Coral Reefs
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RESEARCH

The impact of the 2024 coral bleaching event on corals at a remote atoll in the Tuamotu Archipelago, French Polynesia

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Abstract Coral reefs are under severe threat from global warming, particularly due to the increasing frequency of mass coral bleaching events. This study documents the effects of the fourth global coral bleaching event on corals of Tahanea, a remote uninhabited French Polynesian atoll over a 10-month period. Coral surveys (transects and tracking of individual colonies) and temperature monitoring were conducted by one in situ observer. The marine heatwave lasted 80 days, from January 24, 2024, to April 12, 2024, with a peak intensity of + 1.55 °C above climatological levels. This event was the longest in the past 30 years in the South Pacific region as well as the most intense in terms of cumulative intensity (79.2 °C·days) and daily degree heating week (DHW) annual maximum (reaching 4.7 °C weeks^{-1}). In May 2024, 11–16% of coral colonies showed signs of bleaching, while 27–43% were recently dead. By September, out of the 40 studied large colonies, 50% of corals partially bleached in April were dead, and 80% of those fully bleached in April had died. In September 2024, underwater visual surveys (depth: 0.4–2 m) revealed low live coral cover (15%), with old dead coral dominating substrate composition at Tahanea. This study shows that even isolated, uninhabited coral reefs, far from any direct human pressure, are highly vulnerable to marine heatwaves. This highlights the importance of rapid and drastic reductions in greenhouse gas emissions to conserve coral reefs.

Keywords Coral reefs · Global change · Ocean warming · Marine heatwave · Mass coral bleaching · Tahanea

Introduction

Coral reefs worldwide are subject to sustained and accelerating habitat degradation (Riegl et al. 2009; Mellin et al. 2024), largely due to escalating disturbances caused by anthropogenic climate change. Global warming, associated with anthropogenic greenhouse gas emissions, induces an increase in ocean temperature (the global ocean has already

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Matthieu Juncker and Xavier Raick have contributed equally to this work.

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warmed by 1.45 ± 0.12 °C above pre-industrial levels, World Meteorological Organization, 2024). On top of this gradual warming, marine heatwaves (MHWs), short-lived periods of extreme ocean temperatures, have increased in frequency and intensity over recent decades (Frölicher et al. 2018). These increases in temperature threaten coral reefs' health. When sea temperatures rise abnormally over an extended period, corals expel the zooxanthellae algae, turning white in a process known as bleaching (Lesser & Farrell 2004, Hedouin et al. 2020). Deprived of their primary energy source, corals become highly vulnerable to starvation, competition, and diseases. They may die unless favorable conditions return quickly, and the zooxanthellae recolonize the coral polyps (Mumby et al. 2001). Coral death often leads to a loss of biodiversity (Pratchett et al. 2011), a decline in fisheries resources (Liu et al. 2025; Martin et al. 2025), and a threat to the communities that rely on reefs (Datta et al. 2024).

Mass coral bleaching has intensified in recent decades due to ongoing ocean warming (Hughes et al. 2017a, b, Hedouin et al. 2020, Reimer et al. 2024). The frequency and intensity of marine heatwaves have increased in the last five decades (Coffroth et al. 1990), causing severe and large-scale (pan-tropical) mass coral bleaching and mortality (Reimer et al. 2024, Eakin et al. 2019). Major episodes of coral loss threaten the integrity of coral reef ecosystems, as well as critical ecosystem goods and services (Eddy et al. 2021). During the third global coral bleaching event (GCBE), between 2014 and 2017, numerous studies highlighted that mass coral bleaching varied substantially across regions and underscored the urgent need for action on climate change (Eakin et al. 2019). The National Oceanic and Atmospheric Administration (NOAA) and the International Coral Reef Initiative (ICRI) recently declared the Fourth GCBE, beginning in the boreal summer of 2023 (Reimer et al. 2024) and still going on in 2025. Ongoing studies are documenting its impact on coral reefs worldwide.

In this context, the concept of resilience has become central to understanding how coral reef ecosystems respond to such disturbances. Resilience is defined as the ability of a system to recover from or absorb changes and disturbances while maintaining its services and functions (Carpenter et al 2001; Obura & Grimsditch 2009). It can be provided by either resistance or recovery. Resilience differs from resistance, which is defined as the ability of an ecosystem to withstand disturbances without losing either function or structure, or without undergoing a phase shift (Odum 1989; Obura & Grimsditch 2009). Mass coral bleaching is now the foremost cause of coral mortality on many coral reefs (Hédouin et al. 2020; Heinze et al. 2021; McKay et al. 2022), but corals vary in their susceptibility to bleaching. Some corals demonstrate resilience and could recover relatively quickly, even after repeated bleaching events. Coral survival or mortality appears to be largely determined by the adaptability and resilience of the coral host, its associated zooxanthellae, and the coral microbiome, as well as by anthropogenic stressors acting during or after the bleaching event (Dance 2019; Sully et al. 2019; Burn et al. 2023). Less resistant corals may nonetheless exhibit high recovery capacity, as these two traits are not necessarily linked.

Undisturbed marine ecosystems, such as remote or uninhabited atolls, can play a crucial role in preserving biodiversity. For instance, uninhabited islands can act as biodiversity hotspots or host high levels of endemic species (Kier et al. 2009). They can also serve as conservation refuges, offering protection from threats impacting more anthropized environments (Gibson et al. 2017). Off Australia, it has been shown that the benefits of isolation from chronic anthropogenic pressures can outweigh the costs of limited connectivity (Gilmour et al. 2013). Remote places also offer the opportunity to study impacts of climate change without compounding effects of local anthropogenic stressors (Head et al. 2019). Biodiversity inventories on remote or uninhabited atolls are often opportunistic and lack continuity and thoroughness due to the logistical and financial challenges of conducting monitoring in remote locations (Meyer et al. 2015).

