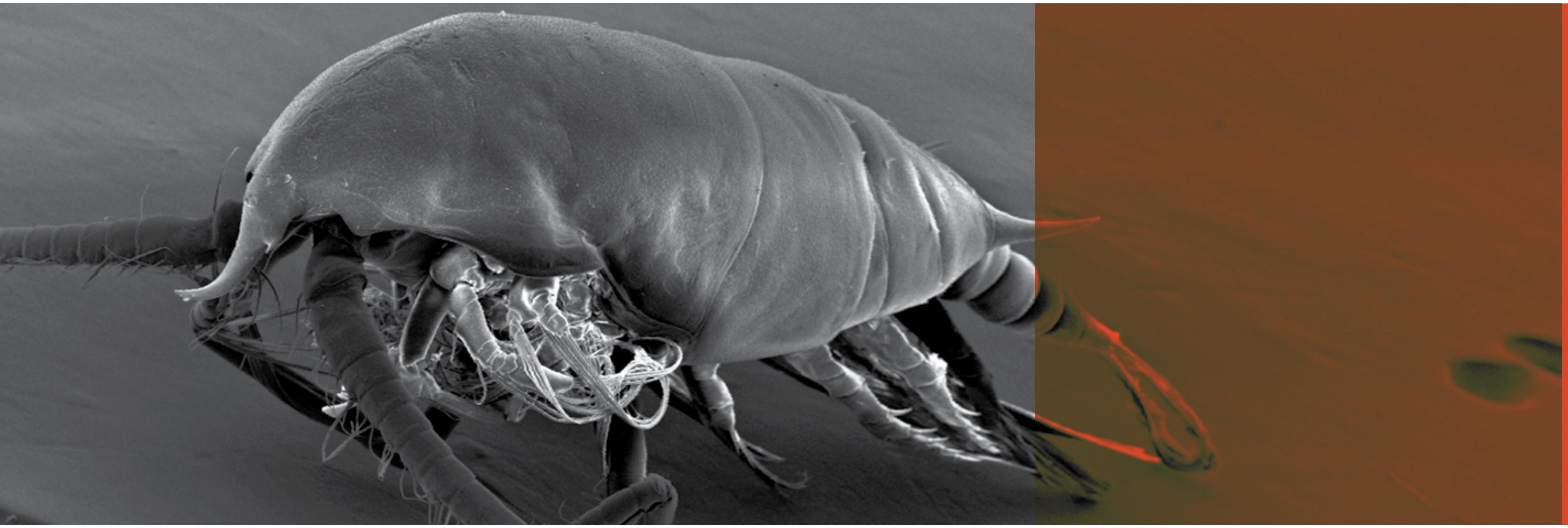
# ENVIRONMENTAL CONDITIONS



Oceanography

Diverse microscopic organisms living within the water column at Scott Reef are part of an intricate food web. Many creatures, including copepods (top row), spend their entire lives in the plankton, while others live on the reef but migrate into the water column at certain times.





Scott Reef's rich ecosystem depends on the water in which it exists. By studying the ocean's movements and temperature, its chemical makeup and biological properties, oceanographers have painted a detailed and sometimes surprising portrait of the aquatic environment that surrounds the reef. Huge waves within the water column peak when they arrive at Scott Reef and channel cold, nutrient rich water into the southern lagoon. These nutrients are utilised by a vast abundance and diversity of planktonic organisms engaging in a microscopic battle of life and death – zooplankton feed on phytoplankton, and phytoplankton die from viral infections – all within a single day.

