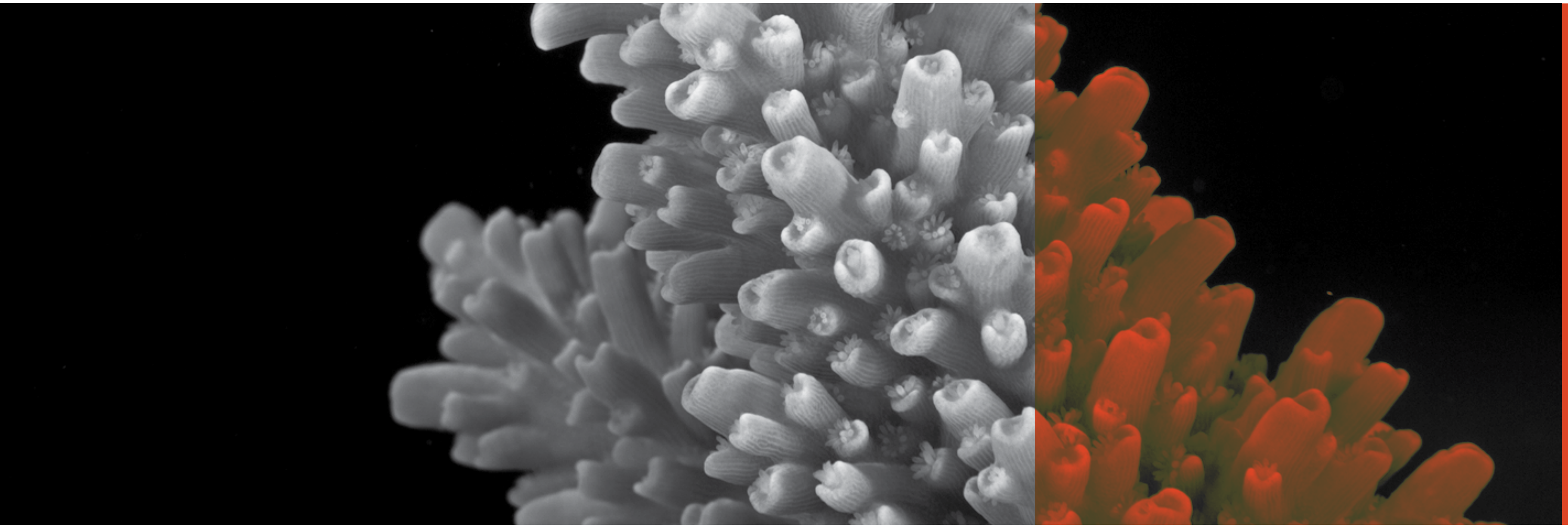
REEF MONITORING



Monitoring Corals

Permanent monitoring locations were established at Scott Reef in 1994 and have been revisited most years since then. At each location, researchers surveyed transect lines running through coral communities at multiple sites and depths. This massive scale of sampling in space and time enables accurate estimates of the condition of the reef.

Coral reefs are dynamic environments that regularly undergo cycles of disturbance and recovery. Depending on how frequent and severe those disturbances are, recovery can take just a few years, or more than a decade. Because these cycles of disturbance span years, long-term monitoring is needed to reveal whether reefs are on a path to recovery, or degradation. However, few studies have gathered the kind of long-term data that allows inferences to be made about the condition of coral communities. The monitoring program at Scott Reef has been one of the longest of its kind, and the invaluable information it has gathered helps clarify what effect our changing climate is having on coral reefs, particularly rising water temperatures and the accompanying mass coral bleaching events.

Monitoring in space and time

Monitoring programs on coral reefs are primarily designed to track their condition – determining whether communities of corals and other organisms are within a natural cycle of disturbance and recovery, or if disturbances have become so severe that they are causing actual reef declines.

Coral reefs can recover relatively quickly from natural regimes of disturbance, which may even increase the diversity of organisms living on the reef by reducing the abundance of coral species that would otherwise outcompete others. However, a consensus is emerging among scientists that human activities are dramatically increasing disturbances to coral reefs. This raises serious concerns as to whether these human impacts are compromising the resilience of reefs to natural disturbances. Will one of these compounded effects become 'the straw that breaks the camel's back' for reefs? The complexity of coral reef ecosystems means this is a difficult question to answer.

