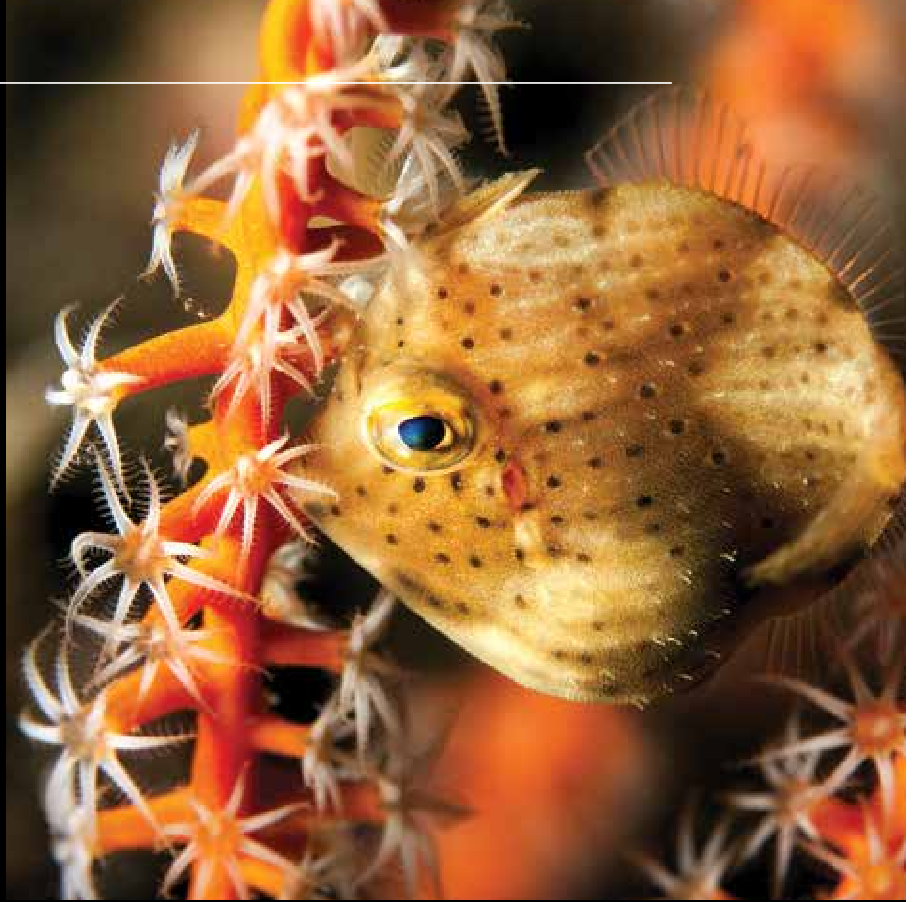
BIOLOGICAL COMMUNITIES

Biodiversity



Coral reefs contain a phenomenal diversity of organisms that are linked together in complex ways. Reefs with high biodiversity may be better able to adapt to changes in their environment, and may contain undiscovered resources.

From its wave-battered outer walls and sunny reef top, to the calm waters of its deep lagoon, Scott Reef is home to a vivid array of life. Surveying the reef, researchers have identified thousands of different species – glittering reef fish, multitudes of shrimp, snails and sea stars, sea urchins and seaweeds – each living within an ecosystem built by corals over hundreds of thousands of years. In turn, these crowds of smaller organisms attract larger animals such as sharks, whales, dolphins, turtles and seabirds.

Like all coral reefs, Scott Reef is an oasis of biodiversity in a vast, relatively unproductive ocean, offering a bountiful supply of food and shelter. Among the most diverse ecosystems on the planet, reefs are home to a quarter of all marine species. The location of Scott Reef adds another dimension to its biodiversity. Its formation near the edge of Australia's continental shelf and unique deep lagoon lend distinctiveness to the biological communities found at the reef.

Diversity and abundance

Biodiversity – the variety of life on Earth – is one of the wonders of our planet. Around the world, millions of different types of organisms inhabit a wide range of ecosystems. This diversity not only creates a beautiful environment, it is functional as well. In a biologically diverse, healthy ecosystem, everything is in balance. Species are inextricably linked and their interactions produce food, shelter and competition, all of which are necessary to maintain the balance and preserve life.