In French Polynesia (South Pacific), five major warming events have caused widespread coral bleaching over the past three decades: in 1994, 2002, 2007, 2016, and 2019 (Penin et al. 2007; Vercelloni et al. 2019; Hédouin et al. 2020). From January to May 2024, French Polynesia experienced a heatwave that raised seawater temperature to over 30 °C for several consecutive weeks, triggering widespread bleaching across its reefs (NOAA/CRW, 2024). The aim of this study is to understand how seawater temperature and coral colonies varied over a 10-month period (April 2024–February 2025) on a remote atoll (Tahanea Atoll, French Polynesia) during the 2024 marine heatwave. In this context, what changes in seawater temperature and coral condition were observed at Tahanea Atoll during the 2024 coral bleaching event?

Material and methods

The present study stems from the unique opportunity to monitor temperature and coral health, in a remote atoll for over 10 months in 2024, while a marine heatwave struck the Tropical Pacific.

Study site

Tahanea is an uninhabited and isolated atoll in French Polynesia, located in the central Tuamotu Archipelago (ca. 500 km east of Tahiti, Fig. 1A). Tahanea has an elliptical shape, covering a surface area of 630 km^2 with a

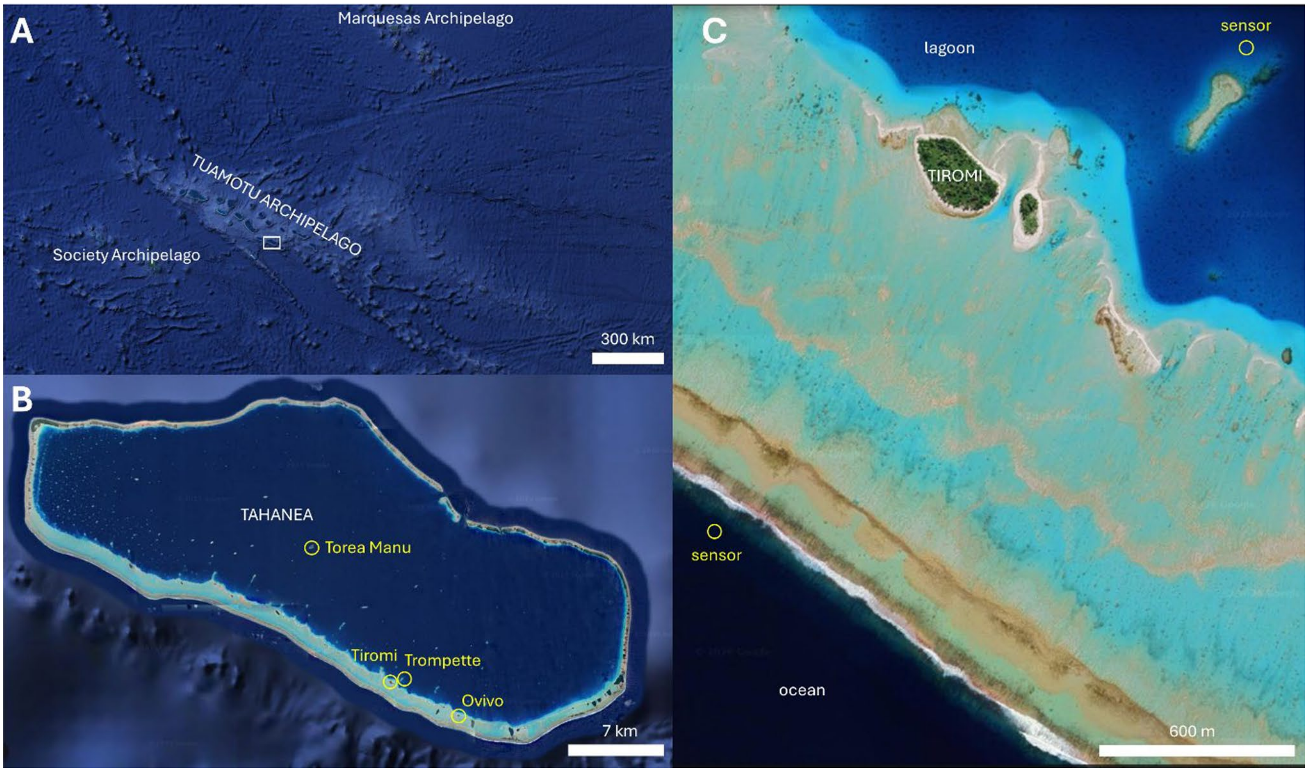

Fig. 1 Location of Tahanea Atoll in the Tuamotu Archipelago (**A** 16°52.00’ S, 144°46.00’ W), and location of the survey sites within the atoll (**B**). Zoom on the location of the temperature and pressure sensors near Tiromi (**C**). **A**: Data SIO, NOAA, US Navy, NGA, GEBCOLandsat/CopernicusImages (2015). **B**: Data SIO, NOAA, US Navy, NGA, GEBCOAirbusData LDEO—Columbia, NSF, NOAA (2015). **C**: Data AirbusData SIO, NOAA, US Navy, NGA, GEBCOData LDEO—Columbia, NSF, NOAA

circumference of 113 km. Its lagoon, interrupted by three channels on the northeastern side, features numerous *motu* (islets) and coral pinnacles (Raust and Stanford 2006). Tahanea is subject to a semidiurnal tidal regime, characterized by two high tides and two low tides per day with a relatively small tidal range typical of oceanic atolls in the central Pacific. Coral assessments and environmental monitoring were conducted between April 2024 and February 2025. This time period encompasses both the dry or cool season (May–October) and the wet or warm season (November–April) (Hopuare et al. 2015).