## Emerging from the deep

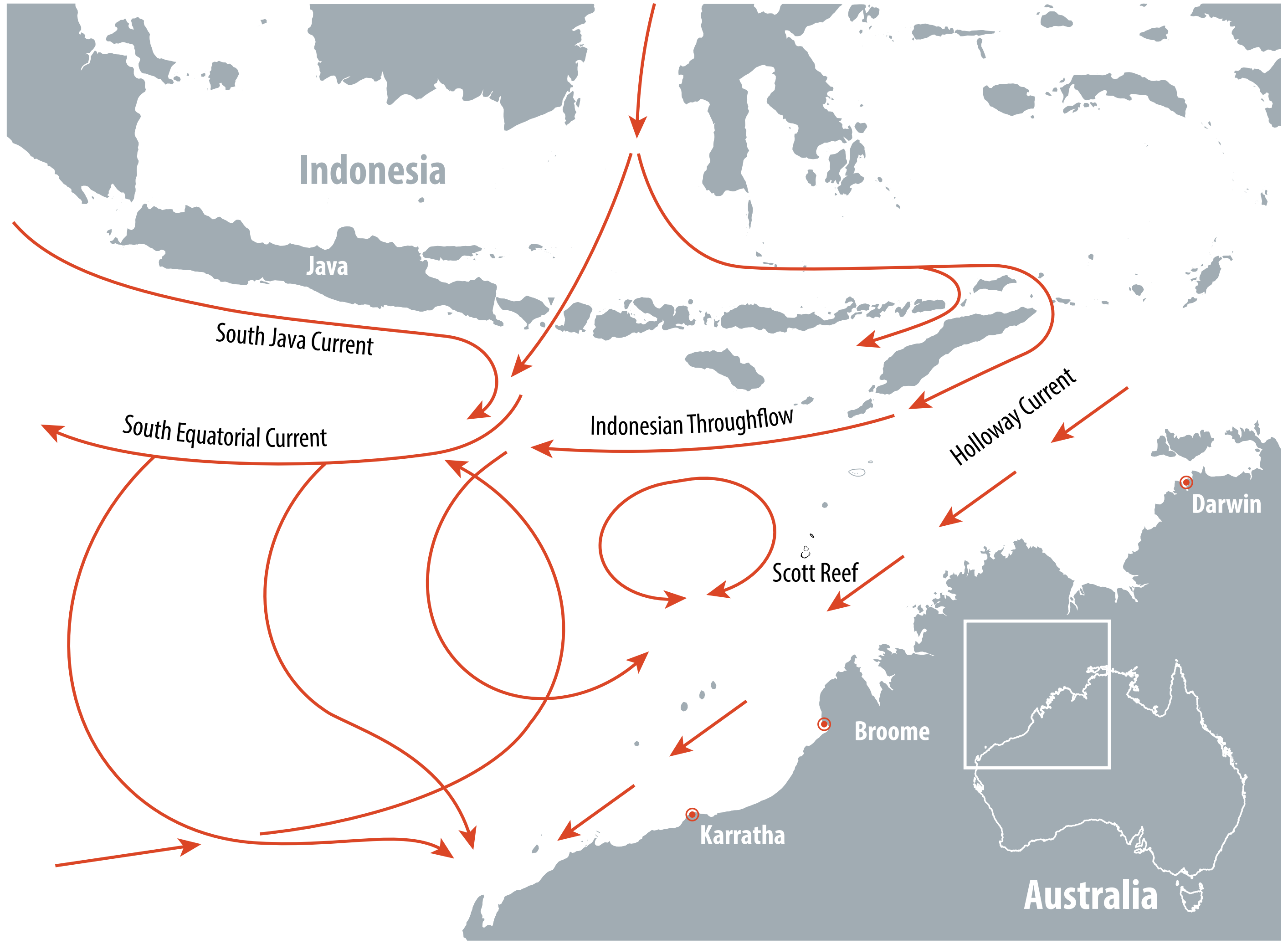
Rising from great depths and surrounded by open ocean, Scott Reef is bathed in nutrient-poor oceanic waters that lack the inputs from river systems or human activities which affect many other reefs.

On the broadest scale, the dominant oceanographic feature in the region around the reef is the Indonesian Throughflow. This critical part of the global ocean circulation transports warm, nutrient-poor water from the Pacific Ocean, through passages between the islands of Indonesia and Timor-Leste, eventually depositing it into the eastern Indian Ocean.

The Indonesian Throughflow contributes to global climate cycles by transporting and redistributing heat between the Pacific and Indian Oceans. These currents are highly variable over the span of months, years and decades, with the largest variations linked to the El Niño Southern Oscillation phenomenon.

The aquatic environment around Scott Reef has been the focus of research for almost 20 years. In 2008, that long-term research was expanded in an intensive two-year project to gain a more thorough understanding of how the reef's physical setting affects its biological communities.

During this study, scientists sampled more than 40 monitoring stations around the reef and deployed a large array of water quality loggers and current meters. These instruments recorded conditions in the South Reef lagoon and deep channel continuously between March 2008 and February 2010, stopping only for retrieval and data download. Additional data characterising seasonal variation in oceanographic conditions around Scott Reef were collected during multiple surveys.