Ecosystems with a wide range of species have a greater capacity to adapt to environmental changes. That diversity also makes them critically important to humans, by harbouring the potential for undiscovered resources, such as medicinal compounds.

At Scott Reef, divers swimming through the clear waters of the shallows, or the deeper blue regions where the exposed edge of the reef drops away into the dark, are surrounded by a remarkable abundance of life. Rays of sunlight illuminate bright red sea fans, schools of darting blue and yellow reef fish, sea snakes, anemones and more. Surveys at Scott Reef have so far identified more than 1200 species of animals and 120 different algae, including more than two dozen species not yet identified anywhere else in Western Australia.

Guard crabs (*Trapezia* spp.) make their home among coral branches, where they are protected from predators. In return, the crab will fight off coral predators, such as the crown-of-thorns starfish. This relationship is just one example of the unexpected ways in which organisms interact to maintain coral reefs.

Reef builders

Scott Reef is made up of the skeletons of countless reef-building organisms that have accumulated over millions of years. Corals and coralline algae contribute their limestone skeletons to the solid reef matrix that forms the platform for the multitude of other species on the reef.

Ultimately, these reef-builders are responsible for harbouring the biodiversity of the entire ecosystem at Scott Reef. Corals are the primary source of food or shelter for many of the organisms on the reef, such as hundreds of species of fishes, crustaceans and echinoderms – many organisms make their homes by boring directly into the coral's skeleton, including sponges, molluscs and worms.

The corals on a reef also contribute indirectly to the lives of a much larger range of organisms – sometimes in hidden ways. For example, the surfaces of dead coral skeletons provide an ideal place for algae and sponges to attach and grow. These algae and sponges are then fed upon by fish and molluscs. When the coral dies, its skeleton will eventually crumble and become part of the sediment that sea slugs, snails and starfish feed upon, and that worms and crustaceans live within.

Many reef organisms that benefit from corals also contribute to the wellbeing of the reef in ways that we are only beginning to understand. Herbivorous fish consume the algae growing on the skeletons of dead corals, preventing it from proliferating and overgrowing live corals. Tiny crabs that live among coral branches fight off crown-of-thorns starfish that attempt to eat their host. The crustose coralline algae that grow over coral skeletons are in turn a favourite settlement surface for coral larvae, which then grow into adult corals. These complex interactions contribute to the cycle of life and death that maintains the ecosystem and its biodiversity.

Organisms not only find shelter among corals, but also within them. Christmas tree worms (a type of polychaete worm) create a burrow inside the coral's skeleton, into which they quickly retract if threatened.

From the largest to the smallest, a huge variety of marine life can be found at Scott Reef.
The largest animals, like the whale shark (above), are typically rare – while smaller creatures, including tiny sea squirts growing in colonies (opposite page), are found in far greater numbers.

Creatures large and small

Generally speaking, scientists have found that the diversity of Earth's ecosystems, Scott Reef included, can be thought of as taking the shape of a pyramid. At the base of the pyramid are large numbers of smaller species of plants, animals and other living things. As the organisms become larger toward the top of the pyramid, there tend to be fewer species, and fewer individuals of each species.

At Scott Reef, smaller species have populations numbering in the thousands, or more, but usually have very short life spans. Less abundant but equally important are the large animals, which may live for decades, or even centuries.

Although most sponges and corals are smaller and shorter-lived, some can grow to sizes of several metres across and live to be hundreds of years old. However, the turtles, dolphins, whale sharks and whales remain the largest animals found at Scott Reef.

Measuring diversity

To measure the diversity of life on the reef, researchers begin by dividing it into distinct habitats. At the simplest level, the reef can be divided into the protected waters inside the lagoons, the exposed reef flat on top of the barrier wall of the atoll, and the outside, exposed edge of the reef. But within each of these zones there are more subtle divisions based on physical characteristics, such as the depth of the water, whether the sea floor is made up of sand or rock, and so on.

Taking samples of the marine life from different reef zones allows researchers to build up a picture of overall diversity and abundance, and to find patterns in distribution. Perhaps the richest diversity at Scott Reef is found in the lagoon of South Reef. In particular, the transition zone between the reef flat and the deep lagoon offers protected waters and a variety of habitats that are home to an amazing array of species.