Temperature data

An underwater RBRduo® temperature and pressure sensor was installed inside the lagoon at 6 m depth near the Tiromi motu (0.9 km from the motu; 16°57.345’ S, 144°43.519’ W) from October 10, 2023, to January 26, 2025. Another sensor was deployed outside the lagoon on the forereef at 10 m depth (16°58.012’ S, 144°44.562’ W) from October 12, 2023, to February 11, 2025. Both instruments were configured for high-frequency data acquisition at one-second intervals. While these sensors provided accurate in situ measurements of sea surface temperature (SST), the limited duration of the time series precluded calculation of climatology-based marine heatwave (MHW) metrics, which require long-term baselines. Therefore, these in situ data were complemented with high spatial resolution satellite observations. In situ and satellite daily temperature time series were compared, and a two-sided T-test tested the statistical significance of their differences.

The NOAA Coral Reef Watch (CRW) version 3.1 Daily Global 5 km SST product (Skirving et al. 2018) was extracted on the 5 km^2 grid cell encompassing both sensor locations (17°31.5’ S, 145°28.5’ W) to identify MHWs over the period 1995–2024. MHW detection is identical to Sen Gupta et al. (2020) and based on Hobday et al. (2016). For each calendar day, temperatures 5 days before and 5 days after were averaged, leading to an 11-day averaging around the given day. Then, a climatology of the 90th percentile of these 11-day window temperatures was computed using the 30 years of the 1995–2024 period. A 31-day smoothing was also applied to the daily temperature. These procedures allowed the definition of a robust 90th percentile threshold as well as anomalies to this threshold, as discussed in Sen Gupta et al. (2020). Here, the satellite SST time series was compared to its 90th percentile climatology and an MHW was identified when the temperature exceeded this 90th percentile threshold for at least five consecutive days. The MHW cumulative intensity was then calculated as the sum of SST daily anomalies above the 90th percentile threshold over the entire duration of each event. Following Skirving et al. (2020) and references therein, two other indicators were computed: the HotSpot, which is the daily temperature anomaly relative to the maximum of monthly means (MMM, Strong et al. 1997) over the 30-year period. The MMM was calculated classically as the maximum temperature reached at each pixel over the monthly temperature climatology (Strong et al. 1997). MMM is considered the critical temperature above which cumulated heat stress may lead to coral bleaching. Finally, the daily degree heating weeks (DHW, in °C weeks^{-1}) was computed as the sum of daily HotSpots exceeding 1 °C over the preceding 12 weeks divided by seven days. These indices, although debated (e.g., Nairn and Mason 2025), are widely used as potential indicators of coral bleaching (e.g., Couch et al. 2017, Beyer et al. 2018).

Coral colonies: tracking of individual colonies

A focused monitoring effort was carried out on 40 large coral colonies ($\geq$ 1 m in length) within a 1 ha reef zone near Tiromi Motu (depth: 0.4–2 m). In April 2024, during the ongoing bleaching event, 20 fully bleached and 20 partially bleached colonies were randomly selected and marked for individual tracking. The composition of colony types was as follows: totally bleached colonies included 7 branched, 11 digitate, and 2 tabular colonies, while partially bleached colonies included 12 branched, 6 digitate, and 2 tabular colonies. Colonies were tagged using strings. A colony was considered partially bleached if at least 20% of its surface retained pigmentation. A colony was classified as fully bleached if its entire surface appeared white. Post-bleaching monitoring was conducted in September 2024.

Coral colonies: transects

Targeted coral health assessments were conducted in May 2024. All coral colonies encountered along two 100 m transects at two sites (Tiromi and Ovivo, May 10 and May 11, respectively, Fig. 1B) were surveyed and categorized into four health states: (i) living coral—no visible signs of bleaching, (ii) bleached coral—colony partially or fully bleached, (iii) recently dead coral, and (iv) old dead coral (Fig. 2).

Benthic cover composition

Underwater visual censuses were also conducted in September 2024 along three 100 m transects, each divided into four 20 m sections, on the reefs of Torea Manu, Tiromi, and Trompette (depth: 0.4–2 m, Fig. 1B). Each 20 m section was separated by 5 m (Job 2018, Lecchini et al. 2021). Benthic cover composition was assessed using the PIT (Point Intercept Transect) method with a 50-cm sampling interval. Benthic cover categories included: living branching coral, living massive coral, living tabular coral, other living coral morphotypes, recently dead coral, old dead coral, coral rubble, macroalgae, and sand. Following Hedouin et al. (2020), corals were classified as alive (pigmented), recently dead (dead coral with intact and clearly defined corallite septa), or old dead (skeleton colonized by crustose coralline algae and other organisms). Although transects targeting macroinvertebrates and fish were conducted, they are not included in the main article and are instead provided as supplementary material.

Raw values were converted into cover percentages (for benthic cover). Differences among sites were assessed using Kruskal–Wallis tests followed by Dunn post hoc tests. P-values were adjusted using the Benjamini–Hochberg method. All statistical analyses were performed in R 4.3.0 (R Core Team, 2023).

Results

Seawater temperature

In situ temperature time series recorded inside and outside the Tahanea lagoon revealed particularly elevated temperatures from late January through April 2024 (Fig. 3). Inside the lagoon, temperatures exceeded 30 °C on 42 consecutive days. Maximum temperatures reached 30.75 °C at 6 m depth inside the lagoon and 29.82 °C at 10 m depth outside the lagoon.

To evaluate the intensity of the 2024 MHW, and its severity in comparison with other MHWs over the past 30 years, satellite SST was used. The statistical comparison between in situ and satellite-derived temperature time series (Fig. 3) showed that, during the austral winter, in situ temperatures measured inside the lagoon were significantly lower than satellite SST (Root mean square error RMSE = 0.36 °C; bias = −0.30 °C, p-value < 10^{-3}), whereas temperatures recorded outside the lagoon at 10 m depth were not statistically different from satellite values (RMSE = 0.29 °C; bias = −0.27 °C, p-value = 0.16). In contrast, during the austral summer, in situ temperatures outside the lagoon were lower than satellite SST (with a significant difference of −0.47 °C, p-value < 10^{-5}) while temperatures inside the lagoon were closer to, and in some cases slightly higher, than satellite SST (nonsignificant difference of 0.07 °C; p-value = 0.80). Besides these slight differences, the overall strong agreement between satellite SST and in situ temperatures outside the lagoon (Pearson

Fig. 2 Examples of different coral colony conditions: **A** live coral, **B** bleached coral, **C** recently dead coral, and **D** old (non-recently) dead coral. **E** Bleaching in a massive Porites colony. Illustration of three study sites: **F** Tiromi reef, **G** Trompette reef, and **H** Torea Manu reef

correlation coefficient = 0.96, $p < 10^{-6}$) supported the use of satellite data to calculate MHW metrics and reconstruct the temporal and spatial characteristics of MHW events in the vicinity of Tahanea.