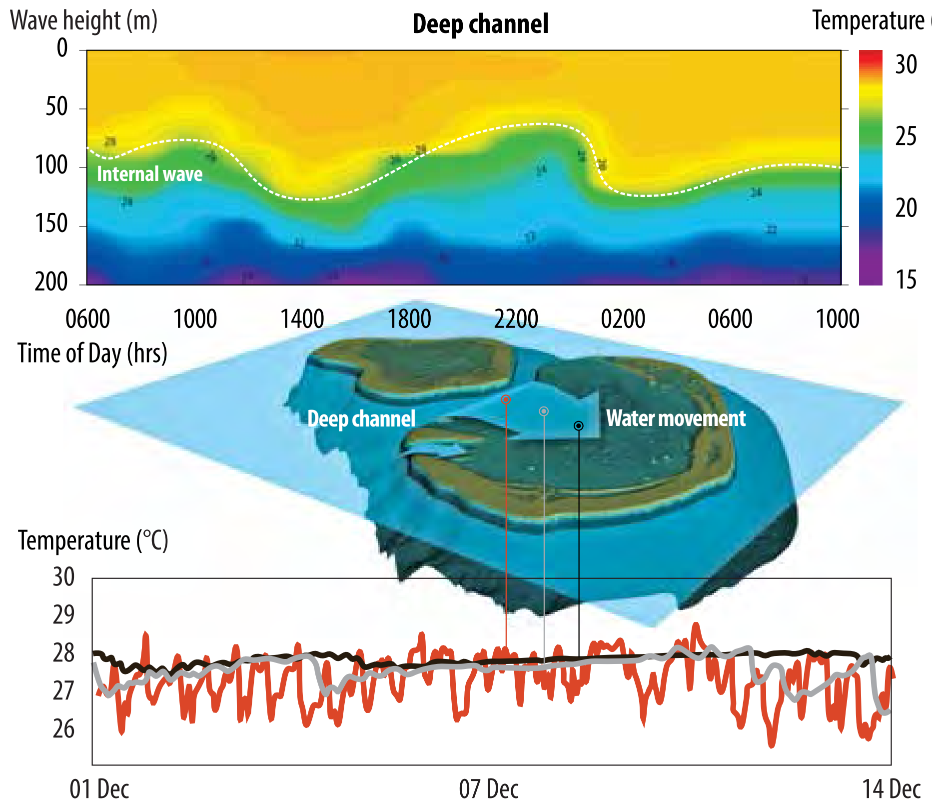

The Scott Reef system rises from the deep ocean near the edge of the continental shelf, and is far from the influence of mainland Australia. The Indonesian Throughflow dominates the supply of water to Scott Reef and its surrounds.

This vast amount of data confirmed that the ocean around Scott Reef, like much of the Timor Sea and eastern Indian Ocean, is characterised by two distinct layers of water. From the ocean surface down to approximately 100 metres is a well-mixed layer of warm, clear water, deficient in nutrients. Below this surface layer is cool water, richer in nutrients but less illuminated because of its depth. At depths of 400 metres, there is no light and the temperature can drop below 10 degrees Celsius.

The stable layering of the ocean around Scott Reef supports the existence of massive internal waves – waves within the water column, undetectable from the surface – which increase in size when they encounter the submerged reefs and banks in the area. These internal waves can reach heights of up to 110 metres, high enough to bring water up through the deep channel between North and South Reef and into the lagoon of South Reef. Driven by tidal forces, these intrusions typically occur twice a day, and bring vital nutrients into the shallow reef areas, increasing the productivity in the water column.



Oceanography




Huge internal waves moving through the deep ocean reach 110 metres in height as they encounter Scott Reef. The internal waves – waves within the water column – force cool, nutrient rich waters from the deep up through the channel and into the South Reef lagoon.

# South Reef lagoon – warm and clear

The main focus of recent oceanographic studies was the deep lagoon, which reaches depths of up to 70 metres, within the large (400 square kilometres) horseshoe-shaped South Reef. Because of its shape, the South Reef lagoon is open to the surrounding ocean via the deep channel to its north. The water here is warmest in April and coolest in late August, with daily averages ranging from 25 to 31 degrees Celsius. Water quality loggers showed that the twice-daily incursion of deep water through the channel contributes to large daily temperature fluctuations of up to four degrees Celsius.

The oceanographic studies also quantified the clarity of the waters in the South Reef lagoon. Within the water column in the central area of the south lagoon there is very little suspended matter, with nearly undetectable concentrations. Consequently, light can penetrate to depths of more than 50 metres. This clear water and available light is crucial to the plant and animal communities in the South Reef lagoon, enabling them to survive in far greater depths than on other reefs with lower water clarity.

# North Reef lagoon – warmer and cloudier?

North Reef has a shallower and more enclosed lagoon than South Reef, never exceeding 20 metres depth, with only two small channels linking it to the surrounding ocean. The oceanography of the North Reef lagoon has not been well studied, but given its shape, researchers expect its water column to be warmer and more turbid than the South Reef lagoon. Considering there is limited scope for flushing, residence times in the north lagoon are long and in sunny periods the water is more likely to become warmer and saltier due to evaporation. During times of extreme rainfall it can also become less saline than the surrounding ocean. Tidal currents are weak, and sediments include a combination of coarse sand and fine silt. This fine silt is resuspended when strong winds blow over the shallow lagoon and light penetration may, therefore, be more variable than in the South Reef lagoon.

# Plankton soup

Around the globe, oceans are filled with small drifting plants, animals, viruses and bacteria known collectively as plankton. The oceanographic study of the plankton around Scott Reef uncovered an abundance of previously undescribed biodiversity.

Within the animal plankton (zooplankton), researchers found more than 260 different species in samples taken around the reef, many of which had never been identified before. A detailed taxonomic study of the group known as copepods found more than 220 species. Almost one-third of these species were new records for Australian waters and at least 14 appear to be previously unknown. Perhaps even more remarkable was the biodiversity within just one family of copepods, the Oncaeidae, which alone comprised more than 65 species.