So far, studies at the reef have produced some impressive numbers. The diversity at the reef includes at least 300 scleractinian coral species in shallow water habitats alone, from almost 60 genera and 14 different families. When researchers surveyed Scott Reef, Seringapatam Reef and Mermaid Reef (Rowley Shoals) they recorded a total of 118 species of crustaceans, 339 molluscs, 52 echinoderms, 132 sponges, 461 fishes and six sea snakes. These surveys showed that some species were unique to only one of the reefs, including 79 of the 132 species of sponge. Not surprisingly, the measure of a reef's biodiversity depends on how much time scientists spend looking, and there are probably many unnamed species still to be discovered at Scott Reef, as well as at its neighbouring reef systems, where additional surveys are still required.

Life at Scott Reef does not end at the ocean floor. Living within the soft sand and sediment of the seafloor around the reef is a host of invertebrate organisms. In 2009, researchers surveyed the 'infauna' within the seafloor at 32 locations across the continental shelf, including deeper waters south and east of Scott Reef, and found 2250 different organisms. In some samples, there were up to 1800 individual organisms per square metre, although others contained far fewer. Overall, the most abundant animals were bristleworms, a class of worms found in oceans around the globe. Other animals included crabs and shrimps, ribbonworms, clams, sea urchins, snails, sea stars and flatworms.

As with many coral reefs, most biodiversity surveys at Scott Reef have been restricted to depths that are safe for diving, usually less than 15 metres, and some habitats and communities have not been surveyed extensively. There is undoubtedly a multitude of undescribed species at Scott Reef, particularly in the deeper-water habitats and in its unique southern lagoon, and the diversity of life at the reef is likely to be even richer than current estimates suggest.

The wider context

With the data that have been gathered so far, researchers estimate that Scott Reef sits in the middle of the biodiversity spectrum for coral reefs. It currently has a similar number of coral species to its neighbouring reefs in the region, but fewer than the 'Coral Triangle' – a centre of maximum marine biodiversity around Indonesia, Malaysia, the Philippines, Papua New Guinea and the Solomon Islands – where each ecological region has at least 500 coral species.

Generally speaking, overall biodiversity tends to decrease further away from the equator. Researchers have found that the distribution of species at Scott Reef is more closely related to the fauna of Indo-Pacific clear water region than to the more turbid inshore Kimberley region, which reinforces the importance of water clarity to the ecosystem.

Habitats

Coral reefs can take many forms, from fringing reefs near the shore to more isolated atoll systems. Although there are many similarities between reefs at the broader level, each also has its own unique characteristics, including the mix of distinct habitats it provides. Describing these habitats is a first step to understanding the ecology of the reef, but when these habitats span hundreds of square kilometres, this is no simple task. At Scott Reef, technological developments over the past 20 years have been combined with more traditional approaches to help map habitats, and to understand the relationship between their physical conditions and biological communities. This approach has identified many habitats that are typical of oceanic reefs, but also revealed some that are unique to Scott Reef.

Home is where the habitat is

A habitat is a home for a community of organisms, with a range of physical conditions that best suit its inhabitants. It is these conditions and the most abundant organisms that researchers primarily use to distinguish between habitats.

In general, coral reefs are found in shallow, tropical waters, where temperatures are warm and there is plenty of light – the most conspicuous organisms are the hard corals that form the reef structure. Within a coral reef, however, smaller variations in physical and biological characteristics create many different habitats. The type of material that makes up the sea floor, levels of sedimentation, and exposure to waves all vary from one part of the reef to another, and are examples of factors that determine the types of corals, fishes and other organisms that live in a given habitat.

Communities of plants and animals are often best adapted to the specific conditions within different habitats. In deep waters, for example, only those species adapted to growing in low light conditions will survive. So deep water corals grow in a fragile spreading form that maximises light absorption. Conversely, in the shallows, corals are exposed to strong currents and waves, so a delicate skeleton may often be damaged, and is unnecessary, as light is readily available.

As well as being influenced by physical conditions, the species within a particular habitat are also affected by the dominant organisms. Some of the best-adapted, and therefore most abundant, organisms within a habitat facilitate the existence of others. The co-existence of corals and fishes is a prime example – the branching corals that characterise some reef habitats provide shelter for many small fishes, which in turn are a source of food for predators. So, when defining a habitat, it is important to first document the dominant organisms as these can provide valuable information about the wider biological community.