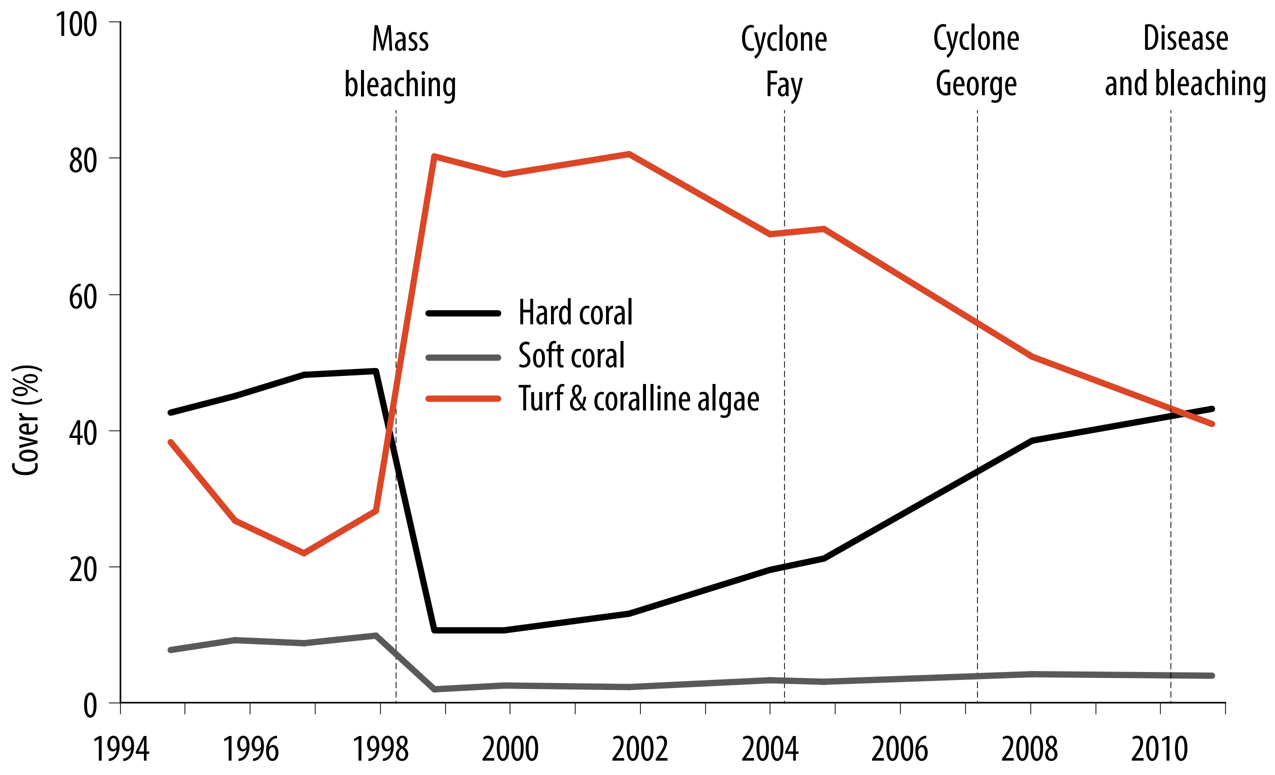
Cycles of disturbance and recovery vary from one coral reef to another, and even between different locations on the same reef. For this reason, a true understanding of the condition of a particular reef requires monitoring over many years at many locations.

Over almost 20 years, researchers at Scott Reef have resurveyed sections of the reef at varying depths and locations, along more than 10 kilometres of defined paths known as transect lines. During each survey, photographic records are taken along each transect and the organisms within each photograph identified. Over the course of the monitoring program this has amounted to around half a million records, providing a detailed description of the organisms present and how they vary through time, particularly in response to different disturbances.

Good times and bad

The most striking changes recorded during the long history of monitoring at Scott Reef followed the destruction caused by large disturbance events. Of even greater interest is how the reef has gradually recovered from these disturbances. Between 1994 and 2010, two events had particularly severe effects: a mass bleaching in 1998, and category 5 cyclone Fay in 2004. Others had moderate impacts: cyclone George in 2007, and the combination of a disease outbreak and bleaching event in 2010.

By far the worst of all these disturbances was the mass bleaching in 1998, which impacted all shallow water corals across the entire reef system. The subsequent disturbances were far less severe and more localised, usually having the effect of slowing the recovery from the 1998 event. The lingering effects of the mass bleaching are still evident today, and scientists have interpreted subsequent changes relative to that disturbance.