Even more abundant than the zooplankton in the waters around Scott Reef were the minute photosynthesising plankton (phytoplankton) they feed on. Researchers found that more than 70 per cent of these were less than two microns in size – about one-fiftieth the width of a human hair. The phytoplankton samples were dominated by the marine bacteria *Prochlorococcus* and *Synechococcus* – these bacteria are among the most abundant photosynthesising organisms on the planet.

Each day, the phytoplankton populations around Scott Reef rise and fall in numbers. During the day, when sunlight is available for photosynthesis, the cells rapidly divide and multiply. At night, numbers dwindle as they are consumed by grazing zooplankton or destroyed by viral infections. These viruses are the most plentiful 'living' organisms within the Scott Reef lagoon and surrounding waters. Each millilitre of water can contain up to 10 million viruses, which mainly infect bacteria such as the *Prochlorococcus* and *Synechococcus*.

The rate at which phytoplankton are killed by viruses and grazing zooplankton is so high that communities of photosynthesising plankton in the waters around Scott Reef are born and die within a single day. This means that nearly all the organic material produced by these organisms is recycled within the water column, and very little sinks down to filter-feeding communities living on the sea floor below. As a result, the deep water corals in the South Reef lagoon obtain most of their nutrition from the photosynthetic algae that live within their tissues and not by feeding on other organisms or organic material.

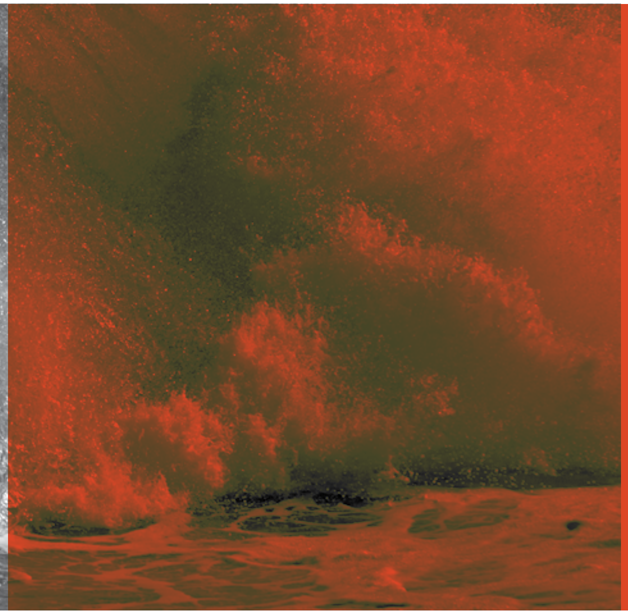
This in turn means that the high water quality of the reef is of critical importance to the health of these deep water coral communities. In fact, the highly transparent, nutrient poor waters that bathe Scott Reef are well suited for the development of coral reefs. This is reflected in the remarkable biological diversity of the reef system, which includes almost 500 species of fish and more than 300 species of coral.






Instrument arrays were deployed into deep water and retrieved several months later for cleaning, servicing and data download. The instruments gathered data about the surrounding waters, including temperature, current speed and turbidity, to help further understand how the physical environment at Scott Reef influences its biological communities.

In the detailed study of zooplankton at Scott Reef, at least 14 species of copepods found were previously unknown to science.



# Disturbances

Tropical cyclones occasionally bring destructive wind and waves to Scott Reef. Cyclone Fay passed over the reef in 2004, causing widespread damage.





Since it was first formed, Scott Reef and its ecosystem have been altered significantly by changes in global climate and ocean level occurring over millions of years. Over time-frames more relevant to humans, other events have also regularly affected the reef and its communities. Occasional cyclones, extreme tides, outbreaks of coral predators and diseases are part of the dynamics at Scott Reef. However, these disturbances are increasingly compounded by human impacts, a situation that threatens coral reefs around the world. Researchers have documented a range of disturbances at Scott Reef since monitoring began in 1994. Their challenge is to understand which of these disturbances – in isolation and in combination – pose the greatest threat to Scott Reef, and whether the reef is likely to be resilient to the more severe regimes of disturbance predicted in the future.