Broad habitat categories rarely reflect all the variation across a reef. The incredible diversity on a coral reef – both physically and biologically – means that there are in fact many different habitats that are rarely uniform throughout. With more detailed information, additional categories can be added to define habitat types at ever-finer scales. Eventually, however, these categories can become so specific that they are based on a single type of coral, or a particular species of algae, and their application to mapping large areas of the reef becomes logistically impractical. This poses a considerable challenge to researchers – at what level should habitats be distinguished, and how can they be most simply defined?

Describing habitats

Describing habitats is a painstaking task. Even the most basic habitat descriptions usually involve measuring many physical conditions, such as temperature, salinity, light, nutrients, turbidity, sedimentation, currents and wave energy; as well as a range of biological components, the abundance and diversity of many different groups of corals, algae and fishes must be described. The abundance estimates are important because they determine which organisms are most typical of the habitat and may be critical to its existence, while diversity estimates identify rare or endemic species.

Given the effort required to describe habitats in detail, researchers aim to identify a few components that can reliably predict the presence of others. For example, combinations of depth, light and seafloor might predict the most common types of corals – and in turn, certain assemblages of hard corals might predict the presence of algae, fish and other corals. The ability to use certain habitat features to predict others requires a good understanding of why organisms are found in different habitats, which comes from the detailed studies of their biology and ecology. This combination of information may ultimately enable entire reefs to be mapped by measuring a subset of predictive components.

The 'rugosity' of the seafloor – its texture and three-dimensional complexity – is an important predictive component used by scientists to determine the habitats found in that area. Sand, rock and different types of coral all vary in rugosity, and detailed mapping of the sea floor provides accurate predictions about the organisms present at any place on the reef.

At Scott Reef, researchers combined a range of techniques to create a picture of the reef's habitats. From a beginning with only basic knowledge of water depths, developments in technology are now helping scientists to predict habitat types more and more accurately.

Bathymetry

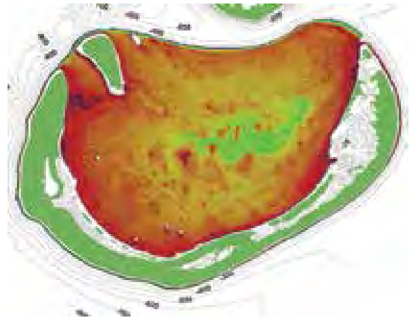
Measurements of the depth of water on and around coral reefs – known as bathymetry – have been collected for hundreds of years, and are among the most reliable predictors of habitat type. Variation in depth on a reef influences a range of other important physical conditions, such as temperature, light, currents and wave exposure, which in turn affect the biological communities.

Satellite photography

Satellite images were first produced in 1959 and today are available in very high resolution, showing features less than one metre in diameter. These images provide a more detailed representation of the structure of the reef, helping to distinguish the boundaries between some important physical and biological characteristics. For example, shallow patches of sand and coral outcrops can be distinguished throughout the shallow lagoon waters.

