo (near Turtle Bay and Aese), Ambae, southwestern Pentecost, central and southern Malekula, southwestern Ambrym, Epi, northern Erromango, southeastern Tanna, and Aneityum.

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[1] Numbers are all sourced from the bleaching projections rasters (601 reef pixels in the Vanuatu EEZ, resolution: 0.043945 (precisely 180/4096th decimal degrees); thermal history data is on a different grid: 432 reef pixels in the Vanuatu EEZ, resolution 0.041667. Precisely 1/24th decimal degree)

[2] RCP8.5 refers to the Representative Concentration Pathway for a high greenhouse gas concentration trajectory in the future (for further information refer to the IPCC Fifth Assessment Report 2014 https://www.ipcc.ch/assessment-report/ar5/).

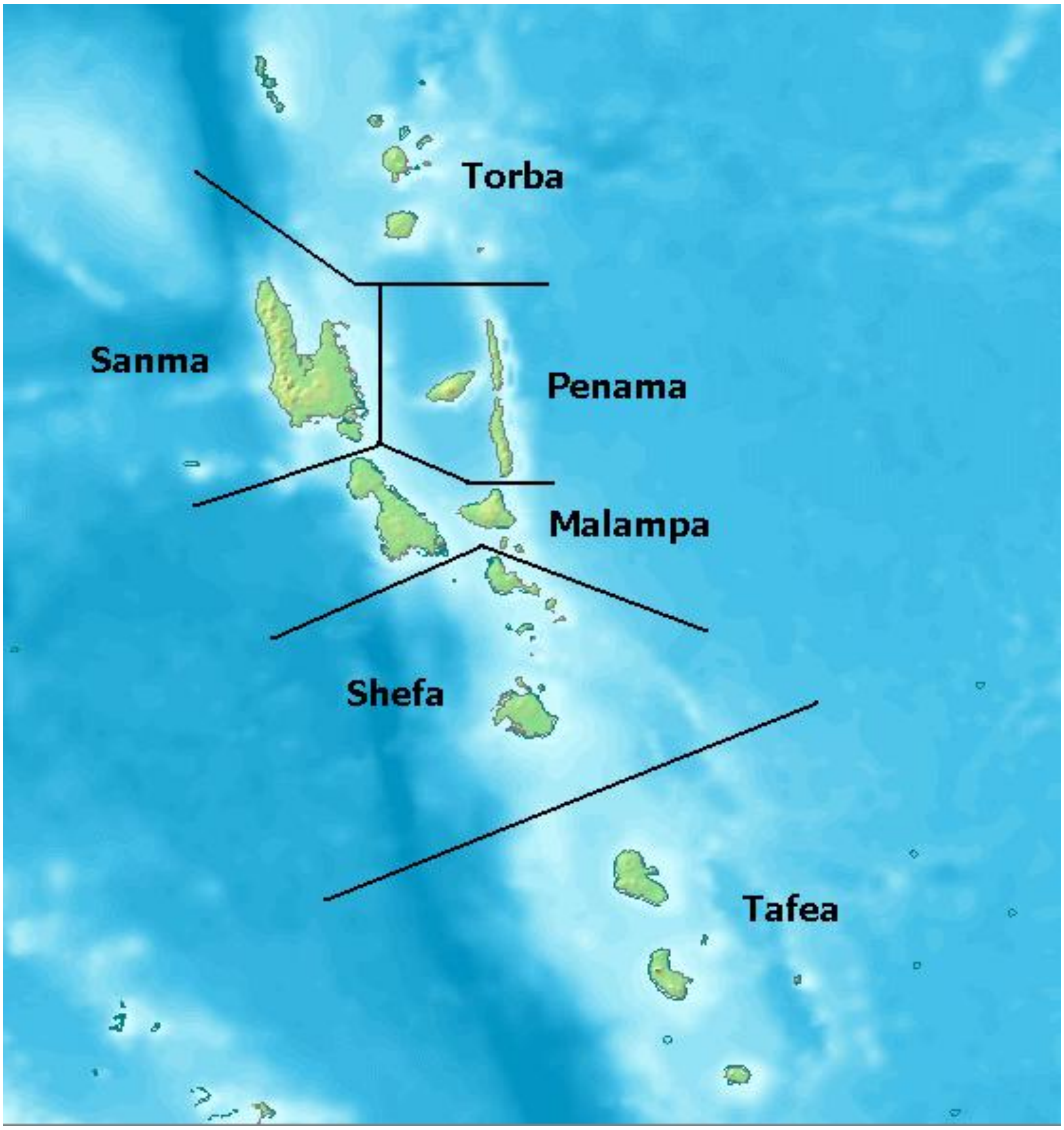

Figure 1. Map of Vanuatu indicating all Provinces

Recommendations:

Climate exposure and vulnerability maps are critical to decisions on marine management and marine protected areas to ensure the best current information on climate change is included in planning processes. Spatial analyses are recommended to combine the data layers presented to identify the specific coral reefs that were historical refugia and are projected to be temporary refugia from thermal stress. These analyses can include data on relative reef resilience (including sensitivity and adaptive capacity) and data on human activities (i.e. anthropogenic stress) to produce maps of relative vulnerability to climate change. This project team can develop climate vulnerability maps for Vanuatu under a future collaboration between Symbioseas/ NOAA, SPREP and the Vanuatu Government.

Introduction:

Vanuatu is one of the most vulnerable countries in the Pacific region to a range of climate-related hazards. Its people and their sources of food and livelihoods are exposed to the increasing impacts of climate-induced hazards such as tropical cyclones, flooding, drought and storm surge, and the effect of slow-onset events such as sea level rise, temperature rise and ocean acidification. Vanuatu has 83 islands managed under six provinces (Figure 1) and as a large ocean state dominated by water (only 1.7% of the nation's area is land), communities, sector and the national economy are highly dependent on marine resources (Johnson et al. 2018a). Most islands are surrounded by fringing reefs that provide fish and invertebrates for food and income, as well as tourism opportunities (Johnson et al. 2017, 2018b).

Coral reefs are under unprecedented pressure. Reef habitats are degrading worldwide due to increasing frequencies of climate-induced coral bleaching events and severe tropical storms (among other episodic disturbances). These acute disturbances occur against the backdrop of chronic stress related to ocean acidification and local-scale human activities, such as coastal development and overfishing. The short- and longer-term consequence of these pressures is reduced reef resilience; a steady loss in the natural ability of coral reefs to maintain key functions and provide ecosystem goods and services (Anthony et al. 2014). Reef fish and reef-associated fish are key among the ecosystem goods and services that reefs provide to island communities in the Pacific (Bell et al. 2009). Coral reefs also attract tourists so can be vital sources of tourism income for Pacific island nations. As the climate changes, coral and reef fish communities will also change – coral reef degradation due to coral bleaching and severe storms will reduce fisheries productivity and can result in declines in tourism income.

Reef fisheries productivity is closely related to the structural complexity of coral reef habitat. Small-bodied fish that are highly vulnerable to predation benefit from using structurally complex reef areas as refugia. They experience reduced mortality in these areas and their abundance increases as a result. This increased survival and abundance results in greater fish productivity, because small-bodied fish comprise prey species and the juveniles of larger predators. A reef with high habitat complexity allows for an increased abundance of small-bodied fish inside crevices. In these areas, there is also an increased abundance of fish excluded from the crevices through competition; these fish are available to predators and also contribute to an increase in productivity (Rogers et al. 2014). Rogers et al. (2014) developed models that contrast the fishery productivity of structurally complex reefs (up to 50% coral cover) with reefs that lack structural complexity (< 30% coral cover). This research showed that reefs losing structural complexity reduces productivity of predatory fish by half and herbivorous fish by more than two and a half times. When assuming most reef fisheries ignore smaller-bodied invididuals, loss of complexity results in a three-fold loss in combined predator and herbivore reef fishery productivity (Rogers et al. 2014).