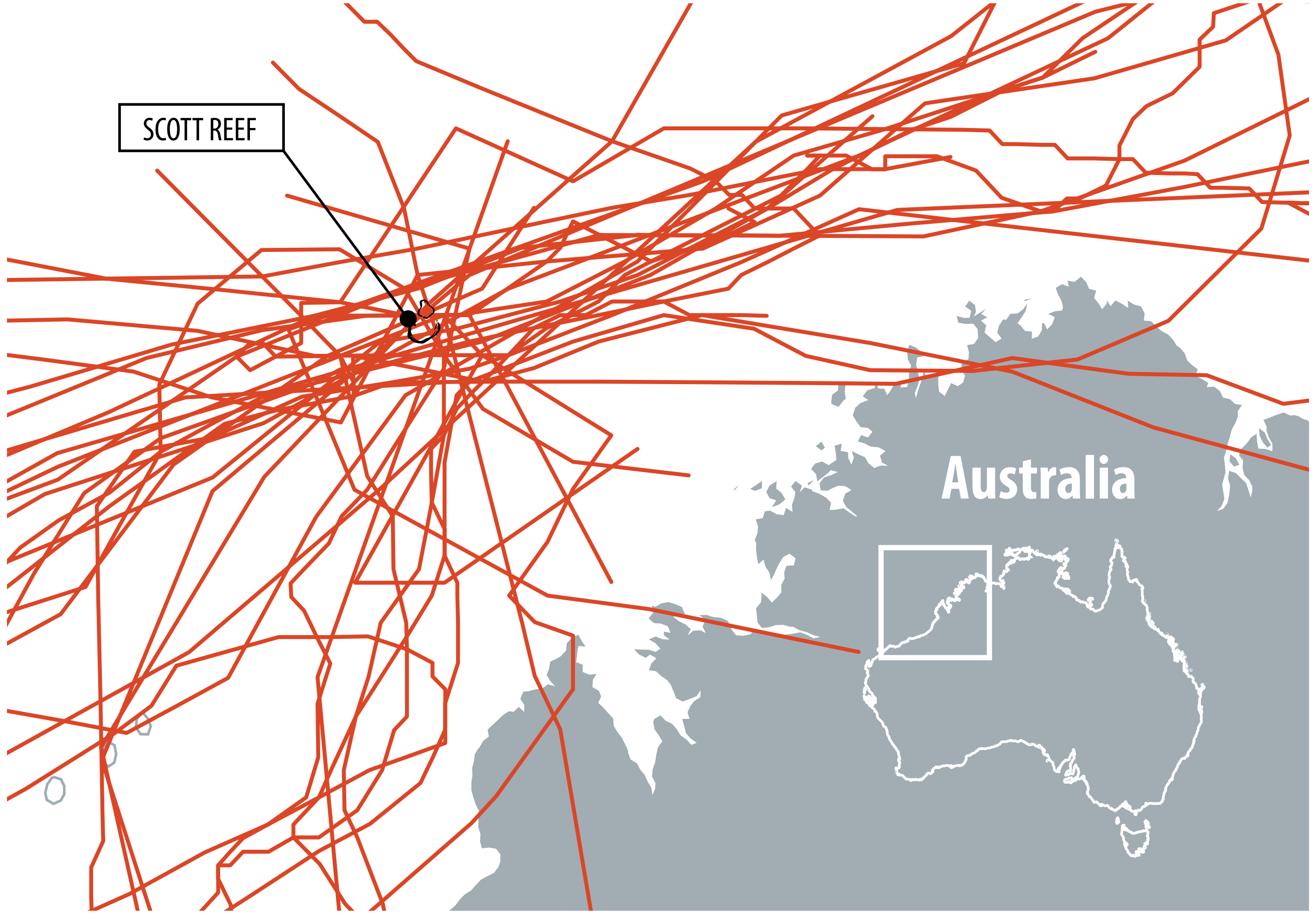
## Historic disturbance regimes

Coral reefs are considered to be resilient to a range of natural disturbances. In part, this is because these disturbances occur only periodically, allowing the reef a chance to recover in the meantime. This resilience also stems from the fact that natural disturbances often have patchy effects – different communities or groups of corals are affected to varying degrees and even a severe event may leave some areas relatively unharmed. When disturbances only affect certain corals and leave survivors, recovery can be quick. The survivors can regrow and produce new offspring, and recovery will be further aided by an influx of coral larvae from nearby areas that were not badly affected.

## Tropical storms and cyclones

Most coral reefs exist in shallow water in tropical climates. Consequently, the disturbances they often encounter include severe storms and cyclones. Powerful swells and waves can smash coral colonies into pieces and bury them under sediment and rubble, and torrential rainfall and freshwater runoff lead to deadly reductions in salinity. However, the impacts from most storms and cyclones are relatively minor, and in some instances the disturbance can actually increase diversity by removing some corals that would outcompete others if left unchecked.

Scott Reef is no stranger to cyclonic disturbances. Indeed, it has been severely damaged by a cyclone every few decades, and moderately impacted every few years.




Cyclones often pass in the vicinity of Scott Reef, but direct hits from severe storms are less common. In the past hundred years, more than 30 cyclones have passed within 50 kilometres of the reef.

When category 5 cyclone Fay tracked directly across Scott Reef in 2004, its 300 kilometre per hour winds caused widespread damage. The damage was most severe along the exposed side of the reef, where thousands of coral outcrops, some several metres in diameter, were dislodged and pushed up onto the reef flat. Studying the reef soon after the storm, researchers found that branching corals at shallow sites were either completely removed or smashed, leaving only stumps.

The damage was not restricted to branching corals. Soft corals and massive corals were also torn from their bases or broken into pieces. There was evidence of such damage down to 20 metres depth, and corals that escaped wave damage were buried under sediment and fragments of other coral colonies.