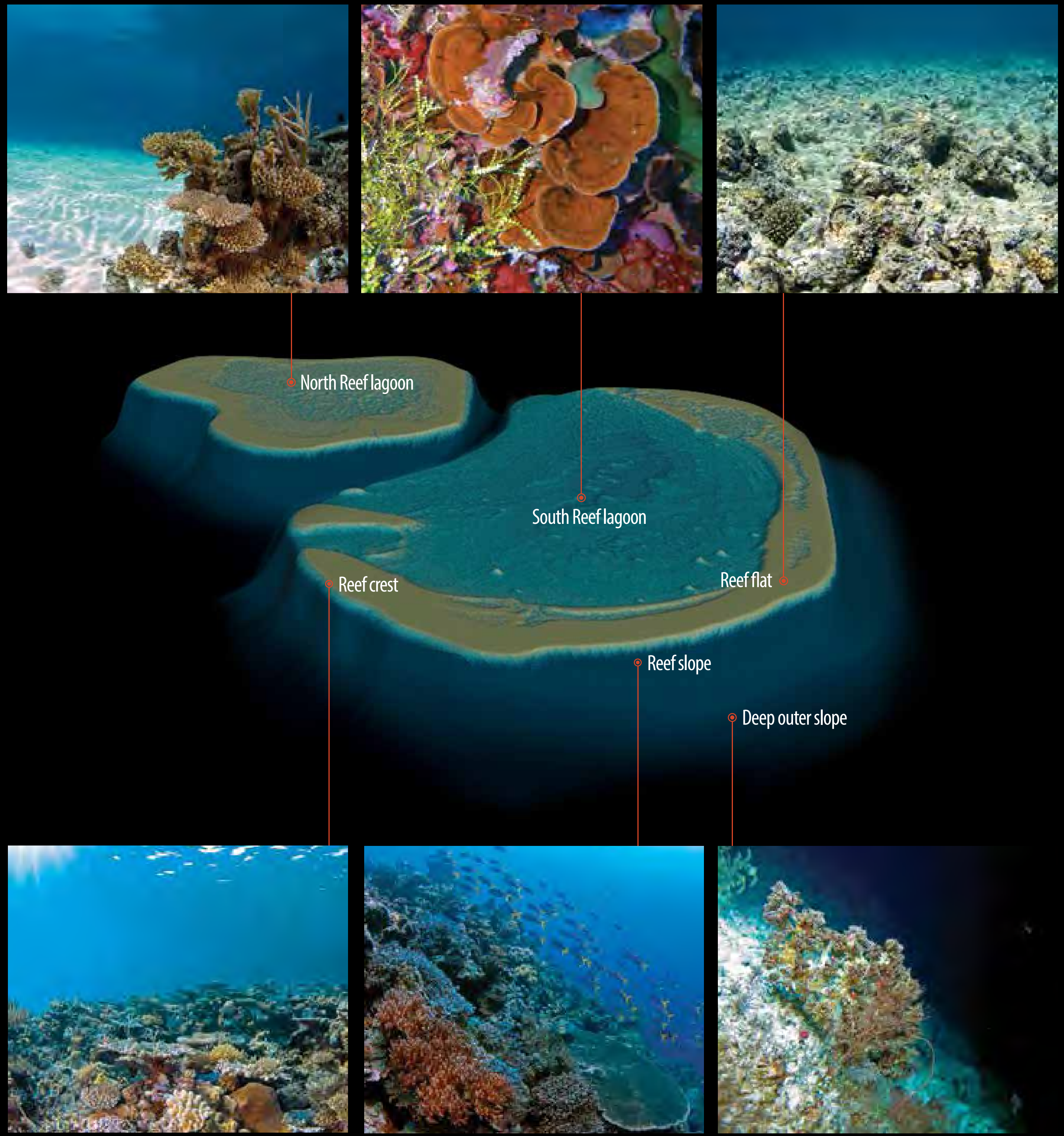
'Ground-truthing' habitat types

Once broad habitats are distinguished, their structure and biological communities must undergo ground-truthing – a process of verifying the classifications using a range of visual techniques. In 2006, researchers created a habitat map for Scott Reef by focusing on particular areas within general habitats. In the shallow waters, divers used photographs and video footage to describe in detail the type and structure of the seafloor, and the biological communities. Over larger distances and in deeper water, drop-cameras and towed-video were used to describe habitats. These data were then overlayed on to a map of existing physical data.



Predicting habitat types

In recent years, technological advances have greatly improved the ability to distinguish habitats over large areas by describing variation in a few important predictors. Technologies such as LiDAR (Light Detection and Ranging), which uses pulses of light, and multibeam sonar, which transmits a broad beam of acoustic signals, provide information about the communities on the seafloor. These data are compared to the detailed descriptions obtained in visual surveys, to determine their predictive capacity. Once refined, this approach may enable rapid habitat mapping over large areas, needing only a small area to be ground-truthed using detailed visual surveys.



Habitat divisions

Like most coral reefs, Scott Reef can be broadly divided into four main habitat types: the lagoon, reef flat, reef crest and reef slope. The lagoon is mostly enclosed by the reef and sheltered from large waves. The reef flat is the shallowest part of the reef structure, being exposed at low tide, and separates the lagoon from the reef slope. Where the reef flat reaches a peak and begins to slope away, it forms the reef crest. As this slope continues downward, the habitat continues to change – this area is referred to as the reef slope. Reef slopes form the edges of the entire reef structure and usually have the highest cover and diversity of corals. At Scott Reef, some of these general habitats are further distinguished by whether they are found in deep water, or located on the sheltered or exposed edges of the reef.