Bleaching events and severe cyclones reduce both the structural complexity of coral reef habitat. Structurally complex fast-growing branching corals tend to be more susceptible to bleaching and die when temperature stress persists. Once dead, algae and other bioeroders colonize the skeleton, which then breaks up into rubble under typical wave forcing and especially during heavy seas caused by cyclones. Structurally complex coral colonies also have greater surface area and therefore are more susceptible to wave damage during cyclones.

Methods:

The objective of this study was to examine past (1985–2017) and projected future (2018–2100) impacts to the reefs of Vanuatu from coral bleaching. Relative refugia are identified – these are locations that have experienced bleaching stress less frequently in the past and that are projected to have lower (later) exposure to bleaching stress in the future. These relative refugia are more likely to provide ecosystem goods and services to the fisheries and tourism sectors than locations severely degraded due to bleaching.

Variables analysed:

Thermal history

- Frequency of events greater than 4 Degree Heating Weeks 1985–2012
- Frequency of events greater than 8 Degree Heating Weeks 1985–2012
- Maximum Annual Degree Heating Weeks 1985–2017
- Annual Trend 1985–2012
- Warm Season Trend 1985–2012
- Warm Season Trend minus Annual Trend 1985–2012
- Warm Season Variability 1985–2012

Methods for the development of these data are described within Heron et al. (2016). Data have a 4-km resolution and are only shown for reef locations in Vanuatu.

Model Projections

- Timing of annual severe bleaching (ASB, ≥8 DHWs) under RCP8.5
- Timing of annual severe bleaching (ASB, ≥8 DHWs) under RCP4.5
- Difference in projected timing of annual severe bleaching (ASB, ≥8 DHWs) between RCP8.5 and RCP4.5
- Timing of 2x per decade bleaching (ASB, ≥8 DHWs) under RCP8.5
- Timing of 2x per decade bleaching (ASB, ≥8 DHWs) under RCP4.5

Methods for the development of these climate model projections are described within van Hooidonk et al. (2016). The projections data have a 4-km resolution and are only shown for reef locations in Vanuatu.

Results: Thermal Histories

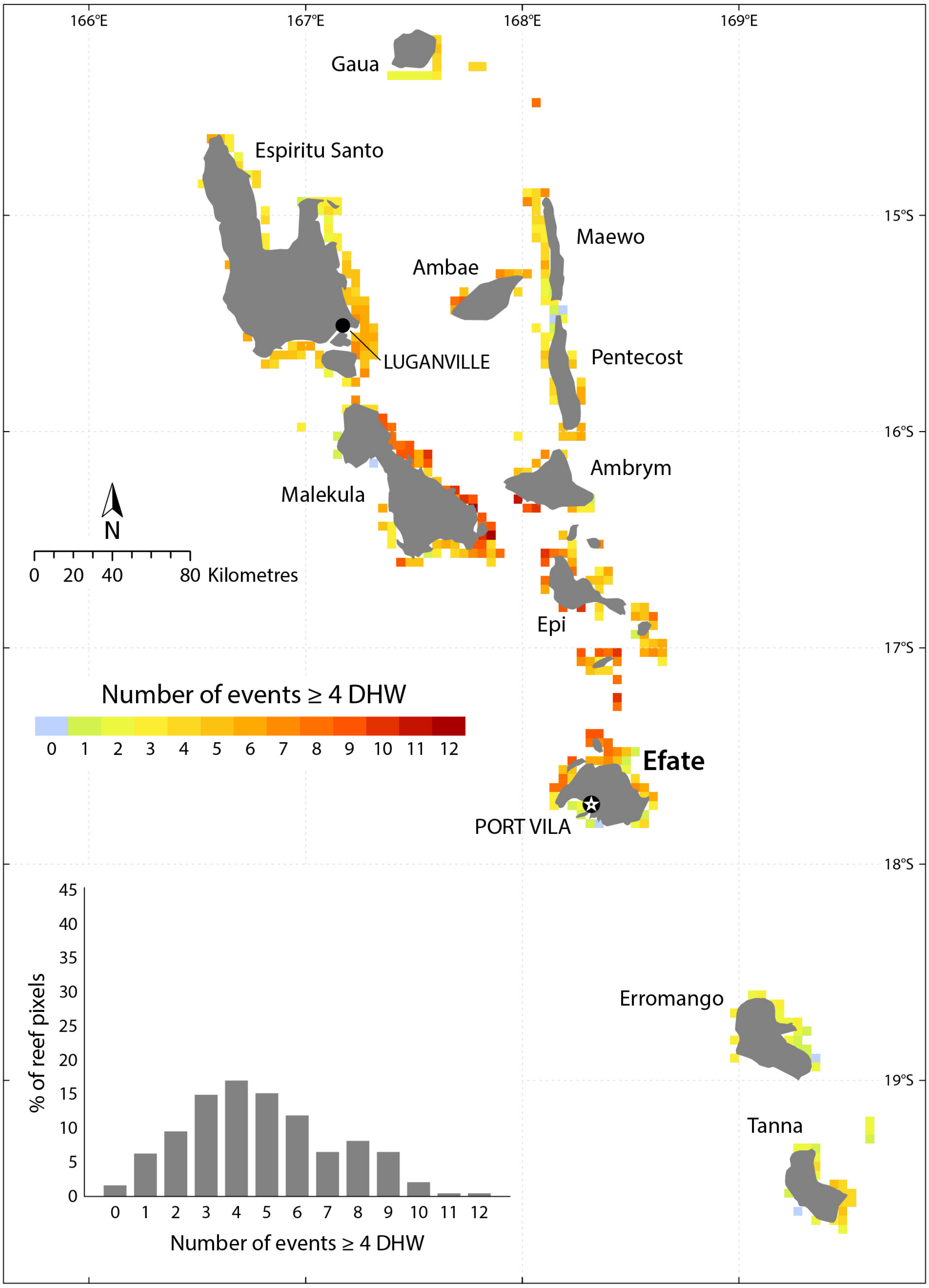

Figure 2. ***Frequency of events greater than 4 Degree Heating Weeks (DHW) 1985-2012.*** *82% of reef pixels in Vanuatu (n=432) experienced <8 events of this magnitude during the 28-year study period. Reefs that experienced >8 events of this magnitude (18%) are located in northern Efate, west Epi, east Malekula and southwest Ambrym islands.*