Cyclones as severe as Fay have been rare at Scott Reef. A storm of this magnitude may only affect the reef every 100 years or so, but in the past two decades others have also caused less severe harm to the coral communities. For example, cyclone George in 2007 damaged many fragile corals in some of the shallow communities at less than five metres depth.





Cyclone Fay generated powerful waves that caused extensive damage at Scott Reef in 2004. On the exposed parts of the reef, boulders up to several metres across were pushed up onto the reef flat, and even the most robust corals were broken into pieces or buried under rubble.

# Coral diseases and predators

Periodic outbreaks of coral diseases and predators may well have affected reefs for thousands of years and, like storms, could also serve to regulate the abundance of a few dominant species. However, large and frequent outbreaks have only been documented more recently – when human activities have disrupted the natural balance of reef ecosystems.

There are about 30 known coral diseases, caused by organisms such as bacteria and viruses. They can be passively dispersed through the water column or transmitted by other animals. With names such as black band, dark spots and white syndrome, these diseases can be lethal to corals.

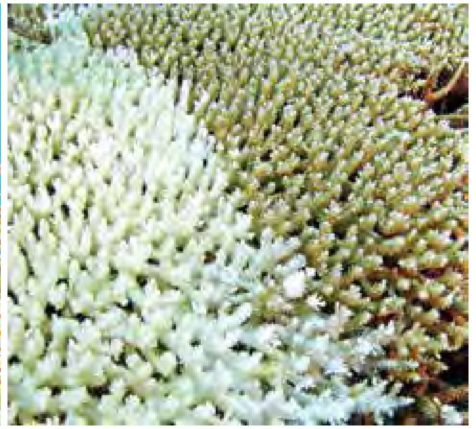
In contrast to the many different diseases affecting coral reefs, outbreaks of coral predators most commonly involve just two animals – the crown-of-thorns starfish *Acanthaster planci* and the marine snail *Drupella*. These predators feed on live coral tissue, leaving behind scars of exposed white coral skeleton.

Many reefs throughout the Caribbean and Indo-Pacific have been severely impacted by outbreaks of coral diseases and predators. Periodic outbreaks of the crown-of-thorns starfish have also severely affected parts of the Great Barrier Reef, as has *Drupella* at Ningaloo Reef in Western Australia. The reasons for these outbreaks are not known, but some theories attribute outbreaks to human activities, such as a higher survival of larvae in areas of poor water quality and high nutrient run off, or a reduced abundance of the organisms that naturally feed on these coral predators.

At Scott Reef, coral diseases and predators are constantly present, but usually in very low abundance. An exception was a recent outbreak of disease in 2010, which primarily affected table corals at a few communities. This outbreak was probably 'white syndrome', which is caused by the bacterium *Vibrio coralliilyticus*. Investigators know that low water circulation, turbidity, high water temperatures and a high cover of susceptible corals can trigger an outbreak of white syndrome. These conditions were present at the few parts of the reef worst-affected by the disease outbreak.

Since 1994, researchers have observed crown-of-thorns and *Drupella* occasionally at Scott Reef, but never in the high densities characteristic of outbreaks. When these predators were observed, they were usually feeding opportunistically on colonies that had already been injured by some other disturbance, such as a cyclone, disease or bleaching.





Periodic outbreaks of coral predators and diseases may have been part of Scott Reef's history, but they have been rare since research began at the reef. The coral-eating snail *Drupella* (left), crown-of-thorns starfish *Acanthaster planci* (centre), and the coral disease 'white syndrome' (right), can all be found on the reef, but are generally uncommon. An exception was a recent disease outbreak that affected some table corals in 2010.





# Contemporary disturbance regimes

In addition to existing disturbances that have shaped the evolution of coral reefs, disturbances associated with human activities are now becoming more frequent and severe. The ultimate cause of these threats is overpopulation and overexploitation of resources. Approximately 850 million people – one-eighth of the world's population – live within 100 kilometres of a coral reef. And by 2015, around half of the world's population will live near the coast, which will only increase pressure on marine ecosystems.

Fifty years ago, coral reefs appeared resilient, able to recover from even large disturbances. However, the growing number and severity of disturbances mean that coral reefs today often face cumulative impacts. When several disturbances occur together or in quick succession, the reef's ability to recover will be diminished.

Local, regional and global phenomena all affect reefs. For example, the local degradation of water quality due to overfishing and increased input of sediments and pollutants can occur alongside the regional effects of high seawater temperatures that lead to coral bleaching.

There is also serious concern that human activities are increasing the frequency or severity of some disturbances. Elevated water temperatures may increase the likelihood of disease outbreaks or the severity of cyclones, nutrients may increase outbreaks of crown-of-thorns starfish, and overfishing increases the proliferation of algae.