Reef flat

In the shallowest waters of Scott Reef, organisms living attached to the reef flat can be periodically exposed to the air, and more commonly endure high water temperatures and wave energy. Consequently, few corals survive in this habitat, and those that do are generally small and robust. In comparison to other habitats, there is generally a lower cover of corals on the reef flat and a comparatively higher cover of other organisms, such as algae and sea squirts.

Reef crest

The reef crest contains a combination of organisms found in the reef flat and reef slope. It can be the first point of contact for waves crashing onto the reef, and the corals have robust growth forms. Some tightly branching colonies are also found at the reef crest, but there are rarely large branching corals, whose growth forms are among the most vulnerable to wave energy.

Reef slope

As the reef slopes away into deeper waters, corals become more diverse and abundant. The ideal conditions for corals are found in the reef slope habitat, from a few metres down to approximately 20 metres depth. Here there is plenty of sunlight for photosynthesis and growth, while extremes in water temperature and wave energy generally do not penetrate below the first few metres. The cover and diversity of corals, fishes, sponges, algae, and many other coral reef organisms are often highest in this reef slope habitat.

The reef slope continues well below 20 metres, but around this depth there is a noticeable change in the biological communities that are present. Light becomes limited in the deep reef slope, so the cover and diversity of corals, and other organisms that rely on light, decreases. Indeed, the communities become sparser and there tends to be a higher concentration of organisms that obtain their nutrition by filtering particles out of the water, including sponges and sea whips.

Deep outer slope

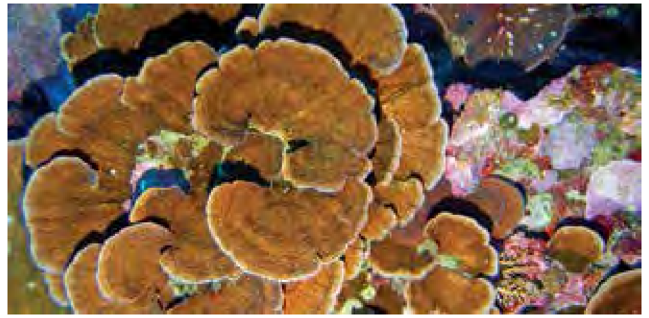
The outer slope of Scott Reef extends to depths of hundreds of metres. In depths of up to 300 metres, areas surrounding the reef continue to slope away, and present an entirely different habitat to the shallower areas of Scott Reef. Here, animals such as sea whips, worms, snails, sea stars and anemones live on, or burrow into, the sea bed.

Sheltered waters

Within a lagoon, the waters are calm and sheltered from the open ocean. But at Scott Reef, the shallow, enclosed waters of the North Reef lagoon contain a range of habitats that are very different to those seen in the deeper, more open lagoon of the South Reef.

North Reef lagoon

The lagoon inside North Reef has a maximum depth of 20 metres, but is generally much shallower. The plants and animals living within this habitat are sheltered from storms, but may be susceptible to the effects of high water temperatures. Little water is exchanged with the open ocean, which might also result in increased risk of disease outbreaks, particularly among corals.



South Reef lagoon

The deep lagoon within the horseshoe-shaped South Reef contains unique habitats. It covers approximately 280 square kilometres and provides corals with an entirely different set of physical variables than the shallow water environments. Corals in the deep water are less affected by temperature stress and wave energy, but they have very little light available for nutrition and growth – these communities are therefore far more susceptible to decreases in water clarity than those in the shallows.

Next steps

A phenomenal diversity of organisms live in each of the many habitats found at Scott Reef – from the worms and urchins found on the sandy seafloor in hundreds of metres of water, to sea squirts and algae that survive extreme temperatures, waves and periodic exposure on the reef flat. Each group of organisms is adapted to deal with the diverse conditions typical of each habitat. Among all these habitats, the shallow reef slope has the most abundant coral communities, but the habitats in the deep southern lagoon are unique.