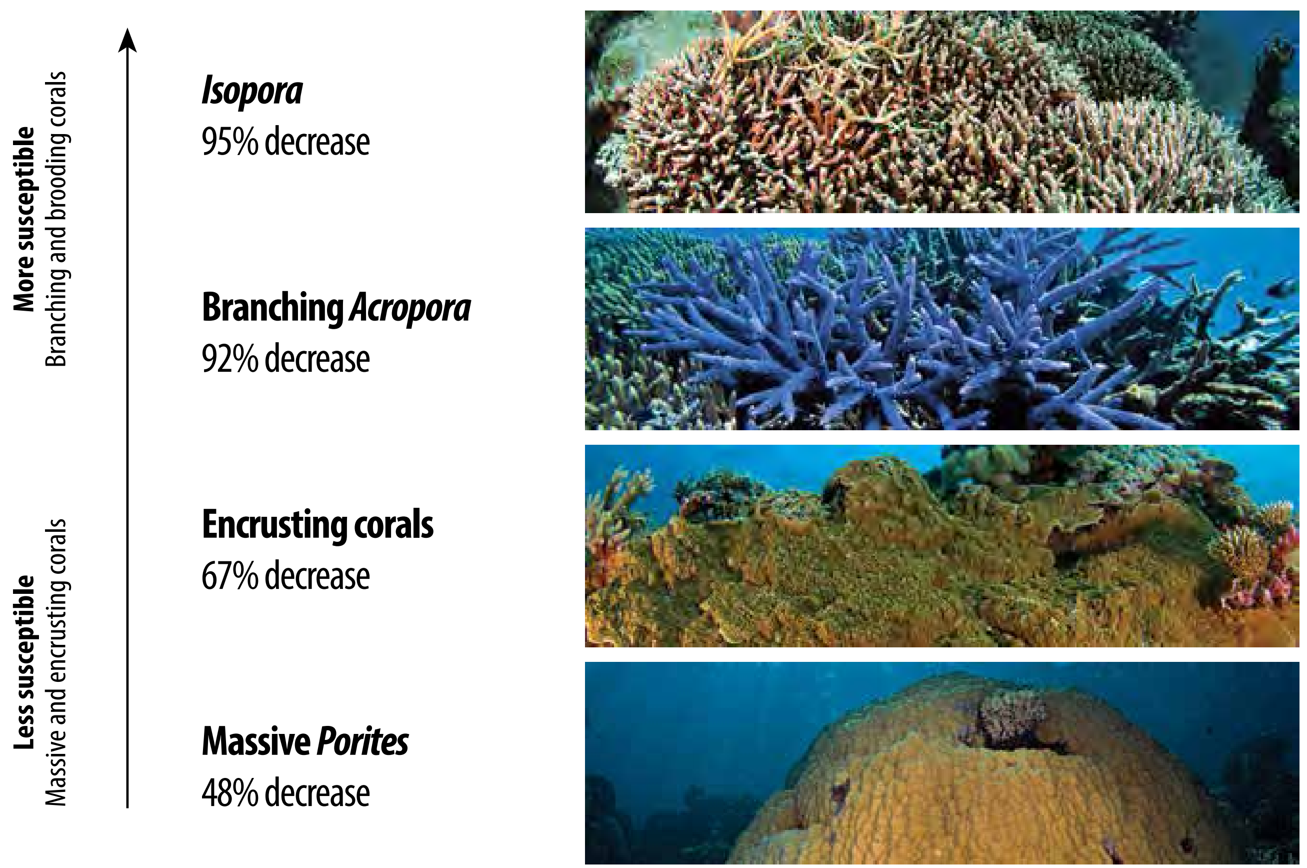
Communities of hard and soft corals at Scott Reef have been impacted by four major disturbances, of which the mass bleaching in 1998 was by far the worst. The high cover, particularly of branching corals, was dramatically reduced by this event and replaced by turf and coralline algae. A decade later, despite additional disturbances, the hard corals had largely recovered from the bleaching but the soft corals had returned to only half their previous cover.

In hot water

Before the 1998 bleaching there had not been a major disturbance at Scott Reef for more than a decade – the reef was densely covered in a highly diverse array of corals, including many large, old colonies.

However, in 1998 water temperatures became so extreme that most hard and soft corals across Scott Reef bleached and died, decreasing their cover by more than 80 per cent. The damage varied between locations on the reef, ranging from a 55 per cent to 95 per cent reduction in cover, depending on the maximum water temperatures and the number of susceptible corals. The cover of the most susceptible coral groups decreased by more than 90 per cent, these being corals with branching growth forms and those that reproduce by brooding larvae. In contrast, massive and encrusting corals were among those least affected by the bleaching, decreasing by around 50–75 per cent. The mortalities observed in all coral groups, even those best able to survive bleaching, gives an indication of just how severe this bleaching event was.

The reef surface that became available following the death of corals was quickly covered by coralline and turf algae. Importantly, however, it was not covered by macroalgae that can outcompete corals and also prevent them from recolonising.