Collectively, a combination of disturbances has dire consequences for coral reefs – one-fifth of the coral reefs around the world have already been severely damaged and 35 per cent are predicted to be lost in the next few decades unless impacts are reduced. Apart from the irreplaceable natural wealth that is lost, this has important implications for the sources of food and income that coral reefs provide to humans – a contribution which during 2010 alone was estimated at tens of billions of dollars.

# The benefits of isolation

Given the role of human overpopulation in the degradation of coral reefs, not all reefs are on the same trajectory. Indeed, those far from the mainland, including Scott Reef, often escape exposure to the degraded water quality or overfishing that affects inshore reefs.

Coral reefs are generally found in nutrient-poor waters, and an increase in nutrient levels can result in algal blooms that effectively smother corals, particularly when numbers of herbivorous fish are low due to overfishing. Decreases in water clarity can reduce the light reaching the corals, and therefore the energy obtained through photosynthesis, and high levels of sedimentation can cover and injure coral tissue. Scientists have measured the water quality at Scott Reef, testing for levels of nutrients, turbidity and sedimentation. Results have shown extremely high water quality – probably a result of its distance from coastal river systems and human sources of nutrients and pollutants.

Similarly, herbivorous fishes are abundant at Scott Reef, and these play a critical role in controlling algae and maintaining space for coral recolonisation following disturbances. Maintaining this high water quality and the abundance of herbivorous fishes is vital for the ongoing health and resilience of Scott Reef.

# Not isolated enough

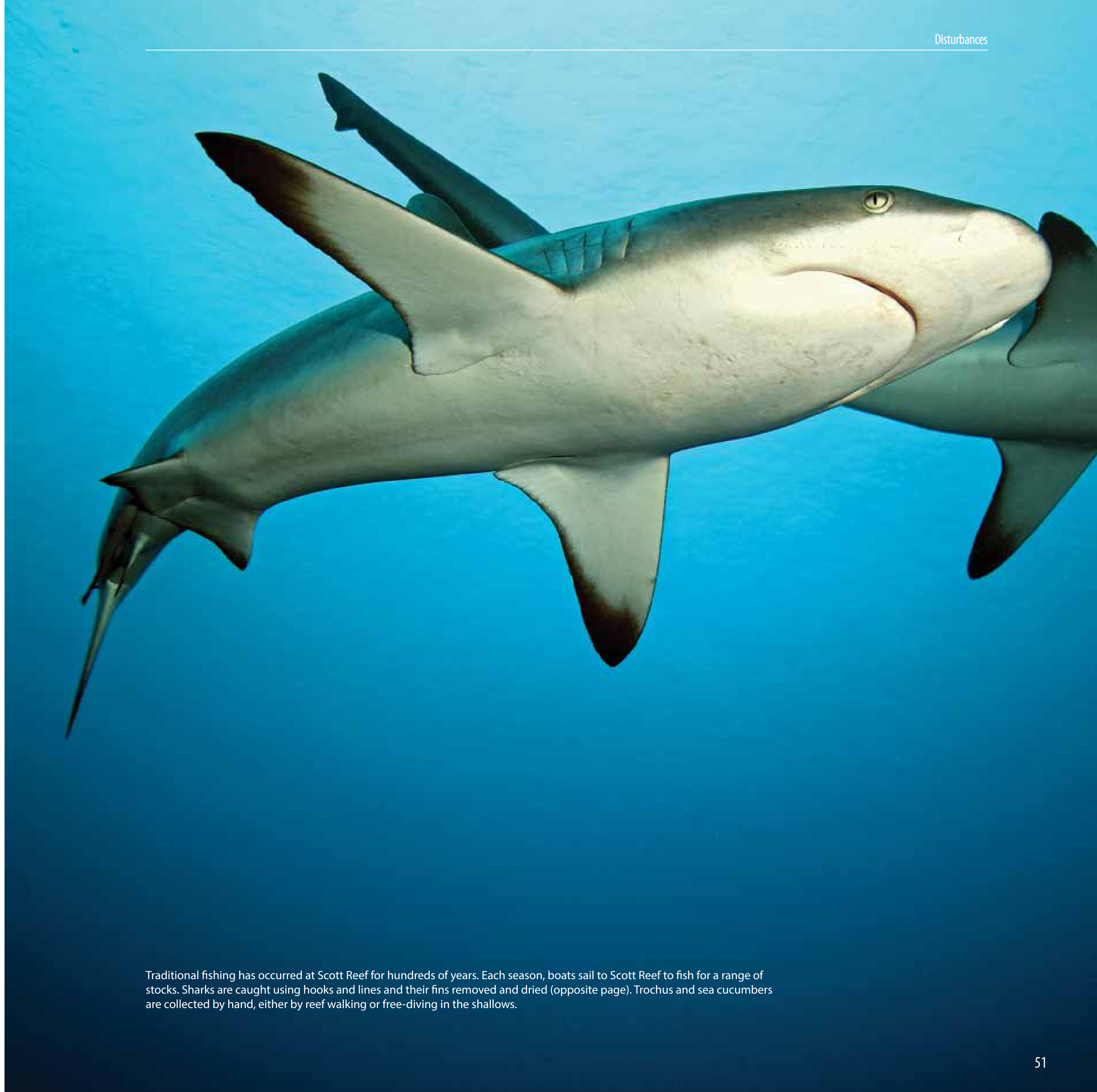
The destruction caused by human activities is far-reaching, and even Scott Reef's isolation cannot protect it from some of the problems facing other reefs around the world.