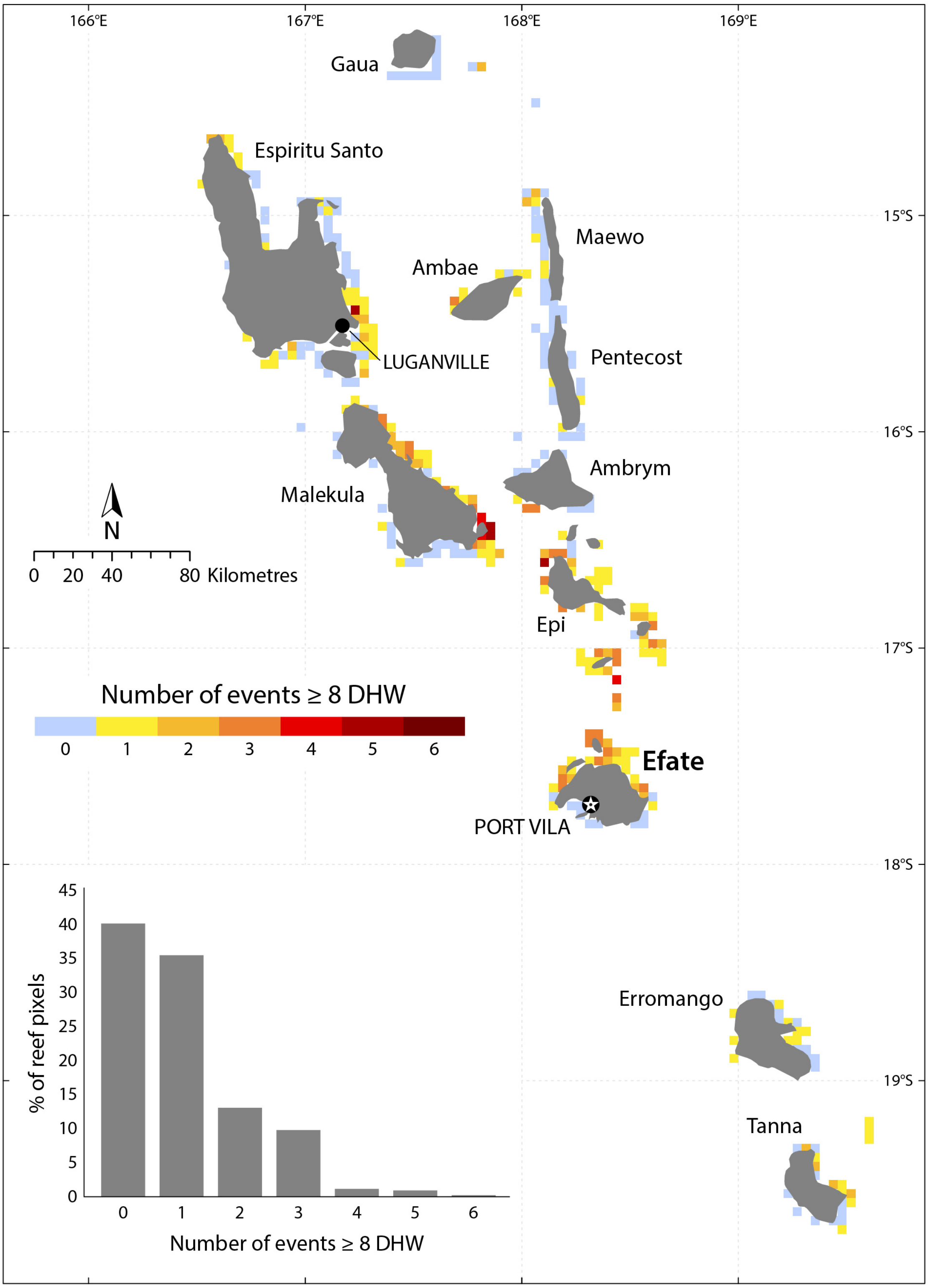

Figure 3. ***Frequency of events greater than 8 Degree Heating Weeks (DHW) 1985-2012.*** *88% of reef pixels in Vanuatu (n=432) experienced <3 events of this magnitude during the 28-year study period. Reefs that experienced >3 events of this magnitude (12%) are located in northern Efate, west Epi, east Malekula and southwest Ambrym islands. Reefs that experienced <3 events of this magnitude (12%) are located in Tanna, southern Efate, Ambrym, north Pentecost and west Maewo islands.*

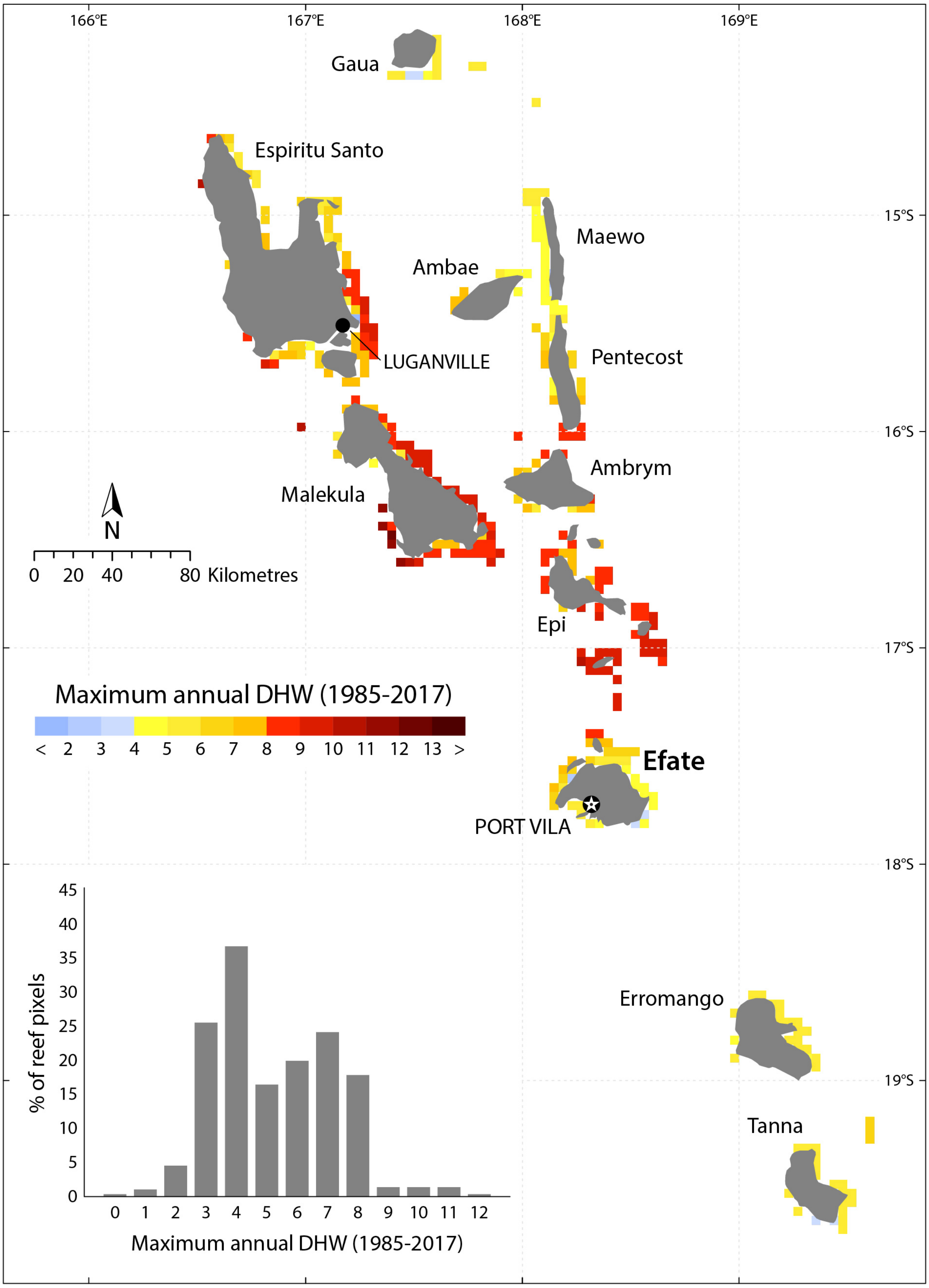

Figure 4. ***Maximum Annual Degree Heating Weeks (DHW) 1985-2017.*** *70% of reef pixels in Vanuatu (n=432) experienced a maximum of <8 DHWs events during the study period. Reefs that experienced severe events (>8DHWs) are located around Epi and Malekula, in eastern Espiritu Santo, and in southern Pentecost islands.*