Different groups of corals varied in their susceptibility to the mass bleaching at Scott Reef in 1998. Some groups decreased by more than 90 per cent, such as the brooding *Isopora* (top), while other groups decreased by less than 50 per cent, such as the massive *Porites* (bottom). Similar patterns of susceptibility to bleaching have been reported on other reefs around the world.

Recovery from bleaching

The mass bleaching in 1998 was so severe that scientists could see little evidence of recovery five years later. Some of the less susceptible corals had survived, albeit with injuries, and the regrowth of these corals contributed to small increases in coral cover. Recovery at some locations was also slowed by cyclone Fay in 2004. Despite its severity, cyclone Fay caused only small decreases in coral cover, because the most fragile corals were still rare. Nonetheless, many of the small recruits that had begun to recolonise the reef were killed, and some massive corals that had survived the 1998 bleaching event were damaged by the cyclone.

Ten years after the bleaching event increases in coral cover had accelerated, but at some locations this recovery had been slowed by yet another cyclone. Fortunately, the effects of cyclone George were far less severe than those of cyclone Fay three years earlier.

As the corals recolonised the reef, there were decreases in cover of coralline and turf algae, and a shift back to a pre-bleaching community was evident. Surveys conducted in 2010 showed that most communities had again become similar to their pre-bleaching state, although recovery at some locations was again slowed by further disturbances. An outbreak of disease and a moderate bleaching event in 2010 affected some corals and locations. The disease outbreak primarily affected table corals *(Acropora)* at two locations, whereas the bleaching mostly affected branching *Pocillopora* corals at a few locations.

Despite the additional disturbances, after 12 years the corals at Scott Reef had largely recovered from the mass bleaching. The diversity of coral genera and the average cover of hard corals had returned to their pre-bleaching level. The cover and types of corals at most locations were also similar to what had been observed before the disturbance, with some notable exceptions.

The puzzle of recovery

Determining whether coral communities at Scott Reef have fully recovered from the mass bleaching, or when they are likely to, is like solving a puzzle of many parts. The severity of the disturbance varied across the reef, depending on the water temperatures and the abundance of susceptible corals. Some locations were exposed to additional disturbances and their recovery was influenced by the rates of coral recruitment, growth and survival. All parts of this puzzle varied over space and time, and will continue to do so unpredictably into the future.

In this complex situation, researchers have contemplated what it means to say a reef has recovered from disturbance. Should coral cover at all locations on the reef be the same as before the disturbance? Should there be the same proportion of different types of corals at all locations? Although the coral cover and proportion of different corals at Scott Reef had mostly recovered by 2012, some variation existed between locations. Some coral communities recovered more fully than others, and these differences can be partly explained by both the life histories of the corals and their location on the reef.

Opposite page: In 1998, Scott Reef experienced high water temperatures that led to a widespread bleaching event. As the corals became stressed, they expelled the symbiotic algae from their tissue. With the loss of the algae that provide its colour, the coral appears white and 'bleached'. The mass bleaching in 1998 was catastrophic for Scott Reef, but a second bleaching in 2010 affected fewer corals.

Recovery and coral life histories

Corals have a range of different survival strategies and some are better equipped to deal with disturbances than others. Ten years after the mass bleaching, some corals may be considered winners, and others, losers.

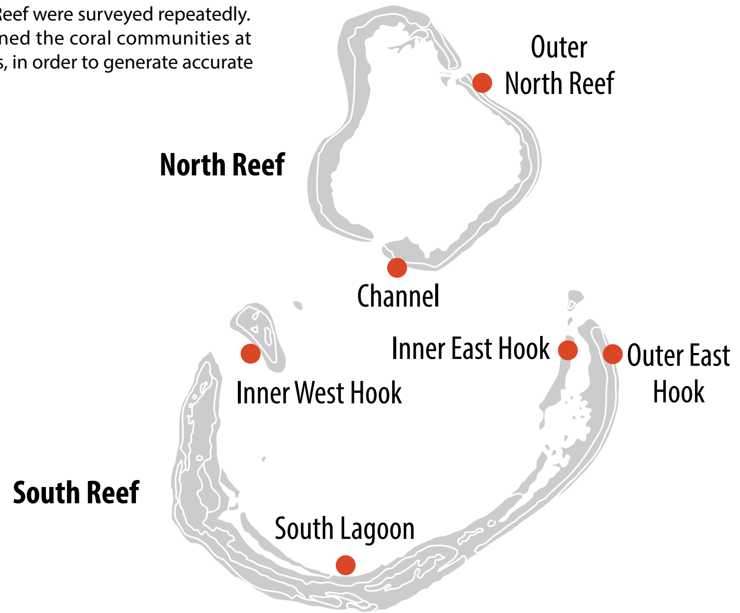
Taking advantage of space made by the damage to other corals, table corals *(Acropora)* were the winners. These corals were only moderately affected by the bleaching and the larvae produced by the survivors dispersed across the reef and were able to colonise newly available space. In this instance, communities that were least affected by the mass bleaching produced new recruits that aided the recovery of those worst affected. The table corals grew and matured rapidly, and were among the dominant corals a decade later.