Scott Reef is under little pressure from industrialised commercial fishing, but has been exposed to traditional fishing for more than 300 years. Fishing at Scott Reef continues in traditional wooden boats, from which sea cucumbers, trochus, reef fishes and sharks are collected. Although this has largely been restricted to a few target species, the pressure on these stocks is considerable and there is concern that additional species are now being targeted, and fishing methods are becoming more destructive. In recent years, around 80 fishing vessels have visited the reef each season, each with approximately 10 fishers on board. Compared to the other offshore reefs in the region where traditional fishing does not occur, there are far fewer sea cucumbers, trochus and sharks at Scott Reef.

Although the fishing pressure at Scott Reef pales in comparison to the destructive practices occurring at many reefs around the world, the removal of target stocks is still likely to have altered the dynamics of the ecosystem. For example, the loss of sharks can affect the numbers of smaller predatory fish, with implications further down the food chain, where pressure on prey species is increased. Fishing has undoubtedly changed the reef ecosystem from a truly pristine state, but for now it has not directly affected the coral communities at Scott Reef.







Traditional fishing has occurred at Scott Reef for hundreds of years. Each season, boats sail to Scott Reef to fish for a range of stocks. Sharks are caught using hooks and lines and their fins removed and dried (opposite page). Trochus and sea cucumbers are collected by hand, either by reef walking or free-diving in the shallows.

# Our changing climate

The isolation of Scott Reef is also not enough to protect it from the global consequences of modern human activities. One of the greatest threats to coral reefs around the world is coral bleaching caused by the elevated sea-water temperatures that accompany climate change. There are few places where this has been more evident than at Scott Reef.

The potentially devastating phenomenon of mass bleaching occurs when higher water temperatures, or sometimes other physical stresses, disrupt the relationship between reef-building corals and the symbiotic algae that live within their tissues. Through photosynthesis, these algae provide the coral with oxygen, glucose, glycerol and amino acids – vital energy the corals use to survive, grow and reproduce. As well as supplying nutrients, the algae also give corals their remarkable range of colours.

Increases in water temperature can cause corals and other organisms to expel their symbiotic algae, leaving them pale or bony white, and without a key source of energy. This is a critical situation for the coral – if temperatures subsequently drop, these corals may recover. If not, they will perish.

Scientists have known about coral bleaching for decades, but the implications for coral reefs in the face of a changing climate have only recently been realised. During the summer of 1997 and 1998, reefs in every region of the world were devastated by elevated water temperatures and mass bleaching. Around 16 per cent of the reefs died, with those in the Indian Ocean being among the worst affected.

At Scott Reef, temperatures rose above normal in February 1998 and remained high for two months. Corals in all habitats down to 30 metres depth, across the entire reef system, bleached and died, reducing coral cover by around 80 per cent. The destruction caused by the mass bleaching is still evident at Scott Reef more than a decade later, and some coral and fish communities have still not fully recovered.

Repeated bleaching events have become a feature of some coral reefs, and a second, less severe, bleaching event impacted Scott Reef following elevated water temperatures in 2010. In contrast to the mass bleaching in 1998, the more recent event affected only a few locations and types of corals. Nevertheless, the latter event highlights the reef's susceptibility to climate change.

# Future disturbance regimes

Although Scott Reef is free of many of the disturbances affecting other coral reefs around the world, in almost two decades of monitoring it has been exposed to a catastrophic mass bleaching event and several other disturbances. These subsequent disturbances were far less severe, but their cumulative effect slowed the recovery of the Scott Reef system following the mass bleaching.

Consequently, the coral communities remained in a relatively degraded state for almost a decade after the mass bleaching, and any additional disturbances would have further slowed the rate of recovery. Indeed, for the communities at Scott Reef to remain in a healthy state will require a disturbance regime less severe than that seen in the previous decade.

As concentrations of atmospheric greenhouse gases rise, many scientists predict that climate change will continue to compound natural regimes of disturbance, and may introduce entirely new disturbances of unknown significance, such as ocean acidification – which potentially weakens the skeletons of marine organisms, including corals. How Scott Reef will respond to its changing regime of disturbance in the coming decades is unknown, but will be a major focus of future research efforts.





Although bleaching in hard corals is often the most conspicuous, in fact all organisms that contain symbiotic algae within their tissues may bleach when stressed. In an anemone, the symbiotic algae provide much of the organism's colour, so the loss of the algae during bleaching means the anemone becomes white or translucent.