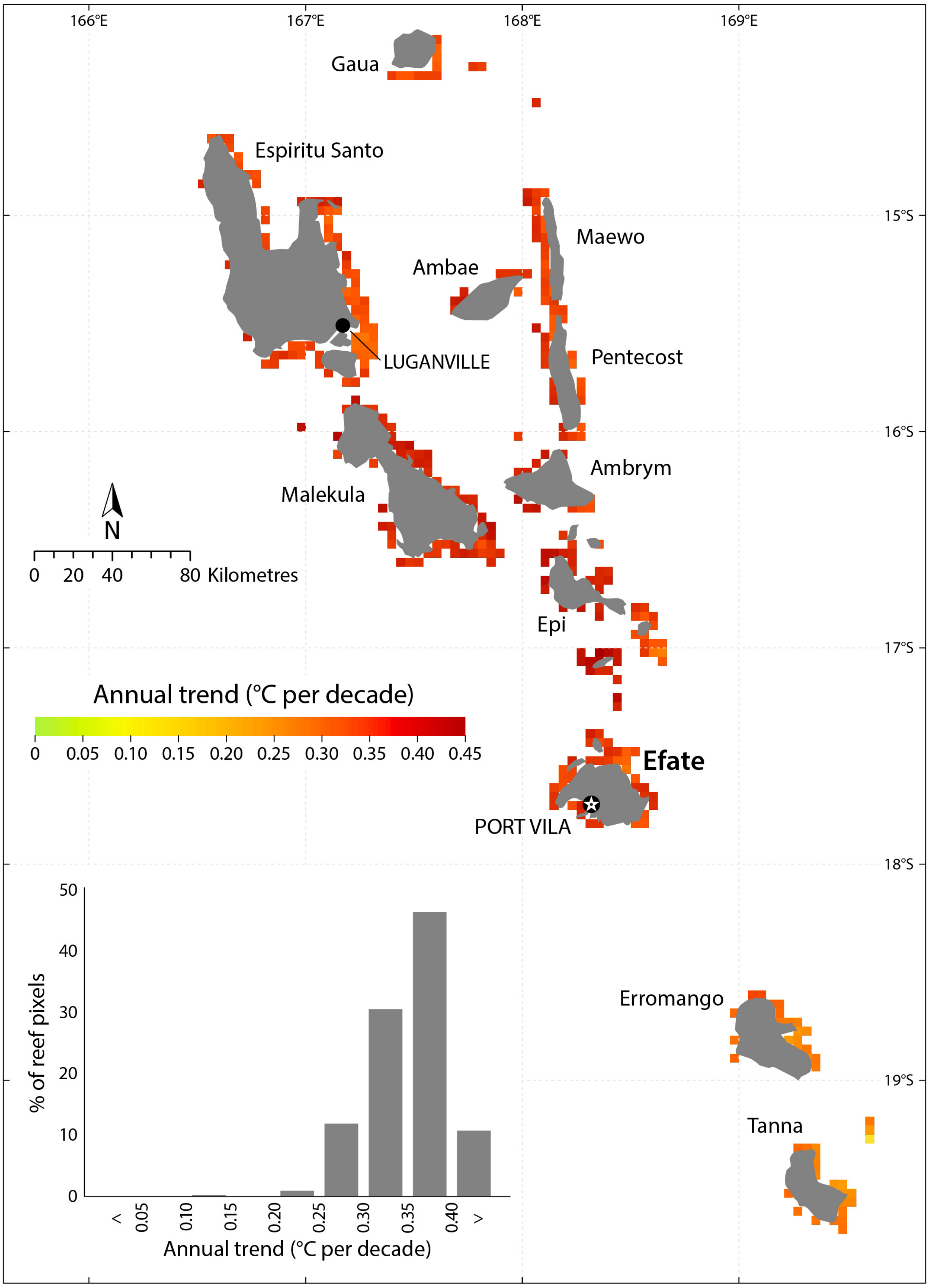

Figure 5. ***Annual Trend 1985-2012.*** *75% of reef pixels in Vanuatu (n=432) experienced a rate of change in the annual average temperatures between 0.3 and 0.4 ℃. There is little spatial variation in Vanuatu in the annual trend. These annual trend values are close to the global average for annual trend of 0.33 ℃ for the study period.*

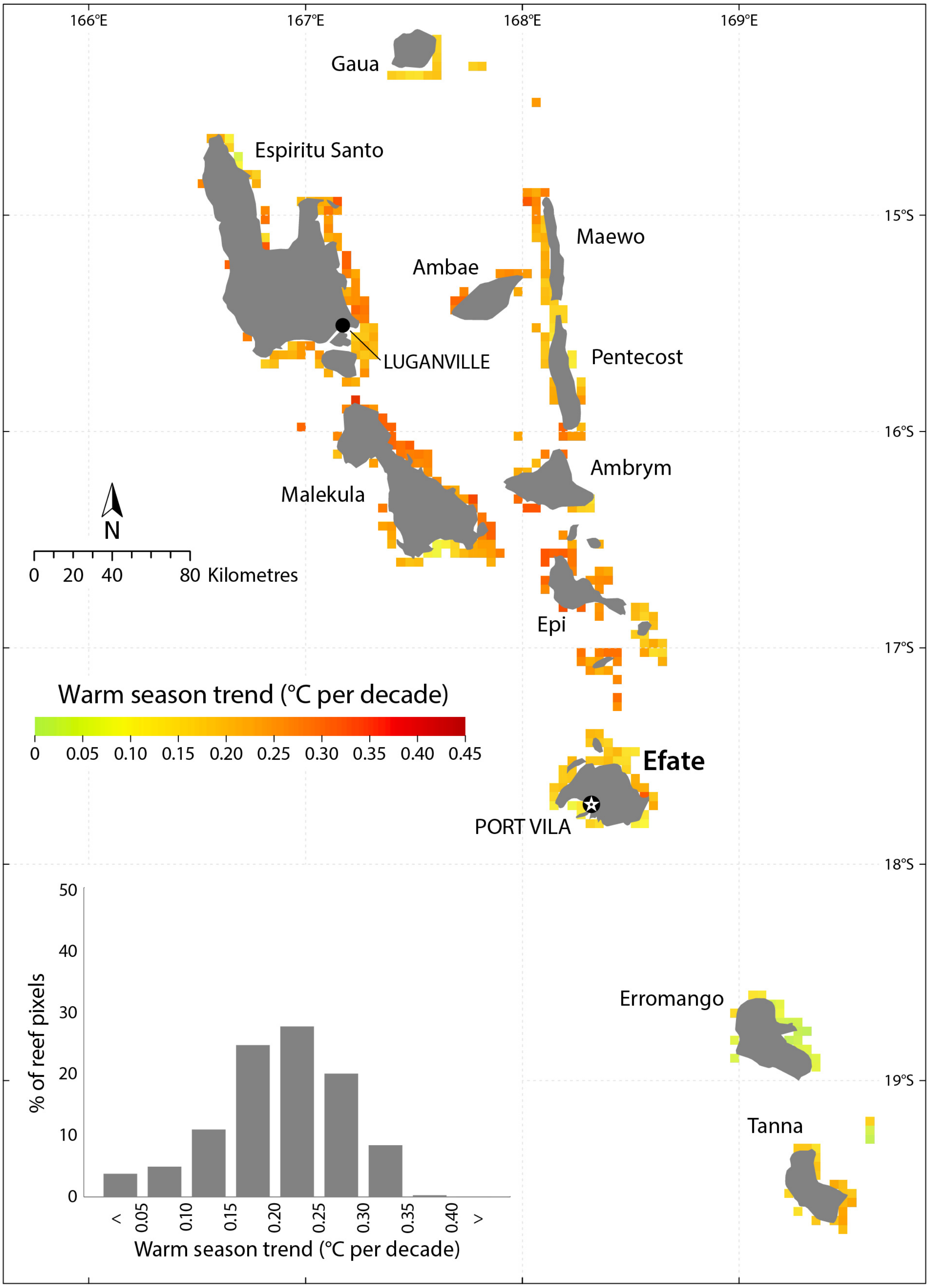

Figure 6. ***Warm Season Trend 1985-2012.*** *28% of reef pixels in Vanuatu (n=432) experienced a rate of change in average warm season temperatures >0.25 °C. These are the locations that experienced the most frequent and most severe thermal stress events during the study period: Epi, eastern Malekula, and eastern Espiritu Santo.*