The satellite SST time series confirmed that the 2024 warm season was abnormally hot compared to previous years (Table 1 and Fig. SP1), with temperatures reaching their highest level since 1995 and a maximum recorded value of 30.34 °C (nighttime measurement). The local HotSpot threshold of 29.75 °C was exceeded for 27 days in early 2024 and the annual DHW peak reached its highest level over the past three decades in 2024 (4.7 °C weeks^{-1}, Fig. 3, Table 1). The MHW lasted 80 days, from January 24 to April 12 (Fig. 3), with a maximum temperature anomaly above the climatology of 1.55 °C, occurring when the HotSpot was exceeded. This MHW was thus also the longest recorded in the past 30 years at Tahanea and the most intense in terms of cumulative intensity (79.2 °C·days, Table 1).

Individual coral colonies

Half of the 20 studied coral colonies that experienced partial bleaching in April 2024 were found dead by September 2024. The remaining colonies showed mixed recovery, with some fully and others partially recuperated/regenerated (i.e., partially dead and alive, Fig. 4A–C). Among colonies that had undergone full bleaching, 80% were found dead (Fig. 4D–F) by September 2024. In May 2024, the average condition of the reef was characterized by 40.67–57.98% live colonies, 10.92–15.79% bleached colonies, and 26.89–42.58% recently dead colonies (Fig. 4G, H).

Transects

Post-bleaching (September 2024), shallow lagoon-side reef areas in Tahanea were characterized by a mean live coral cover of 15 ± 7.3% (range: 7.5–35%), dominated by

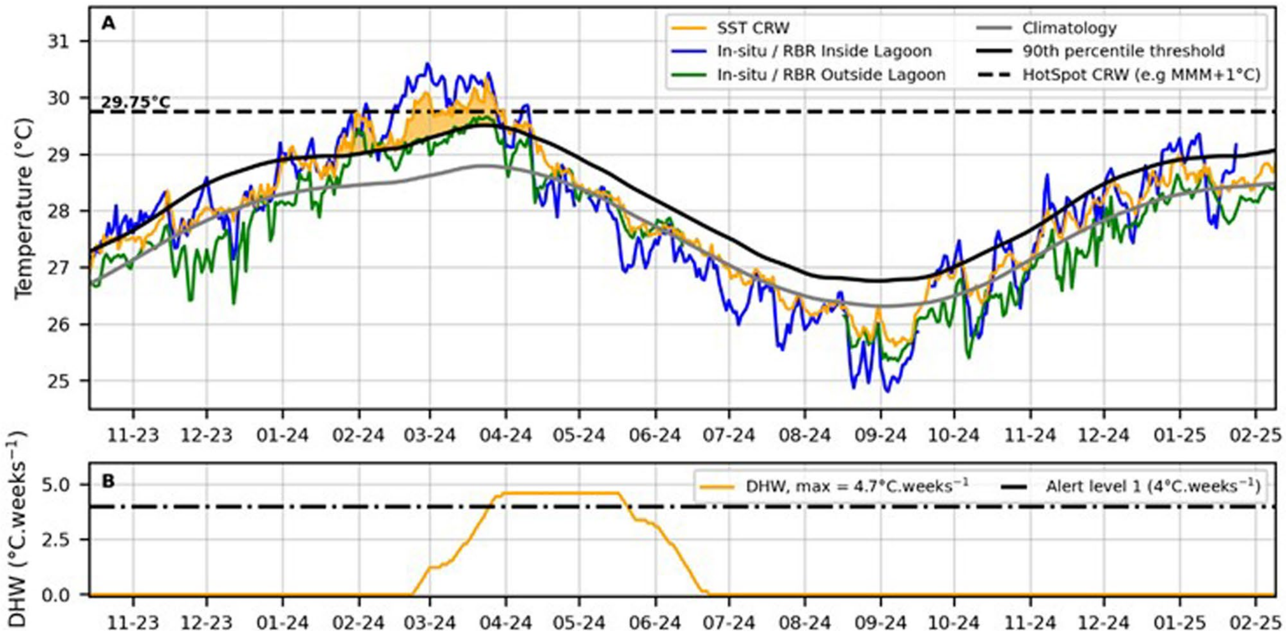

Fig. 3 Daily temperature time series from the coral reef watch (CRW) satellite sea surface temperature (SST) product (orange), from the in situ temperature sensors inside the lagoon at 6 m depth (blue) and outside the lagoon at 10 m depth (green) (**A**). Daily minima were used for in situ sensors to allow comparison with satellite data (night-time measurement). Daily climatology (gray) and 90th percentile (black) computed over the period 1995–2024 are represented, along with the marine heat wave detected in 2024 following the Hobday et al. (2016) definition (shaded area in orange). The HotSpot value, equal to the MMM + 1 °C and corresponding to the threshold from which heat stress was accumulated in the DHW computation, is illustrated by the horizontal dashed black line. DHW time series computed from CRW SST data over the same period are shown (**B**). The alert level 1 as defined by the NOAA CRW's bleaching alert system (if DHW exceeds 4 °C weeks^{-1}, bleaching is expected) is also indicated by the horizontal black line

