

Comment

Because governments are unlikely to act without sufficient public pressure, a global ‘wildlife-safe’ shipping eco-certification scheme could be crucial. Similar to NOAA’s ‘dolphin-safe’ tuna-can labels – which aim to signal compliance with US laws and regulations around tuna fishing operations – this would help to increase consumer awareness of the problem and enable informed choices. Scaling up the success of voluntary certification programmes, such as Friend of the Sea’s Whale-Safe label, alongside its certification of seafood from sustainable fisheries and aquaculture, would greatly increase the visibility of this issue.

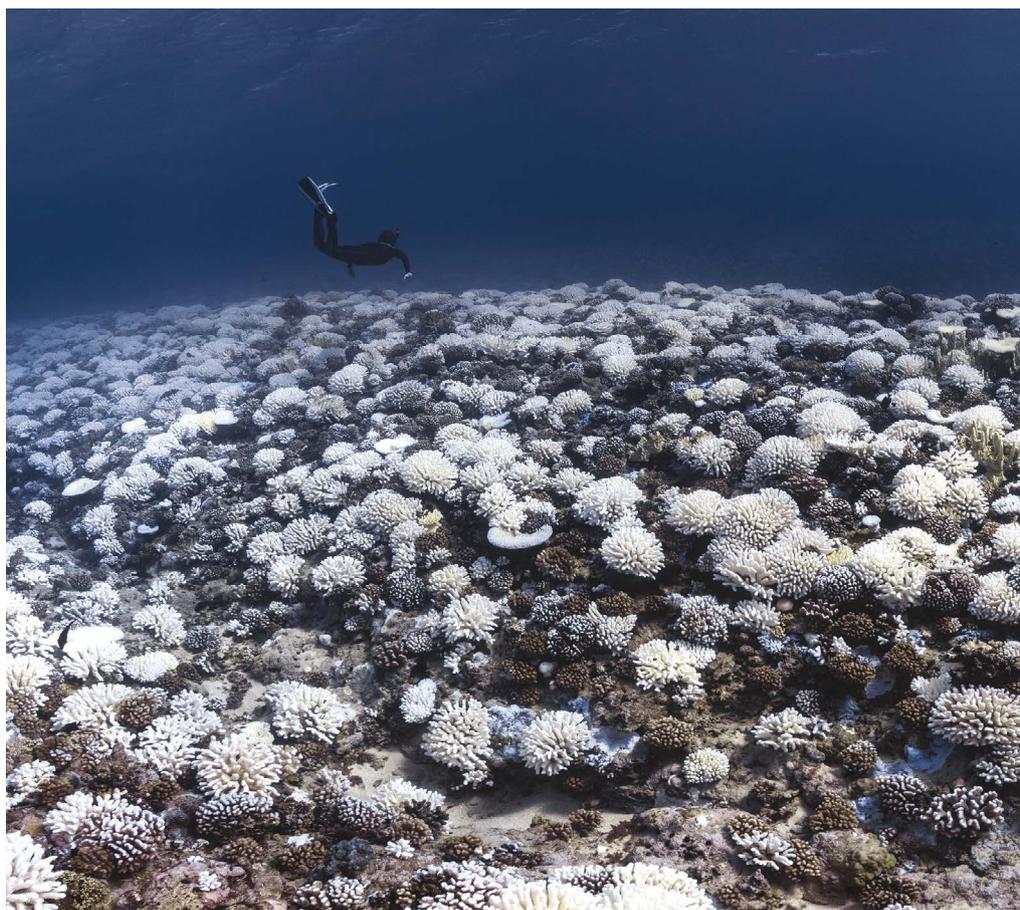
Loss of the ocean’s largest animals will have major unforeseen consequences for the health of the seas. Making ship strikes a higher priority globally is one immediately achievable way to help to conserve the world’s most vulnerable and iconic marine species.

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Bleached corals in the reefs of the Society Islands in the South Pacific Ocean.

With the arrival of El Niño, prepare for stronger marine heatwaves

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Record-high ocean temperatures, combined with a confluence of extreme climate and weather patterns, are pushing the world into uncharted waters. Researchers must help communities to plan how best to reduce the risks.

Oceans are warming up, and dangerously so. Since April this year, the average global sea surface temperature has been unusually high and rising; by August, oceans in the Northern Hemisphere had reached record-high temperatures, even surpassing 38 °C in one area around Florida.

These extreme temperatures, fuelled by the climate crisis, have manifested as a series of marine heatwaves – periods of anomalously warm sea temperatures that can last for weeks, months or even years – across the Northern and Southern hemispheres. In some areas around the United Kingdom and Ireland, for



including through economic losses from impacts on fisheries and aquaculture. The Peruvian anchoveta (*Engraulis ringens*), for example, disappears from its usual fishing grounds during marine heatwaves. In 2015–16, the sea off eastern Tasmania in Australia saw high mortality rates for oysters and abalones during a warm spell. And although tourism has played a part in the degradation of corals, mass bleaching of coral reefs also dents tourism,

“Marine heatwaves are more intense, last longer and occur more frequently than they used to.”

because white corals do not appeal to snorkellers and divers. The impact of a heatwave on marine industries can run into billions of dollars³.