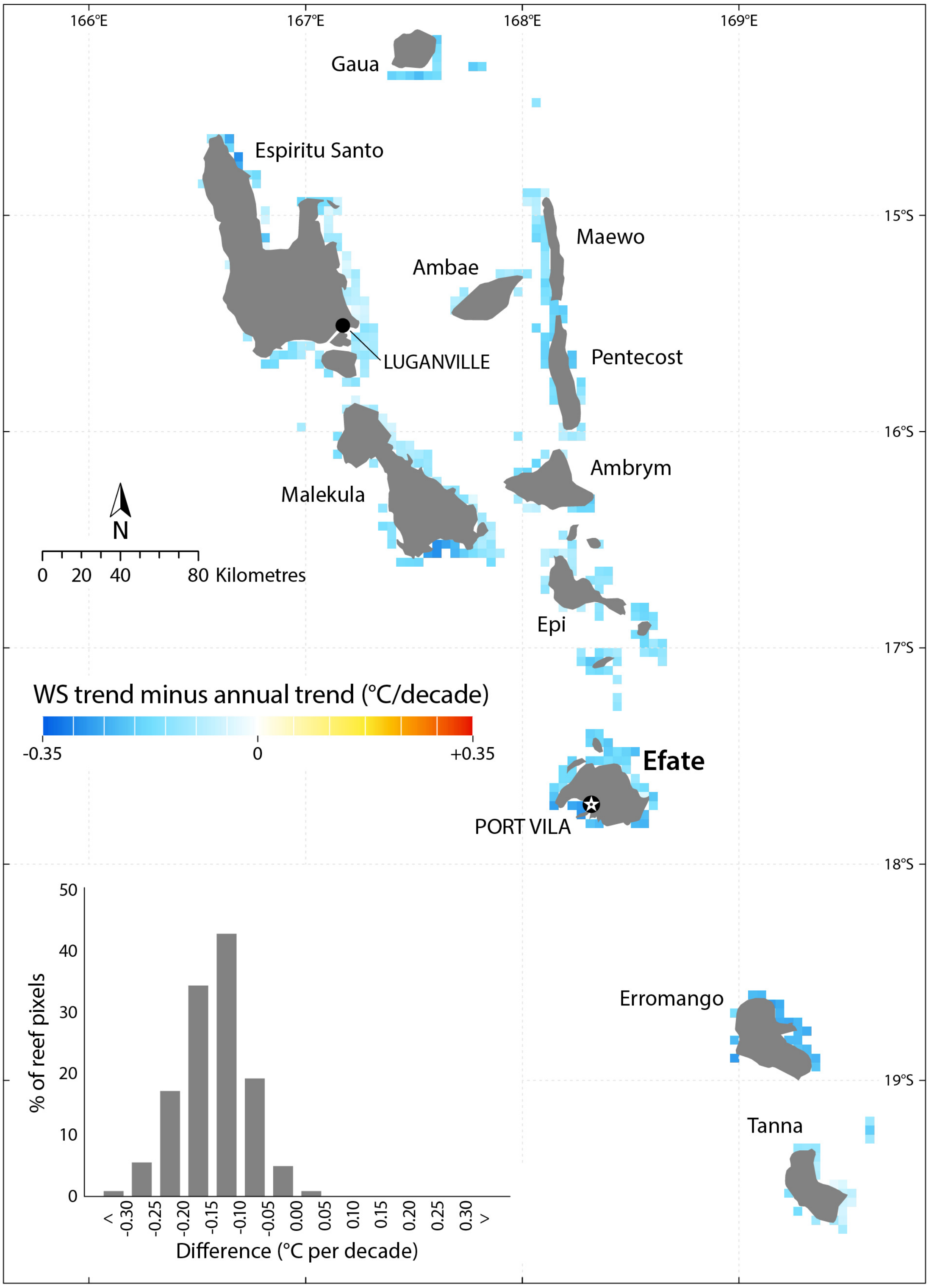

*Figure 7. **Warm Season Trend minus Annual Trend 1985-2012.** In Vanuatu, the annual trend exceeds the warm season trend at >95% of reef locations, indicating a suppression in seasonality. Corals are getting less of a reprieve from warm season temperatures (i.e. experiencing a shorter cool period).*