After years of work, researchers now have a clear understanding of the different habitats at Scott Reef, and how physical and biological characteristics vary among them. Defining these communities has required considerable effort and utilised a range of different methods and technologies, and the knowledge gained from this research will make future efforts to map coral reef habitats far easier. The next step is to gain a better understanding of the characteristics that are most critical to the existence of each habitat, and how they can be used to predict the distribution of biological communities at Scott Reef and other reefs throughout the region.

Deep Water Communities

Scientists used ROVs to explore and sample the communities in the deep waters of South Reef's lagoon.

Of all Scott Reef's remarkable communities, perhaps the most intriguing are those that endure in the depths of its semi-enclosed south lagoon. Reaching depths of up to 70 metres, the sheltered expanse of crystal clear water in the lagoon at South Reef covers an area of more than 280 square kilometres. Historically, the sheer depth of these waters limited the amount of research that could be carried out in this part of the reef – much of it simply lay beyond the reach of researchers using SCUBA. In recent years, scientists have taken advantage of developments in remote technologies to survey these deep communities using cameras and remotely operated vehicles (ROVs). These studies have led to some remarkable discoveries about the extensive coral communities in the deep lagoon and how they adapt to living in the low light, low nutrient conditions.

A diverse ecosystem

When researchers sent cameras and ROVs into the depths of the South Reef lagoon they revealed a diverse community of hard and soft corals, sponges, algae, urchins and other organisms that covered much of the sea floor.

Down to depths of 60 metres, leaf-shaped foliaceous corals are the dominant growth form. Encrusting corals and branching *Acropora* corals are also widely distributed, albeit less densely than the foliaceous varieties, along with the bright green calcareous algae *Halimeda*, deep-red coralline algae, assorted sponges and high densities of soft corals, in different parts of the lagoon. Over 51 species of hard corals alone have been identified, many of which are also found in the shallows. However, in the shallows these species do not usually occur in high numbers, and often live in caves or under ledges, in low light and low current conditions similar to those in the depths.

Coral nutrition

Corals are unique among animals – reef-builders that gain much of their energy from sunlight. To obtain energy from light, corals host tiny, single-celled algae within their tissues, which contain light-harvesting pigments known as chlorophyll. These algae are from the genus *Symbiodinium* and they transfer the products of photosynthesis to their host, the coral.

In exchange for providing nutrition to the coral, the algae are provided a safe place to live and utilise the waste products of the corals for their own nutrition – this relationship is a true symbiosis that benefits both organisms. Maintaining this symbiosis is paramount to the health of the coral – if the environment changes and the algae are expelled, then the coral bleaches and may well die. The needs of the symbiotic algae often determine the ability of corals to withstand environmental stresses.

For reef-building corals to exist at a wide range of depths – from 0 to 100 metres – the symbiotic relationship must adapt to large differences in the amount of available light. Scientists have discovered different types of algae within a single species of coral, which may be important in allowing corals to live in diverse environments. Also, the number of algal cells, the amount of photosynthetic pigment in each cell, and the metabolic rate of the coral, can all be adapted to the different environments in deep and shallow waters. These adaptations may assist corals to live in a wide range of environmental conditions.

In the majority of cases, corals rely on sunlight for much of their nutrition. The symbiotic algae that live within their tissues use the light through photosynthesis to provide energy to the corals, in the form of carbohydrates. However, there is much less light available at the bottom of Scott Reef's lagoon than in shallower waters. Researchers calculated that just one per cent of the light available to support coral growth at the water's surface penetrates to the depths of the lagoon. How then are corals able to obtain enough food to build and sustain these abundant, diverse deep water communities?

Corals can also gain nutrition by feeding on particles they capture with their tentacles. For the majority of corals, this only makes a small contribution to their energy supply, but researchers hypothesised that given the lack of light, this type of feeding might be more important to the deep water corals. One theory held that nutrient-rich water entering the lagoon through the deep channel could cause plankton blooms, which would then sink to the deep water corals as a 'rain of food'. Yet investigations of this theory determined it was not the case. Most of the nutrients were rapidly cycled while still in the water column by tiny planktonic organisms, with very little reaching the lagoon floor to feed corals.