Other groups of corals may be considered the losers – at some sites, soft corals and branching *Isopora* were less abundant than before the bleaching. This is partly due to the way these corals reproduce and recolonise the reef. The recovery of soft corals depended on the growth of local survivors and their colonisation of adjacent areas by colony growth and division. The recovery of branching *Isopora* at each location also depended on the local survivors, as the brooded larvae they produce disperse over short distances and colonise nearby areas. Consequently, the recovery of these corals was much slower at the locations worst affected by the mass bleaching, because it was not aided by the supply of larvae from the less-affected areas.

It is important to note that while some corals can be considered winners and others losers at a particular point in space and time after the mass bleaching, other patterns will continue to emerge. For example, the table corals that were so abundant at Scott Reef in 2008 were most severely affected by the outbreak of disease in 2010, and are among the most susceptible to future cyclone damage. It is exactly because coral communities are so dynamic that long-term data are needed to assess the ongoing changes in their condition.

The susceptibility of different groups of corals, and their modes of growth and reproduction, influenced the recovery of the reefs from the bleaching. Ten years later, table corals (opposite page) were the winners, having a much higher cover than before the bleaching – soft corals (below) were the losers, having around half the cover.

Monitoring locations across Scott Reef were surveyed repeatedly. At each location, scientists examined the coral communities at multiple sites, transects and depths, in order to generate accurate estimates of the reef's condition.