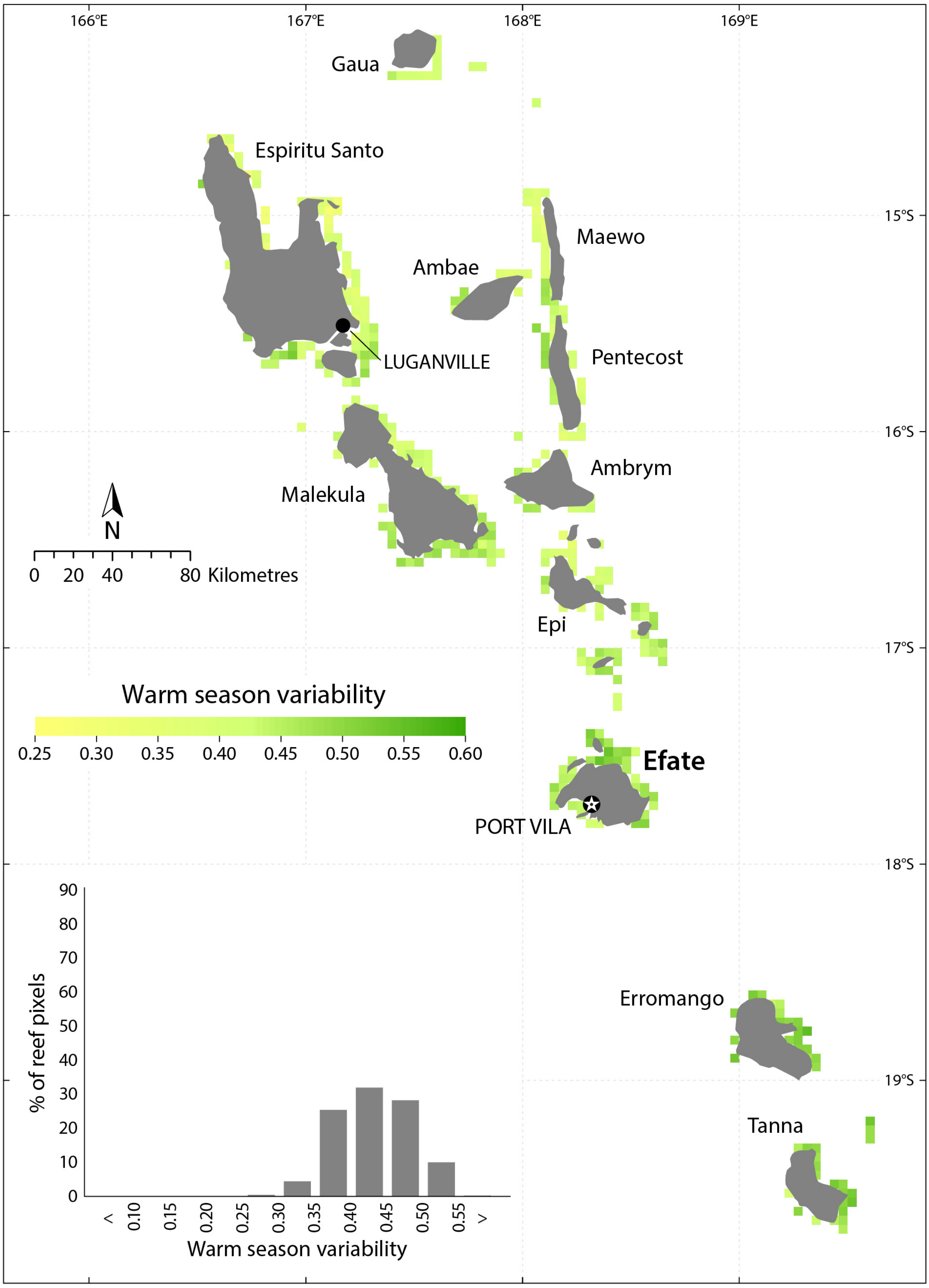

Figure 8. ***Warm Season Variability 1985-2012.*** *38% of reef pixels in Vanuatu (n=432) had warm season variability greater than 0.45. Research to date has provided no clear threshold defining "high" variability. Reefs with relatively high warm season variability are in locations that had low frequency of exposure to severe thermal stress, in Erromango, Tanna, west Pentecost and southwest Espiritu Santo.*

Results: Future Projections

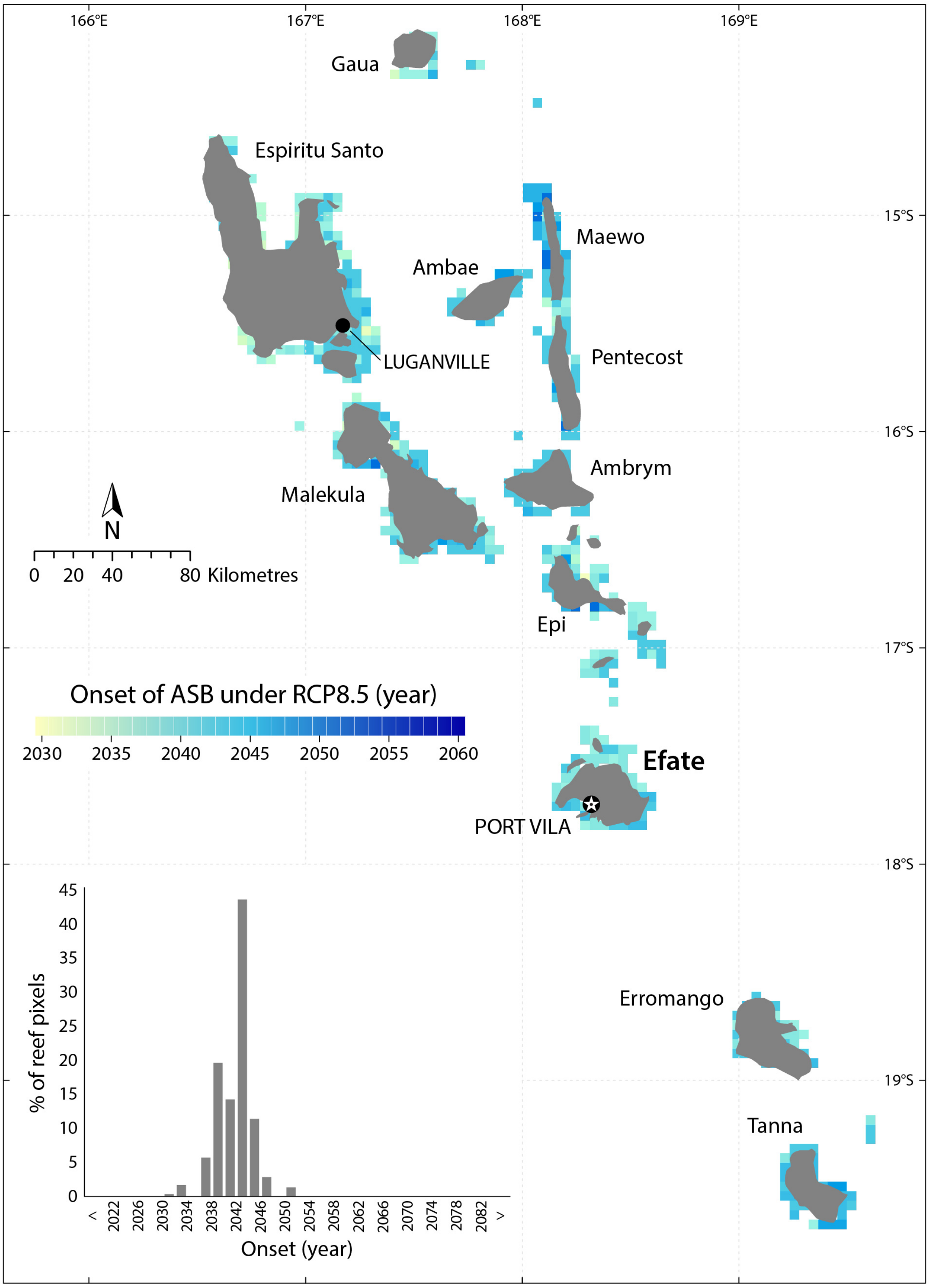

Figure 9. ***Timing of annual severe bleaching (ASB, >8 DHWs) under RCP8.5.*** *16% of reef pixels in Vanuatu (n=432) are temporary refugia under RCP8.5. At these refugia locations, ASB is projected to occur later than 2045. Refugia in Vanuatu are mostly in southern Epi and western Maewo islands.*