Given the impending overlap of El Niño conditions with long-term warming trends, it is pressing to closely monitor regions with a high likelihood of marine heatwaves, and to develop and implement a range of approaches for reducing risks to wildlife and economies. Here, we urge decision makers in marine and coastal biodiversity conservation, fishing, aquaculture and tourism industries to devise such a strategy for the coming months as well as for the decades ahead. We set out four priorities.

Identify threatened regions

Where communities are prepared, impacts can be mitigated, at least partially. This depends on knowing which regions are most likely to be affected.

An analysis of historical data can reveal which areas experienced marine heatwaves during previous El Niños, and suggests where such events are most likely to occur when it develops: in the northeast Pacific (affecting coastal waters from California to the eastern Bering Sea); the tropical central-to-eastern Pacific and the shelf waters of Ecuador and Peru; off eastern Australia; and the Indian Ocean, including off the east coast of Africa, southern India, and southeast Asia (see ‘El Niño and marine heatwaves’ and Supplementary information). These areas are known to be susceptible to mass die-offs of diverse marine habitats, from tropical coral reefs to temperate kelp forests⁴.

El Niño occurs as part of a cycle (see ‘What is El Niño?’), but this is not the only climate cycle to influence marine heatwaves. Other ocean and atmospheric patterns operate on timescales ranging from a few years to several decades. These manifest as natural variations in temperature in different ocean basins⁵. For instance, the current negative phase of the Pacific Decadal Oscillation is associated with warming waters around Australia, the northwest Pacific, the northern Indian Ocean and parts of the South Pacific and South Atlantic. In the next few months, a positive Indian Ocean Dipole is also predicted to start to warm the western Indian Ocean. This pattern, reinforced by El Niño, typically brings a warm and dry summer for many parts of Australia.

There are counter trends, too – although El Niño drives rising temperatures in many areas, it suppresses the likelihood of marine heatwaves in a few regions, including the waters off Papua New Guinea, New Zealand, the Philippines and western Australia.

Although our understanding of marine

example, surface waters in June and July were 4–5 °C warmer than is usually recorded at this time of year. Temperatures are also soaring off the coast of Florida and into the Gulf of Mexico, extending across the tropical Pacific, around Japan, and off the coasts of Ecuador and Peru. Marine heatwaves are more intense, last longer and occur more frequently than they used to. From 1925 to 2016, the number of days classed as experiencing marine heatwaves increased by 54% (ref. 1).

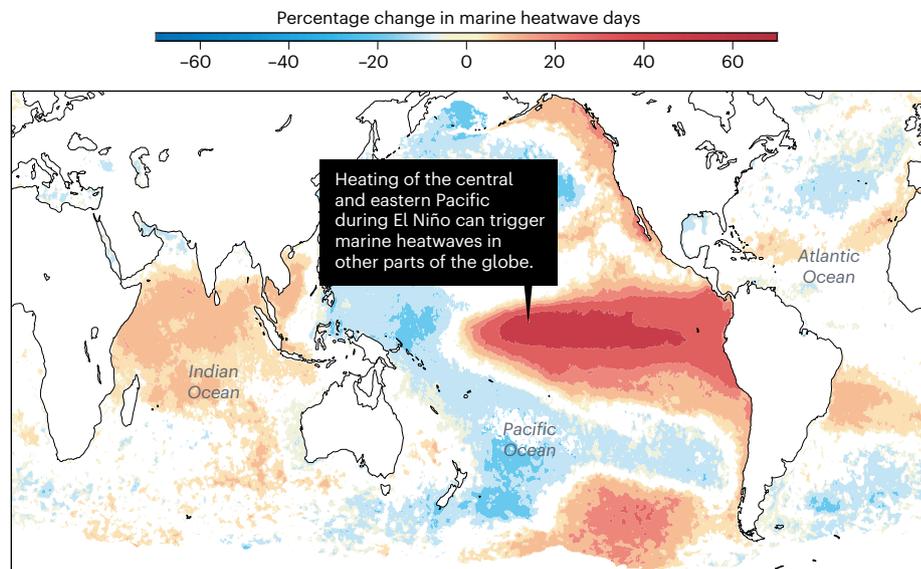
This makes the concurrent likelihood of a strong El Niño – a climate phenomenon that is typically associated with a rise in global temperatures – particularly worrying.