Table 1 Marine heatwaves (MHW) characteristics along with the annual maximum of daily degree heating weeks (DHW) computed from coral reef watch (CRW) sea surface temperature (SST) data (0.05° resolution) at the closest pixel encompassing sensors' locations, for years where DHW was strictly positive

	1998	2003	2012	2016	2017	2019	2024
Duration (days)	[6, 7]	[20, 22]	[5, 43]	[6, 33]	[5, 63]	[7, 20]	80
Intensity cumulative (°C·days)	[4.4, 7.0]	[13.4, 21.2]	[3.0, 33.7]	[3.7, 32.9]	[4.2, 42.1]	[4.2, 15.2]	79.2
Max. of DHW	0.8	1.2	0.3	2.5	0.1	0.1	4.7
Annual maximum of temperature (°C)	29.97	30.09	29.85	29.99	29.77	29.79	30.34

MHW characteristics are given as ranges [minimum, maximum] of all MHW detected during the associated year, except for 2024 as only one MHW was detected. The annual temperature maximum is also indicated

branching corals (mean ± SD: 6.04 ± 4.82%, range: 0–15%) and massive corals (6.67 ± 11.15%, 0–35%, Fig. 5). Old dead corals constituted most of the benthic cover (30.42 ± 13.18%, 10–57.5%) and their proportion was consistent across all reefs (Kruskal–Wallis test, $\chi^2 = 3.60$, df = 2, $p = 0.16$). The second most abundant benthic cover type was macroalgae (15.21 ± 12.94%, 0–35%), which was unevenly distributed among the sites ($\chi^2 = 7.38$, df = 2, $p = 0.02$), with significantly higher abundance at Trompette reef compared to Tiromi (Dunn post hoc test, $Z = -2.58$, $p = 0.03$). Recently dead corals accounted for less than 10% of the observations and did not differ significantly among sites (9.79 ± 9.32%, 0–27.5%, $\chi^2 = 5.51$, df = 2, $p = 0.06$).

Discussion

In this study, we examined seawater temperature and coral cover over a 10-month period encompassing a mass bleaching event, and conducted post-bleaching surveys of coral colonies. Documenting coral health on atolls, especially uninhabited ones, is critical to predicting the future of coral reef ecosystems, which are vital sources of food

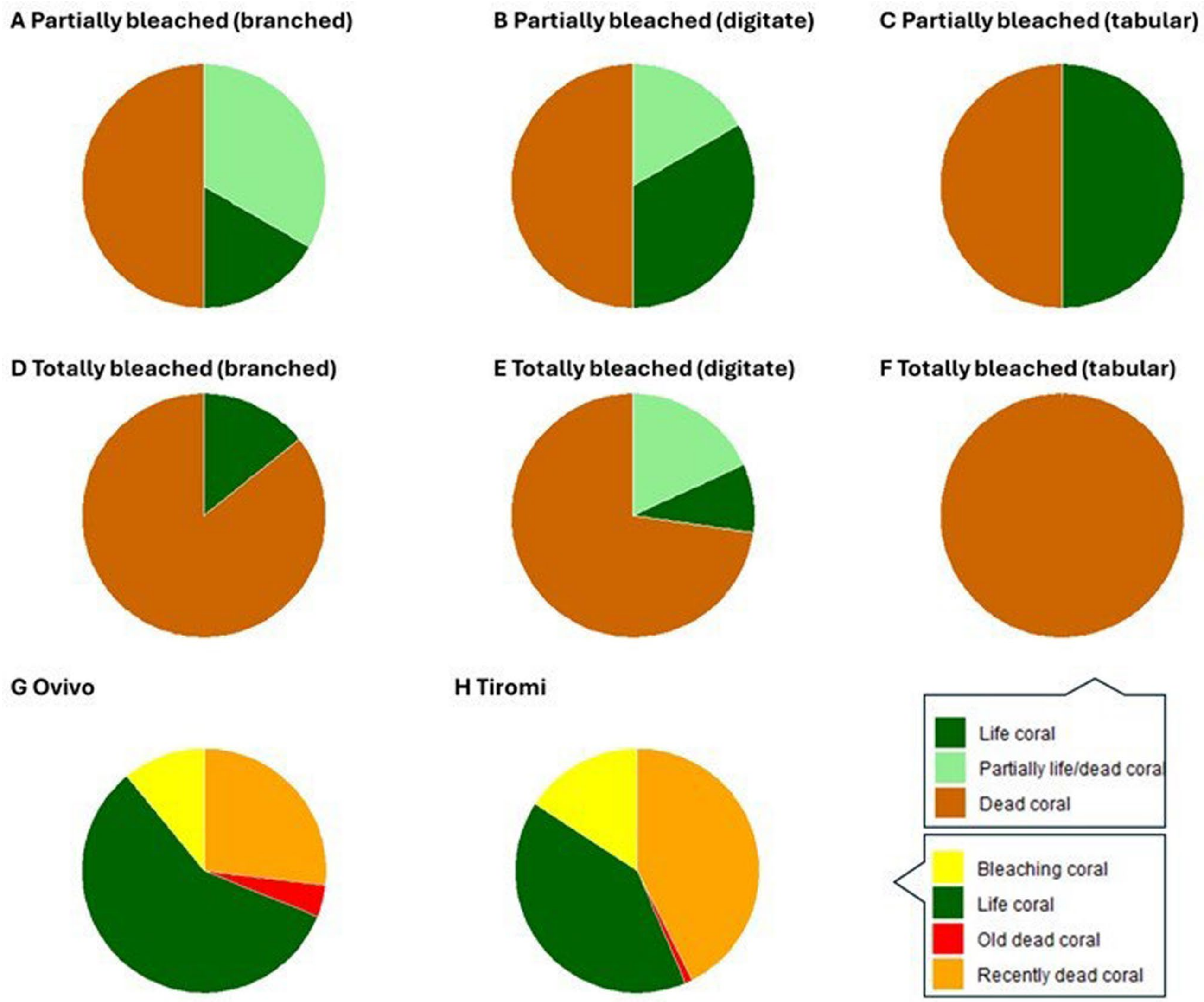

Fig. 4 Status in September 2024 of coral colonies that experienced partial bleaching (**A–C**) or total bleaching (**D–F**) in April 2024; and the situation of colonies in May 2024 at Ovivo (**G**), and Tiromi (**H**)

and livelihoods for millions (Lecchini et al. 2021). Unfortunately, uninhabited atolls are rarely studied because of the logistical and financial challenges they present. In this study, the ten-month survey duration allowed verification that bleached corals either died or had recovered by the end of the observation period.