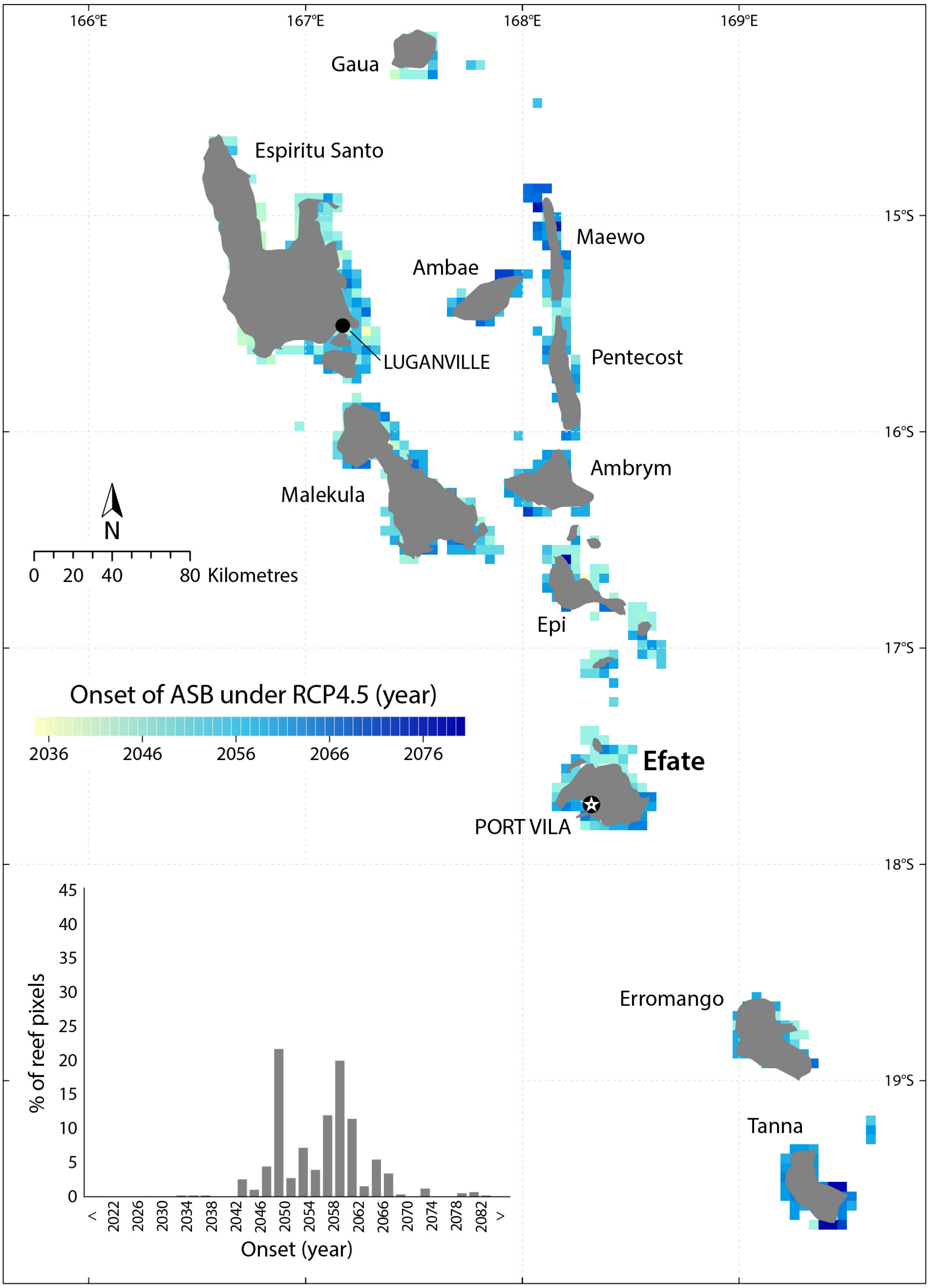

*Figure 10. **Timing of annual severe bleaching (ASB, ≥8 DHWs) under RCP4.5.** RCP4.5 could represent emissions concentrations mid-century if we multiply Paris Agreement pledges to reduce emissions by 1.5 and if emissions reductions to that extent become reality. Reefs in Vanuatu would have 20 more years, on average, before ASB occurs if RCP4.5 characterizes emissions concentrations mid-century. 25% of reef pixels in Vanuatu (n=432) are temporary refugia under RCP4.5. At these refugia locations, ASB is projected to occur later than 2060. Refugia in Vanuatu are near Epi, Ambrym, Maewo and Tanna islands.*

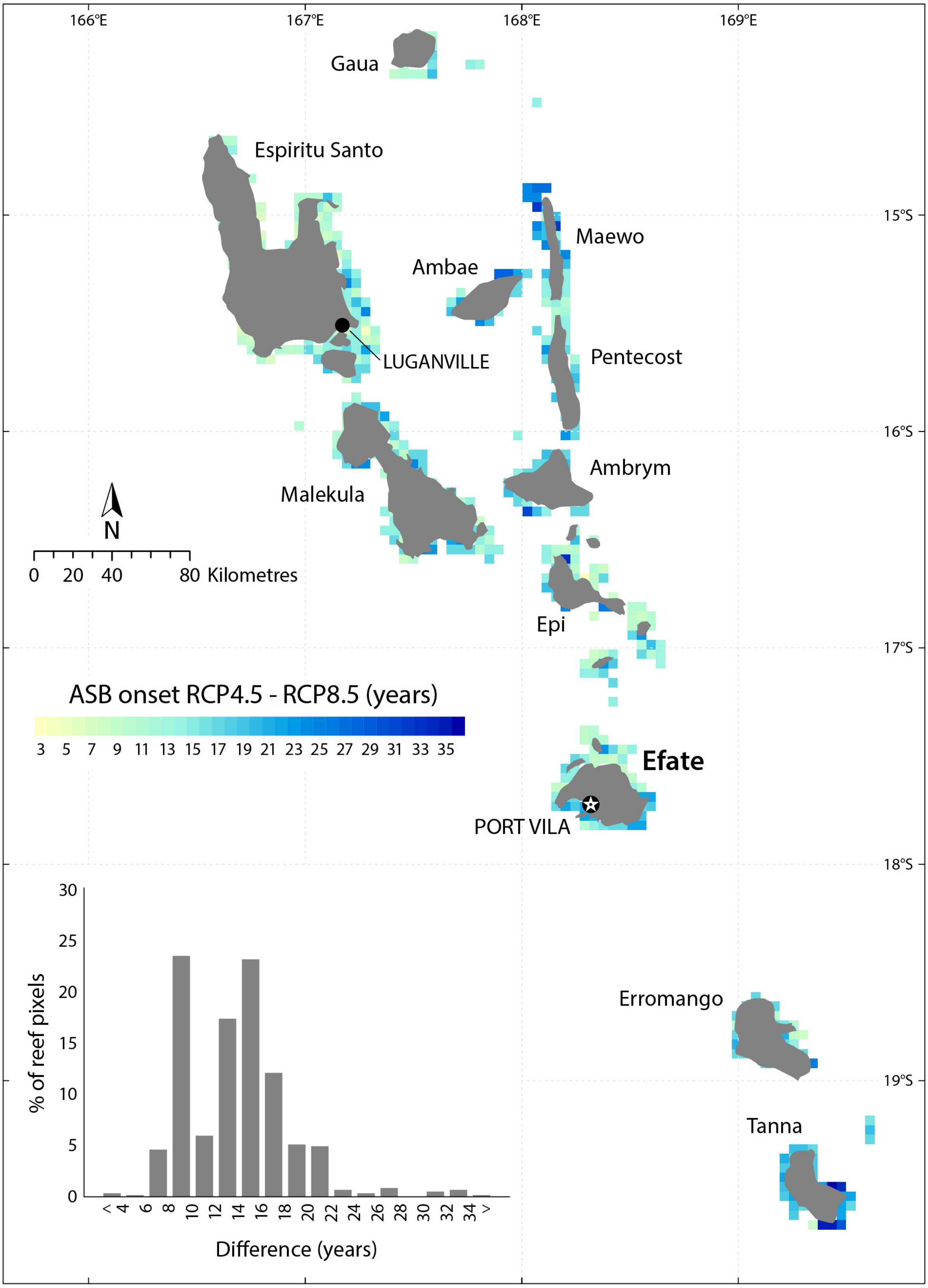

Figure 11. ***Difference in projected timing of annual severe bleaching (ASB, ≥8 DHWs) between RCP8.5 and RCP4.5.*** *The greater the difference between emission scenarios the greater the benefit to coral reefs, in terms of delayed timing of frequent exposure to severe thermal stress. The reefs of Tanna and northern Maewo islands would benefit most from emissions reductions pledges becoming a reality.*