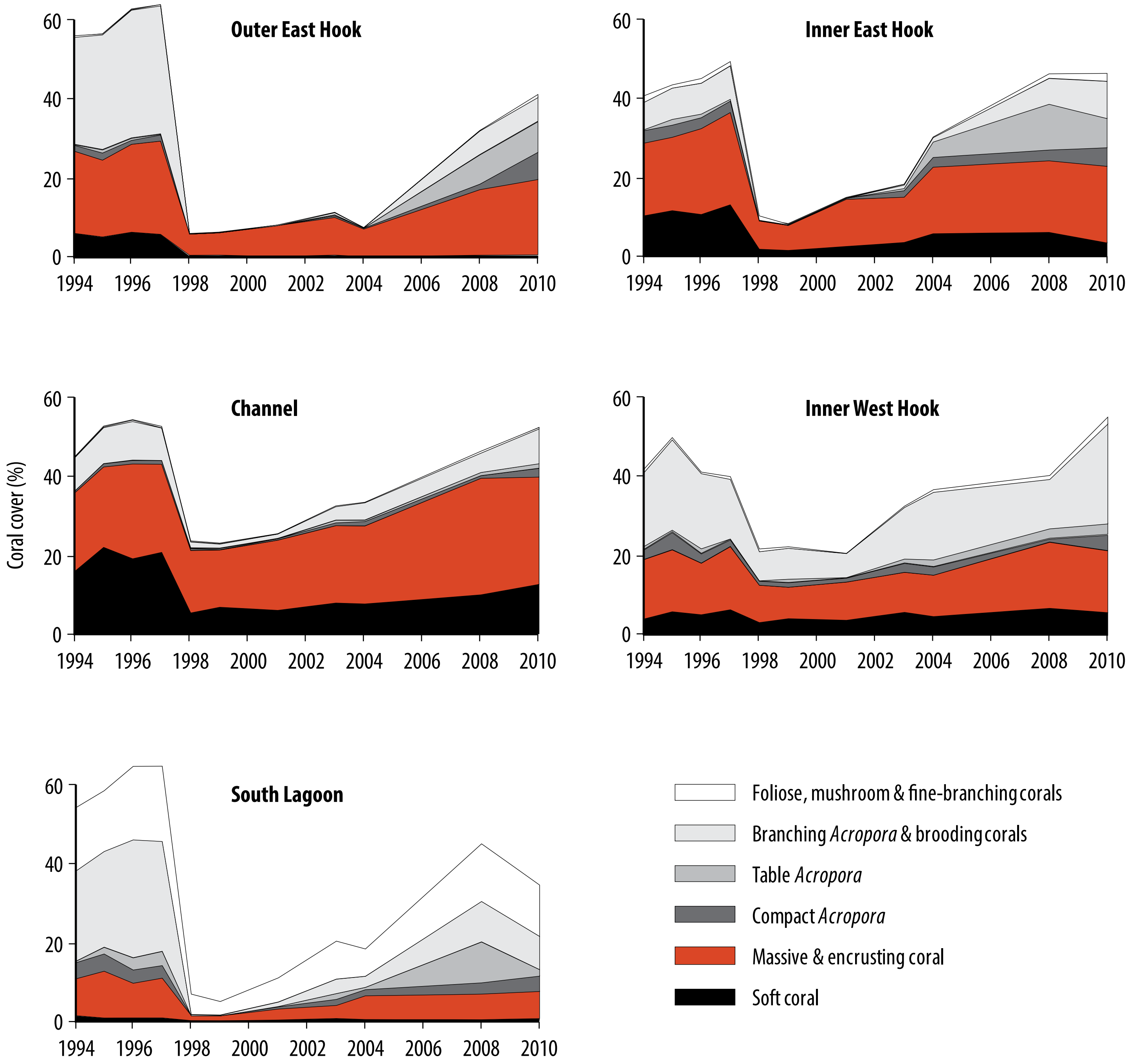
Recovery and coral locations

Each location around Scott Reef has distinct characteristics that have also influenced the recovery of coral communities from the mass bleaching. However, the conditions that favour one location in some situations can also leave its corals more vulnerable to other disturbances.

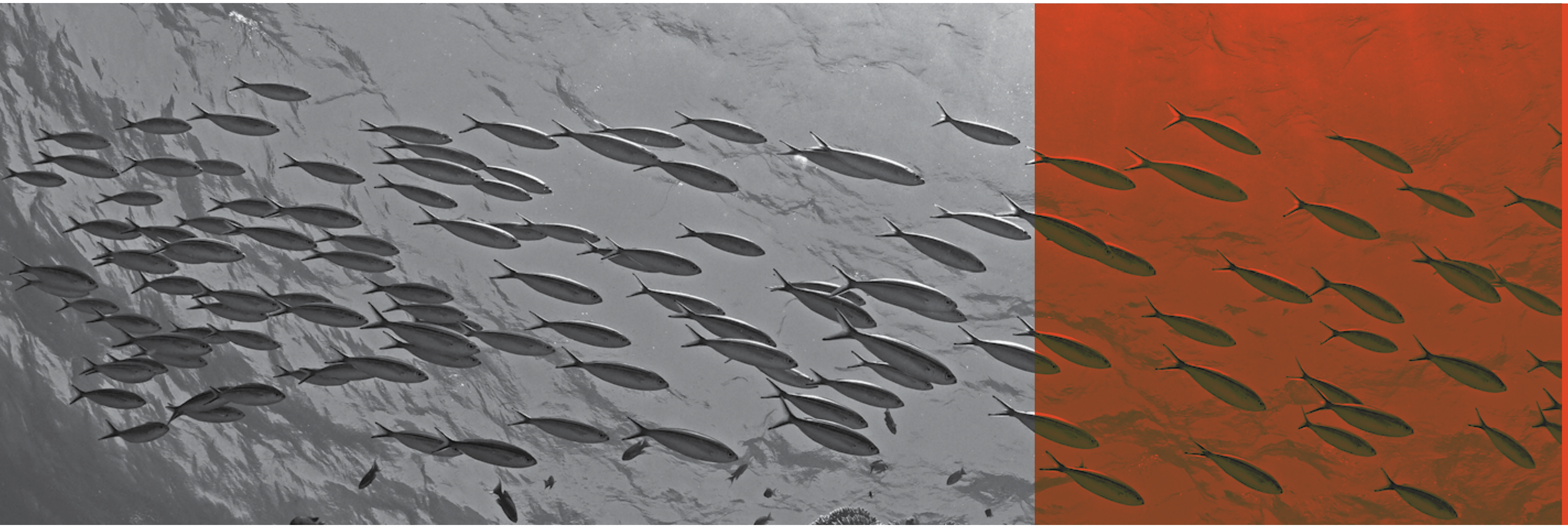
For example, the coral community at Inner West Hook was protected from the 1998 mass bleaching by the flow of cool water through the deep channel, but the location was also more exposed to large swells from passing cyclones. The opposite is true for corals in the southernmost part of the South Lagoon, which were sheltered from cyclone swells, but more susceptible to bleaching events and outbreaks of coral disease due to low water flow and higher turbidity.

The location of communities also influences the number of new coral recruits they receive and, therefore, their rates of recovery. Coral larvae are carried on currents before they settle onto the reef and grow into adults, so areas located in eddy systems can receive many new corals from upstream and recover faster. Researchers working at the reef found that the community at Inner East Hook received many coral recruits and recovered relatively quickly from the mass bleaching, whereas just a few kilometres away at Outer East Hook, coral larvae were carried away by the currents and this community was the slowest to recover.