Our observations indicate that the isolated reefs at Tahanea were strongly affected by the 2024 MHW. In May 2024, 11–16% of colonies showed bleaching signs, while 27–43% were recently dead. By September, half of the colonies with partial bleaching in April had died, and 80% of those fully bleached had perished. According to satellite temperature data, the MHW lasted 80 days (from January 24 to April 12), with a maximum reached temperature of 30.34 °C, a cumulative intensity of 79.2 °C·days, and a maximum DHW of 4.7 °C·week with 27 days above the local HotSpot threshold (29.75 °C). In situ observations revealed slightly higher temperatures inside the lagoon than outside. During the MHW, the higher satellite SST relative to in situ temperatures outside the lagoon (10 m depth, Fig. 3) may indicate either that warming was more intense in the surface layer than at depth, or that the satellite SST was influenced by interpolation and the elevated temperatures inside the lagoon. Green et al. (2019) highlighted that interactions between oceanic and atmospheric processes can significantly influence local (< 1 km) reef temperatures, leading to variations in heat stress and bleaching severity. Our results support this finding, as we observed differences between temperatures recorded outside the lagoon at 10 m depth, inside the lagoon at 6 m depth, and at the surface using satellite

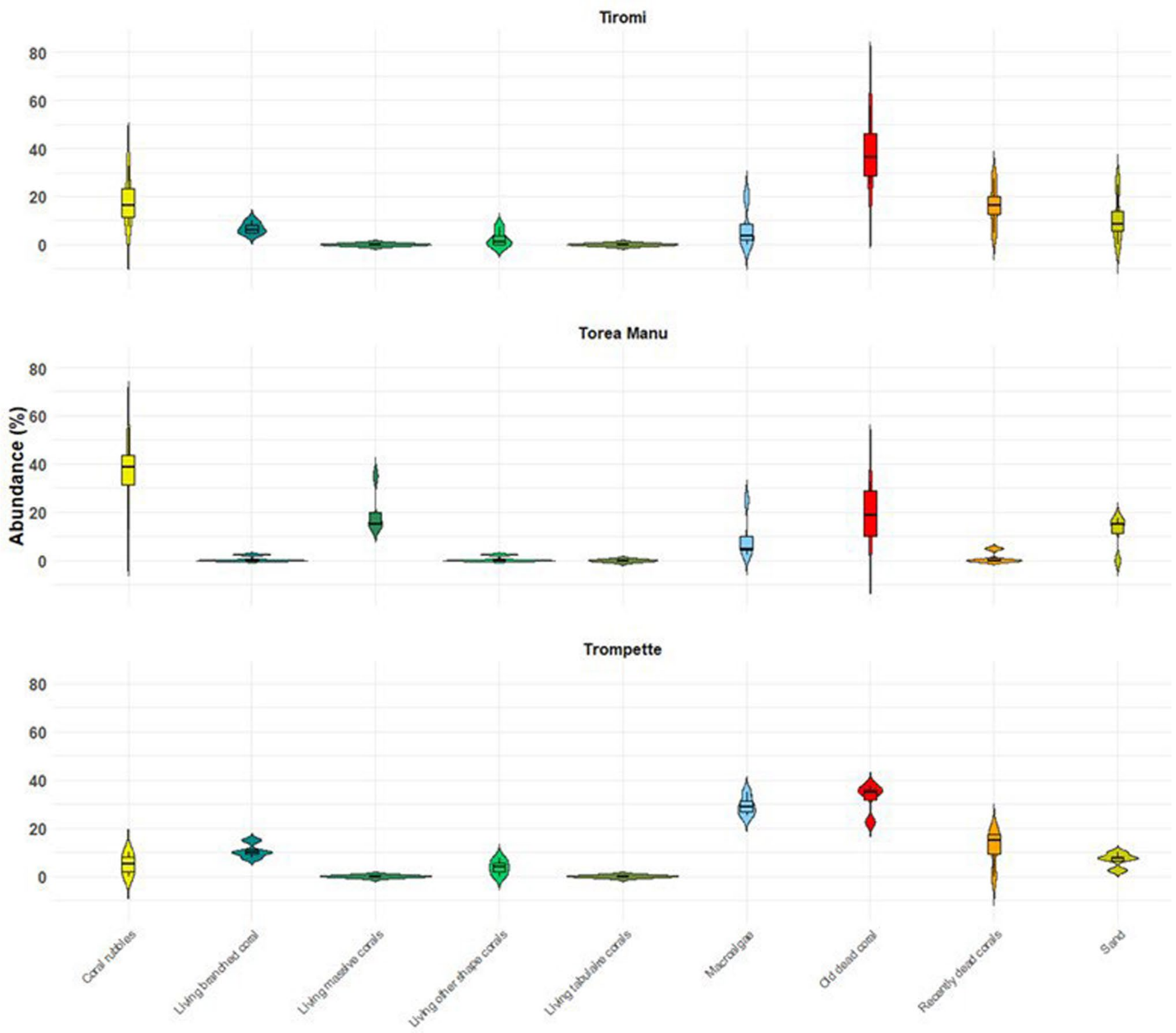

Fig. 5 Benthic cover abundance at each study site in September 2024. Yellow: coral rubble; green: living coral; blue: macroalgae; red: old dead coral; orange: recently dead coral; golden: sand. Violin plots represent the distribution and density of benthic cover values for each category across sites, with the width of each violin proportional to the frequency of observations. Central tendency is indicated by the median, and the interquartile range is shown within each distribution

data. However, these discrepancies also raise questions about the accuracy of satellite data for precisely estimating local and cumulative heat stress in such environments.