Marine heatwaves disrupt, threaten and damage ecosystems. They are particularly dangerous for temperature-sensitive organisms that live in cool waters, such as kelps, and immobile warm-water organisms, such as corals. Many species might be susceptible to disease or mortality, with knock-on effects. For example, in 2014–15, a marine heatwave off the west coast of the United States, dubbed the Blob, caused widespread loss of sea stars. This in turn caused a bloom of sea urchins (on which sea stars predate), which in turn damaged kelp forests². Rising water temperatures can also cause some species to migrate to cooler waters.

Such events also affect local communities,

EL NIÑO AND MARINE HEATWAVES

El Niño is associated with an increased likelihood of marine heatwaves. This map shows where that risk is strongest, by comparing the number of marine-heatwave days during past El Niños with the number occurring during neither an El Niño nor the cooler La Niña phase.



ALEXIS ROSENFIELD/GETTY

SOURCE: ANALYSIS BY A.J. HOBDAY ET AL. BASED ON DATA FROM MARINE COPERNICUS EU; SEE SUPPLEMENTARY INFORMATION

What is El Niño?

The Pacific Ocean phenomenon has wide-ranging effects.

Short-term patterns in global climate such as El Niño are superimposed on long-term anthropogenic warming, with serious consequences predicted for many regions of the globe.

The El Niño–Southern Oscillation is a major climate phenomenon that comprises a warm phase (El Niño), a cool phase (La Niña) and a neutral phase. These switch, irregularly, every few years. El Niño — when winds over the tropical Pacific falter and the warmest waters in the western Pacific flood eastwards, disrupting the entire atmospheric circulation — has the most widespread impact on sea surface temperatures globally.

For the past three years, the world has been experiencing La Niña conditions, associated with cooler global temperatures and cooler-than-average sea surface temperatures in the central and eastern tropical Pacific. Earlier in 2023, conditions in the tropical Pacific began to reverse and El Niño seems to be developing. It is likely to amplify until the end of this year and possibly into next year as well, and is poised to trigger major marine heatwaves.

heatwaves has lagged behind that of their atmospheric counterparts, researchers have learnt a great deal about these extreme events since the last El Niño. A better grasp of how different climate cycles are connected, as well as their influences, will aid preparations.

Improve forecasts and warnings

Work is progressing on predicting spikes in seawater temperatures⁶. Ocean weather forecasts are reliable a week or so in advance⁷, probabilistic seasonal forecasts give indications several months ahead^{8,9}, and centennial-scale climate projections that take into account anthropogenic greenhouse-gas emissions provide the longest view¹⁰.

Spatial maps showing probabilities of marine heatwaves are most accurate in open oceans where climate drivers, particularly El Niño, are strongest, and less so nearer coasts, where local ocean and atmospheric conditions become important. Building predictive power for these regions — by improving coupled ocean–atmosphere models and assessing the accuracy of their predictions — is crucial



SUZANNE LONG/ALAMY

An autonomous glider is deployed into the Indian Ocean to monitor marine conditions.

for local biodiversity conservation efforts as well as the fishing, aquaculture and tourism industries.

Plan local responses

This year, countries such as Australia and the United States are using seasonal-scale early warning systems, with lead times of several months, to provide marine-heatwave briefings to conservation agencies, the fishing and aquaculture industries, and the public.

Options to alleviate potential impacts or improve recovery after a marine heatwave vary by industry (see ‘Managing marine heatwaves’ and Table S1 in Supplementary information). These steps depend on the marine environment and the species or ecosystems of concern, as well as on the expected timing, severity and spatial extent of the forecast event.

In the case of marine heatwaves predicted to develop in winter and spring, when waters are generally coolest, aquaculture industries might need to change the feed mix for species such as salmon, prepare for disease outbreaks, or change the time of harvest to ensure animals are in prime condition. For summer and autumn events, when temperatures exceed the coping range for many species, fisheries might need to reduce catch limits or close an area altogether, to enable species to cope with the stress of warmer waters. Without such interventions, marine heatwaves can result in reduced catches for

several years, as was seen in crab and scallop fisheries off western Australia following a 2011 event.

Changes in the distributions of species could also challenge jurisdictional management for fisheries. For example, when mackerel and squid moved from southern to northern Californian waters in 2016, quota management, employment and market prices were affected.

The fishing and aquaculture sectors can shift harvesting and production schedules to maximize yield before temperatures rise, move inactive fishing vessels to cheaper moorings and reduce seasonal staff hiring in regions where activities are poised to decline. Other management strategies might include delaying restoration of kelp and seagrass in previously affected areas when further marine heatwaves are forecast. Innovative approaches, such as restoration that introduces species adapted to warmer conditions or the temporary alteration of clouds to protect coral reefs from solar radiation, need to be investigated.