The Scott Reef story is unique, and the long-term monitoring program documenting it is one of the few examining the recovery of an entire coral reef system from a catastrophic mass bleaching event. A shorter, less detailed study would not have captured the full cycle of impact and recovery, and would have been clouded by the variable recovery that occurs among locations. This research helps us to better understand the resilience of coral reefs to climate change, which is emerging as one of their biggest threats.



The coral communities at Scott Reef vary considerably among locations – some were hit badly by bleaching and cyclones, while others escaped more lightly. Some locations also recovered more rapidly than others, depending on the number of new corals arriving in that area in the years after the disturbance.



Monitoring Fishes

Slipping into the waters of Scott Reef, divers may find themselves surrounded by a flurry of activity. Larger fishes swim away quickly while dozens of smaller fishes shelter among the coral below. Descending deeper, divers observe brightly coloured butterflyfish and wrasse moving constantly across the reef. Massive parrotfish make scraping sounds as they bite off pieces of coral, while surgeonfish pick and scrape across algal mats. Predatory carnivores patrol in the distance as hundreds of small damselfish emerge and dart around before again sheltering among the corals.

The complex world of these reef fishes has been the subject of almost two decades of research. Scientists are now beginning to understand the changes within Scott Reef's fish communities, and how they are intrinsically linked to the corals that provide the fishes with food and shelter.

Discovering dependencies

Studying the many thousands of fishes that make their home among the corals and algae is an endeavour that requires great care and effort.

All researchers must first undergo dedicated training to standardise their identification of fish species and estimates of size and abundance, to minimise any biases among observers. At the reef, study sites must be approached carefully, so as not to disturb the fishes as they go about their daily activities.

The scientists swim through permanent sites replicated across Scott Reef. The large and mobile fish species are counted first before they swim away, and then the small, numerous species that shelter among the corals. These surveys have been repeated over many years, with hundreds of thousands of fishes counted and identified. When combined with the coral surveys at the same sites, these data provide new insights into the relationship between the corals and fishes at Scott Reef. It has long been known that corals are critical to the existence of reef fishes, but the extent to which these two groups of organisms influence each other, and the importance of fishes for the persistence of corals, has only recently been recognised.

Coral reefs are home to approximately one-quarter of all known marine fish species. They range from tiny blennies less than a centimetre long, which live in the sediment, to giant wrasse that roam across the reef. This diversity of fish life has traditionally been classified into taxonomic groups according to their physical features, such as body shape. However, as knowledge of their role in coral reef ecosystems has emerged, species of fish are also commonly classified into functional groups, which primarily reflect their feeding preferences. The abundance of these groups has important implications for the processes that maintain coral reefs. Indeed, functional groups of fishes are being used increasingly as one proxy for assessing the condition of coral reefs.

Studying the fish assemblages at Scott Reef involves identifying and counting a huge number and diversity of fish, ranging from the large mobile species such as the humphead wrasse (*Cheilinus undulatus*, pictured) to the smaller species that hide among the corals.

An incredible diversity of fish life exists on a coral reef. Fishes are traditionally classified into taxonomic groups according to evolutionary relationships and variations in body shape.

Functional fishes

Functional groups are used to classify fish species according to their role in the complex food web of the coral reef. Members of each functional group are specially adapted to feed in a certain way.

Carnivores feed mainly on fishes, crustaceans, molluscs and worms. Their different mouth types depend on their primary food source, ranging from the tiny razor sharp teeth of the lie-in-wait predators to the strong grinding plates of fish that consume hard-shelled molluscs. Carnivores occupy an influential place within the fish community – their removal allows prey to proliferate and can have flow-on effects to many other groups within the food chain.

Corallivores eat the tissue of hard and soft corals, and many have small mouths well suited to picking tiny coral polyps out of their skeletons. Their survival is directly linked to the abundance of corals, so they are a visible component of healthy reefs.

Herbivores bite off pieces of macroalgae or scrape away fine filaments of algae. They may have strong beak-like teeth adapted for scraping at hard surfaces. Herbivores play a critical role on coral reefs by controlling the amount of algae. When over-fishing reduces the numbers of herbivores, then algae can exclude and outcompete young corals – a situation that is difficult to reverse.

Detritivores feed on plant and animal material within the sediments and algal turfs common on coral reefs. Some have flexible teeth that comb through these algal turfs to sift out their food. By consuming detritus they recycle organic material on the reef and clear sediments from algal turfs for consumption by some herbivores.

Planktivores feed on tiny plankton in the water column, particularly small crustaceans. Planktivorous fishes are often brightly coloured and extremely abundant on the reefs, being an important food source for carnivorous fishes. Many coral reef fishes are planktivores during their larval stages, switching later to a different feeding mode.