Comparison with previous MHWs

The MHW impact on coral bleaching and death at Tahanea can be compared to several past studies in other locations (Table 2). In the Tuamotu Archipelago (French Polynesia) in 2016, Hedouin et al. (2020) recorded DHW values of 5.9–9.2 °C weeks and coral cover losses of 50–71%. In Mo'orea Island (Society Archipelago, French Polynesia), Hedouin et al. (2020) also reported bleaching when seawater temperatures exceeded 29.2 °C.

Comparison with other reefs in the South Pacific indicates that other remote coral reef systems have also experienced severe bleaching events in the past. In the Coral Sea, Harrison et al. (2019) showed that even remote reefs experienced severe bleaching in 2016 and 2017, though coral cover did not decline significantly by 2017. At Jarvis Island in 2015–2016, corals endured maximum heat stress above the bleaching threshold (28.72 °C) for 66 consecutive weeks, causing hard coral cover to decline from 18 to 0.4% in May 2016 (Vargas-Ángel et al. 2019). At Scott

Table 2 Comparative quantification of examples of recent coral cover decreases and bleaching associated with marine heat waves (MHW) in French Polynesia (FP) and other parts of the world

Location	Coral cover	Temperature	Reference
French Polynesia			
Tahanea	May 2024: 27–43% of colonies recently died and 11–16% of colonies showed signs of bleaching. September 2024: half of the colonies partially bleached in May had died, and 80% of the colonies fully bleached in May had perished.	42 days with lagoon temperatures above 30 °C. Maximum recorded temperature: 30.75 °C. Satellite data indicated a maximum recorded temperature of 30.34 °C. The local hotspot threshold (29.75 °C) was exceeded for 27 days, annual peak in DHW reached 4.7 °C weeks^{-1}, the MHW lasted 80 days, and cumulative intensity reached 79.2 °C·days	Present study
Tuamotu	2016: coral cover losses ranged from 50 to 71%	DHW: 5.9–9.2 °C weeks	Hedouin et al. (2020)
Mo’orea (2016)	Level 1 bleaching alert. 37% of *Acropora* and 28% of *Pocillopora* colonies exhibited bleaching. Bleaching duration was shorter on the east coast, whereas coral mortality was higher on the north coast in 2019. Local differences were observed: 100% *Acropora* colonies bleached, and twice as twice as many *Pocillopora* colonies bleached at some places. The 2016 event did not cause widespread coral mortality, contrary to observations from 2019	Seawater temperatures exceeded 29.2 °C. In the lagoon, temperature peaked at 30 °C in early April and exceeded the MMM of 29 °C. From 15 March to 15 April, temperatures averaged 0.4 °C above the upper 95% confidence interval of the decadal mean temperature. On the west coast, heat stress was higher, with peaks of ~5 °C weeks of cumulative heat stress	Edmunds (2017), Donovan et al. (2020), Hedouin et al. (2020)
Mo’orea (2019)	72% of pocilloporid colonies bleached. Colony mortality ranged from 11 to 42% around the island four months after heating stress subsided. On the north coast, unprecedented coral mortality was observed. Between 2015 and 2021 (before and after the 2016 and 2019 bleaching events), coral cover varied between −34% and + 21%	22 days of severe heating (> 8 °C days) at 10 m depth on the north coast fore reef	Burgess et al. (2021), Planes et al. (2023), Raick et al (2025)
Bora Bora (fringing reef)	Increase in the proportion of dead coral and decrease of the live coral cover between 2023 (before the bleaching event) and 2024 (after the bleaching event)	Temperature above 30 °C for several weeks	Lecchini et al. (2026)
Bora Bora (reef drop)	The 2024 bleaching event had little negative effect on the proportion of live coral	Temperature above 30 °C for several weeks	Lecchini et al. (2026)
Outside French Polynesia			
Coral Sea	Reefs experienced severe bleaching in 2016 and 2017 (2016: 81–95% of colonies bleached, in 2027: 20–72% of colonies bleached), although coral cover did not decline significantly by 2017	DHW ranged from 0.5 to 12.5 °C weeks	Harrison et al. (2019)
Isolated reefs of the Chagos Archipelago	2015: severe bleaching and mortality, caused a 60% decline in coral cover	DHW: 7.5 °C weeks	Head et al. (2019)

Table 2 (continued)

Location	Coral cover	Temperature	Reference
Palmyra Atoll	2015–2016: on the fore reef (10 m depth), 90% of live coral cover bleached (32% severely), while on the shallow reef terrace (5 m), bleaching affected 93% of colonies. Following the bleaching event, coral cover on the fore reef declined by 9% between 2014 and 2017, whereas terrace coral cover remained unchanged	DHW: 11.9 °C weeks	Fox et al. (2019)
Persian/Arabian Gulf	2017: 94% of corals bleached, and two-thirds died between April and September	Reef bottom temperatures were among the highest ever recorded, with mean daily maxima averaging 35.9 ± 0.1 °C, and temperatures remained above bleaching thresholds for nearly two months	Burt et al. (2019)
Jarvis Island	2015–2016: hard coral cover declined from 18 to 0.4% by May 2016	Maximum heat stress remained above the bleaching threshold (28.72 °C) for 66 consecutive weeks	Vargas-Ángel et al. (2019)
Aldabra Atoll	2015–2016: bleaching-induced mortality reached 50%, with hard coral cover declining by 51–62% on outer reefs and by 34% in the lagoon	Bleaching risk conditions persisted from December 2015 to June 2016, approaching the 4 °C week threshold	Cerutti et al. (2020), Koester et al. (2020, 2023)
Houtman Abrolhos Islands (Australia)	2011: an average of 12% of corals bleached, with mean mortality reaching 50%	Maximum daily water temperatures reached 29.54 °C, corresponding to 4.2 °C above the mean maximum daily temperatures recorded between 2008 and 2010	Abdo et al. (2012)
One Tree Island (Australia)	2020: half of the hard coral cover was severely bleached	Temperature anomalies above 27.5 °C were recorded daily throughout February 2020	Nolan et al. (2021)
Huatulco (Mexico)	2023: coral mortality exceeded 50–93%	SST exceeded 31 °C, approximately 2 °C above historical records	López-Pérez et al. (2024)
Dry Tortugas (Florida, USA)	2023: 100% mortality of *Acropora palmata*	Maximum in situ temperature: 32.52 °C, maximum daily SST: 31.94 °C, DHW: 14.35 °C weeks	Thompson et al. (2025)