Some tourism enterprises, such as diving or snorkelling firms, might reduce numbers of staff during marine heatwaves, or modify their activities to minimize job losses. Whale-watching trips could be increased, for example, as happened off the coast of San Diego, California, during the Blob. Sports-fishing companies should ensure they have the appropriate permissions,

equipment and staffing when warmer-water species move to areas where they are not usually seen.

Monitor impacts of warmer waters

For the scientific community, warnings months ahead of likely rises in temperatures provide the opportunity for in-depth studies. Hypotheses can be developed and tested, data can be gathered – for example, by using underwater gliders to determine the vertical structure of heatwaves – and samples can be collected and analysed.

To better understand ecological responses to extreme warming events, researchers should scale up monitoring efforts to characterize a region's physical and biological conditions before a heatwave's onset. They should deploy sensors to measure key variables (such as temperature, oxygen levels, salinity, and the abundance and composition of nutrients and plankton) across multiple scales in time and space and at high resolution, from the surface to deeper waters. Although intense sampling during an extreme event provides a wealth of information, robust characterization of an ecosystem before a heatwave is also crucial, to provide a baseline. Data should be collected to assess changes in habitat types as well as the growth, reproduction and survival of species.

A wide range of approaches, including remote sensing (such as for monitoring phytoplankton), fisheries surveys (to assess changes in fish distribution and abundance, for example), environmental DNA collection and citizen science (for detecting species outside their normal ranges) can help. Indigenous and local communities might notice early changes in the environment and should lead monitoring and planning endeavours.

Predictions of which species or habitats will

be affected by a marine heatwave, on the basis of existing information or ecological theories, will allow hypotheses to be tested – such as the idea that impacts are greatest in the warm part of a species' range. Species that can survive only in a narrow range of temperatures, such as tropical corals, and those living close to their thermal limits, can serve as indicator species for wider impacts.

Oceanographic survey tools such as gliders and autonomous underwater vehicles should be deployed to sample the evolution of marine heatwaves. They can record a range of data, including on temperature and salinity but also levels of ocean acidification and of oxygen and nitrogen, to better understand environmental change. Where threatened species or popula-

“Robust characterization of an ecosystem before a heatwave is also crucial, to provide a baseline.”

tions might be affected, being able to collect and ‘biobank’ samples to preserve genetic diversity would be an important step for further research and subsequent restoration.

Worryingly, the climate crisis could eventually cause oceans to reach a permanent heatwave state relative to historical baselines¹¹, and some regions might no longer support certain species and ecosystems. The ecosystems that emerge might not operate and respond to warmer waters in ways that can be anticipated¹². Scientists might not be able to prevent these consequences, but it is crucial to devise and implement adaptive strategies to keep them at bay temporarily or soften their

impacts wherever possible. This could buy time for species and ecosystems, and the industries that rely on them, to adjust and transform⁹.

Regardless of whether a full-blown El Niño event occurs this year, these preparations will aid many marine businesses, because all projections indicate that more-frequent, stronger and longer-lasting marine heatwaves are inevitable in the near future.

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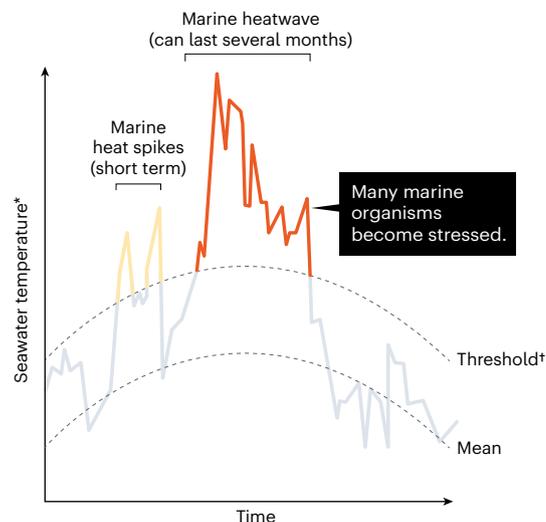
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MANAGING MARINE HEATWAVES

Periods of anomalously warm marine waters that can last from five days to more than a year require appropriate preparation and response, involving researchers and coastal communities alike.

Steps: 1 ▶ 2 ▶ 3 ▶ 4 ▶ 5 ▶ 6 ▶ 7



*Temperature and time illustrated schematically. †Usually the 90th percentile.

- 1 **Establish baseline**
Researchers can use historical records and long-term monitoring.
- 2 **Assess risk and plan responses**
Identify vulnerable ecosystems, species and industries and ways to protect them.
- 3 **Respond to forecasts**
Shift aquaculture species to cooler sites, for example.
- 4 **Adjust to cope**
Close fisheries, reduce quotas, cull pests.
- 5 **Evaluate impacts**
Assess recovery time post-heatwave.
- 6 **Collect new baseline data**
On temperature, salinity, acidity, oxygen and nutrients.
- 7 **Reset quotas and activities**
Targets must be adjusted for any change in baseline.