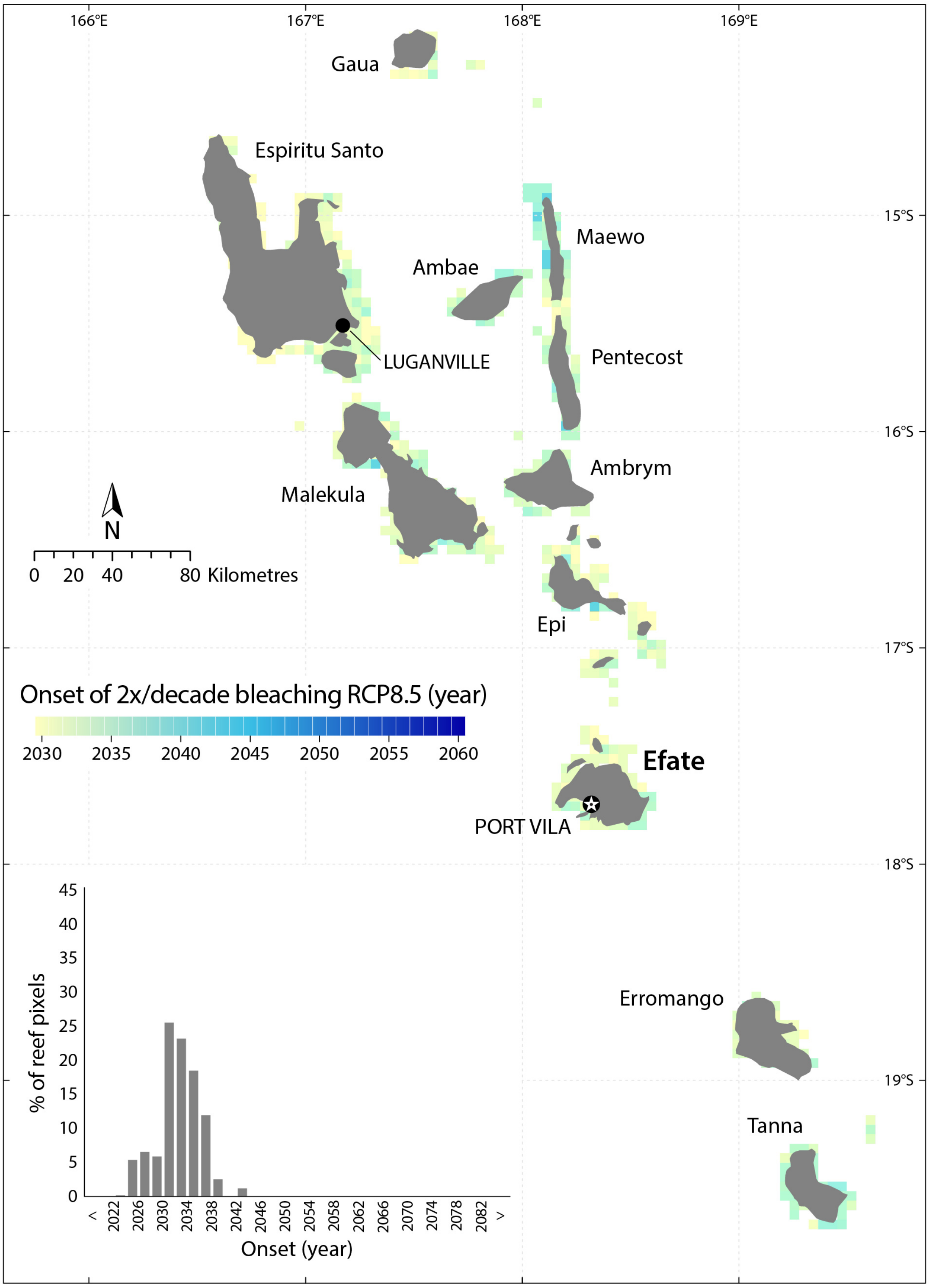

Figure 12. ***Timing of 2x per decade bleaching (ASB, ≥8 DHWs) under RCP8.5.*** *96% of reef pixels in Vanuatu (n=432) are projected to experience 2x per decade severe bleaching before 2038. There are no refugia from 2x per decade bleaching conditions.*

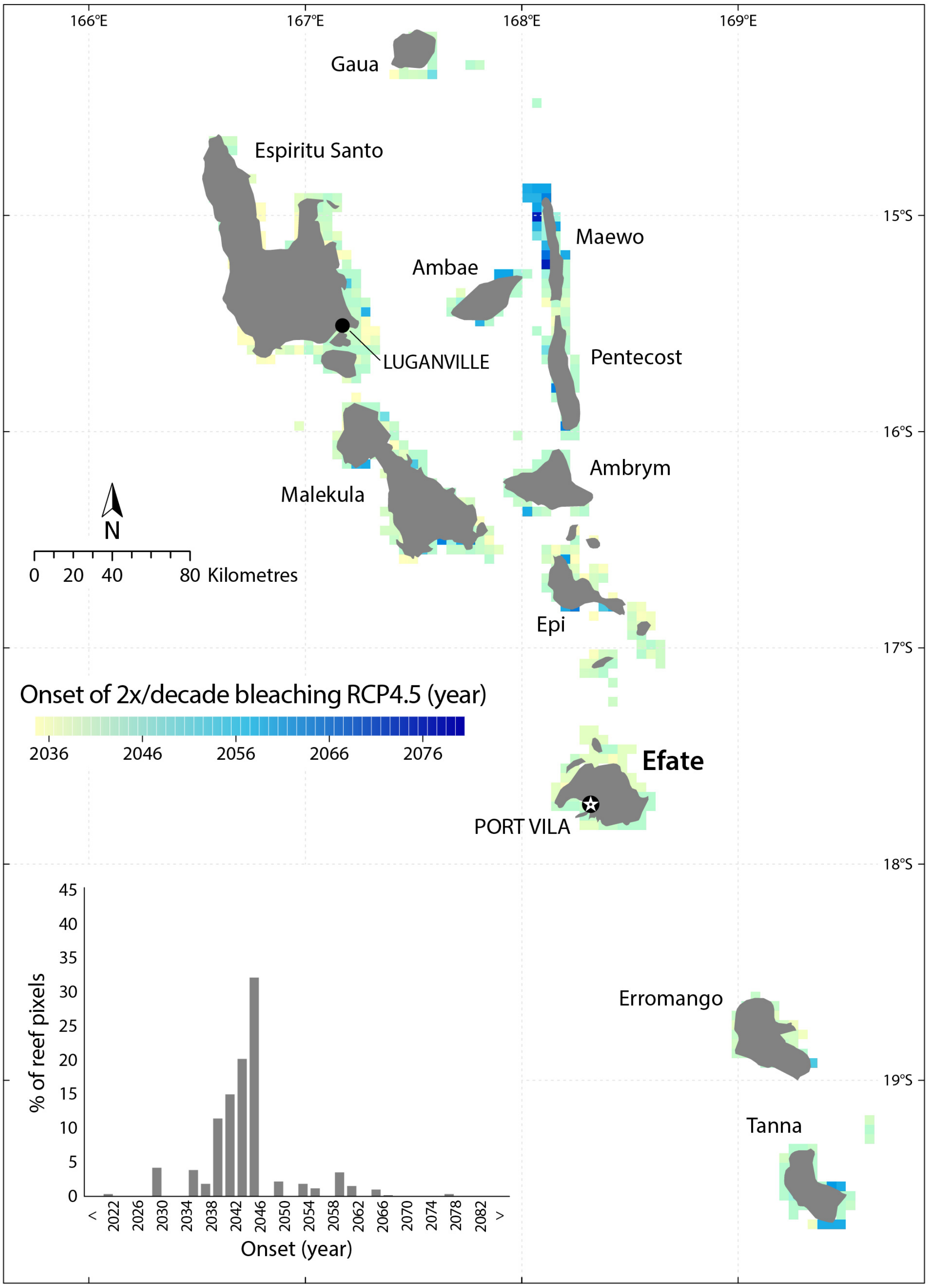

Figure 13. ***Timing of 2x per decade bleaching (ASB, >8 DHWs) under RCP4.5.*** *RCP4.5 could represent emissions concentrations mid-century if we multiply Paris Agreement pledges to reduce emissions by 1.5 and if emissions reductions to that extent become reality. Reefs in Vanuatu would have 20 more years, on average, before ASB occurs if RCP4.5 characterizes emissions concentrations mid-century. There is great variation in the projected timing of ASB under RCP4.5. 20% of reef pixels are projected to experience 2x per decade severe bleaching under RCP4.5 before 2040, while 10% are projected to experience 2x per decade severe bleaching after 2050. These temporary refugia are in Tanna and northern Maewo islands; these locations would experience the greatest relative benefit, in terms of delayed timing of severe thermal stress, of RCP4.5 characterizing emission concentrations mid-century.*

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