DHW = Daily degree heating weeks

Reef (300 km off the northwest coast of Australia), during the severe bleaching event in 1998, average coral cover in exposed sites dropped from 54% to less than 10% over the top 30 m (Bird 2005). These comparisons underscore the variety and magnitude of coral responses to heat stress (Burn et al. 2023). However, under some local conditions (e.g., low nutrients, high wave energy, access to cooler deep water), reefs may resist bleaching-induced mortality.

Similar bleaching and mortality patterns have also been documented in the North Pacific and the Indian Ocean. During the third GCBE, Head et al. (2019) found that the isolated reefs of the Chagos Archipelago (central Indian Ocean) suffered severe bleaching and mortality in 2015 after a 7.5 DHW thermal anomaly, causing a 60% decline in coral cover (Table 2). In Palmyra Atoll, the 2015–2016 warm water event produced maximum cumulative heat stress of 11.9 °C weeks (Fox et al. 2019). On the fore reef (10 m depth), 90% of live coral cover bleached (32% severely), while on the shallow reef terrace (5 m), bleaching affected 93% of colonies. Post-bleaching, coral cover on the fore reef declined by 9% between 2014 and 2017, while terrace coral cover remained unchanged. During the third GCBE, Burt et al. (2019) reported that reef bottom temperatures in the Persian/Arabian Gulf in 2017 were among the hottest on record (mean daily maxima averaging 35.9 ± 0.1 °C) with corals spending nearly two months above bleaching thresholds. They observed that 94% of corals bleached, and two-thirds died between April and September 2017.

The 2024 MHW

The 2024 MHW observed at Tahanea was not an isolated event. It is consistent with warming that broadly affected French Polynesia, with persistent extreme surface temperatures observed across the Society, Tuamotu, and Marquesas Archipelagos over the same period (Fig. SP2). This MHW occurred in the context of the 2023/24 El Niño, which ranks among the three most intense El Niño events of the past 30 years based on the Oceanic Niño Index (ONI). It was characterized by widespread positive SST anomalies across the tropical Pacific, extending from the dateline to the coasts of Central America (Fig. SP3). Previous studies have shown that this type of El Niño, similar to the 2015/2016 event (Pagli et al. 2025), strongly impacts the warm season (November–April) in French Polynesia leading to unusually warm surface waters north of 20°S, where Tahanea Atoll is located (Fig. SP3). This El Niño context strongly favored the development of MHWs across northern French Polynesia and contributed to the exceptionally severe MHW observed in Tahanea in early 2024.

Conclusions and limitations of the study

Science often requires extensive spatial and temporal replication, which poses logistical challenges for equipment and personnel. As a result, data from isolated reefs, atolls, and islands (where field support is limited) remain scarce. Here, we combine high-resolution satellite temperature data with in situ observations of temperature, coral bleaching, and mortality. Regarding temperature, we used both RBR loggers and satellite data. Combining these two methodologies was not always straightforward, as illustrated by the 0.5 °C deviation observed during the first temperature peak when comparing in situ measurements in the lagoon with the corresponding satellite pixel.

Climate models project that by the end of the twenty-first century, MHW frequency, intensity, duration, and extent could increase 10- to 40-fold, with tropical regions seeing some of the most severe changes (Frölicher et al. 2018; Capotondi et al. 2024). Our results show that the combination of relatively moderate thermal stress (DHW ~ 4.7) can cause significant coral mortality. However, other parameters could also partly explain this result, namely limited prior exposure to thermal stress, local sensitivity, or high spatial variability within the reef system. Further monitoring in the future will therefore need to be carried out on this Tahanea Atoll to better account for these parameters. By documenting bleaching and mortality on an isolated atoll, this study provides a baseline of coral response to thermal stress with minimal local human influence. These findings highlight the vulnerability of even remote reefs and the importance of understanding spatial variability in bleaching.

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Author contributions D.L., X.R., and M.J. conceptualized the study; D.L., M.J., C.C., B.P., C.M., Sw.J., Sa.J., M.D., and X.R. were responsible for methodology; X.R., C.C., and B.P. assisted with software and visualization; D.L. and X.R. performed validation, supervision, and project administration; M.J. and X.R. conducted the investigation; X.R., M.D., C.C., B.P., C.M., Sw.J., Sa.J., and M.D. carried out the analysis; X.R., M.D., S.J., L.H., and D.V. helped with resources; X.R., C.C., B.P., and M.D. curated the data; M.J., D.L., X.R., C.C.,

B.P., C.M., Sw.J., Sa.J., and M.D. took part in writing—original draft preparation; X.R., Sw.J., B.P., C.C., and M.D. participated in writing—reviewing and editing; and D.L. acquired the funding.

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Data availability The data supporting the study are openly available on Zenodo (https://doi.org/10.5281/zenodo.16238313). In addition, more information can be found as part of the Supplementary Material.

Declarations

Conflict of interest The authors declare no conflicts of interest.

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