Carnivores


Corallivores


Herbivores


Detritivores

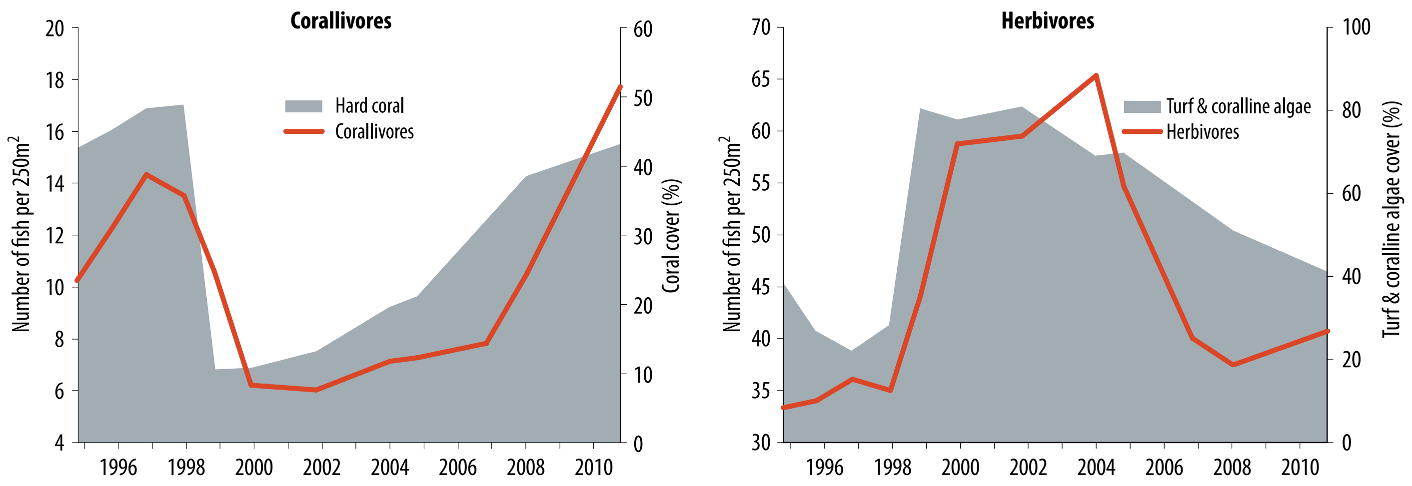

Planktivores

The effects of disturbance

The changes in community composition at Scott Reef, through a cycle of impact and recovery from mass bleaching, exemplify the close relationships that exist between corals and functional groups of fishes on the reef.

The effect of the mass bleaching event in 1998 was most striking on species that eat coral, such as butterflyfish. To a lesser extent, fishes that use coral for shelter, such as many damselfish, were also affected. In some instances, the relationships between the corals and fishes are quite specific. For example, decreases in the number of soft corals following the bleaching caused corresponding reductions in one species of butterflyfish *(Chaetodon melannotus)* – there were also comparable changes in a species of damselfish *(Chromis ternatensis)* and the branching *Isopora* coral within which it shelters. However, as the coral cover increased over the following decade so did the numbers of these species, along with other coral-dependent fishes.

For some fishes, the bleaching was a chance to prosper. The numbers of herbivores increased because dead coral skeletons were overgrown by algae – the abundance of detritivores also increased because they feed on the organisms within algal turfs and the sediment they trap. However, as the corals eventually recovered the cover of algae decreased, and there were corresponding reductions in the numbers of herbivores and detritivores.



Changes in the fish communities after the 1998 bleaching were closely linked to the fishes' food source. The number of corallivores (fish that eat coral) responded closely to changes in coral cover (left). For herbivores, changes in their algal food source corresponded to similar changes in numbers (right).

Monitoring Fishes

Vital herbivores

Another major theme in the study of fish communities at Scott Reef is the important role herbivorous fishes have played in aiding the recovery of corals following the 1998 bleaching event.

Numbers of herbivorous fishes increased sharply up to five years after the bleaching, controlling the cover of algae on the reef and maintaining space for coral larvae to recruit and grow to adulthood. In the absence of herbivores, this space may have otherwise been overgrown by algae, preventing corals from recolonising. The findings at Scott Reef support evidence gathered from many other studies around the world which shows that herbivores are vitally important to coral reefs.

The recovery of coral communities is thus tightly linked to the fish community. For Scott Reef to remain resilient to damaging events, it is important that all fishes, particularly herbivores, remain abundant within the ecosystem. In addition to protecting the reef from other pressures, ensuring that herbivores are not targeted by fishing is a vital step in safeguarding the future of the coral reef as a whole.