So, the deep corals must still rely on energy produced by photosynthesis within their symbiotic algae. Investigations then turned to other adaptations that allow the deep water corals to survive in the low light conditions available at these depths.

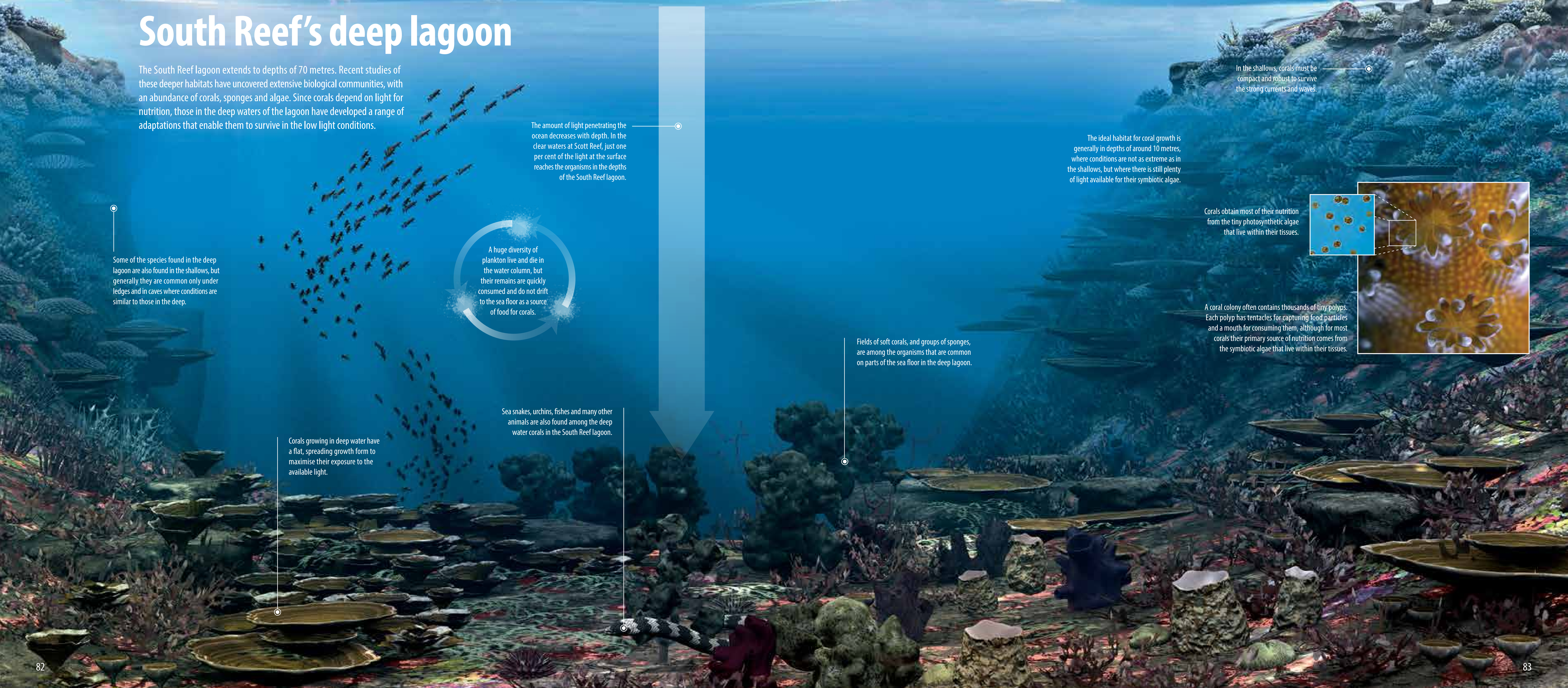
Researchers discovered extensive coral communities surviving to depths of 60 metres in the South Reef lagoon. The foliaceous corals were the most abundant, although corals with branching, massive or encrusting growth forms were also common. Regardless of their exact shape, all the corals growing in the depths had a spreading growth form that maximised their exposure to the available light.

Although corals typically receive much of their nutrition from the tiny symbiotic algae living within their tissues, they can also capture particles of food with their tentacles.

Deep Water Communities

South Reef's deep lagoon

The South Reef lagoon extends to depths of 70 metres. Recent studies of these deeper habitats have uncovered extensive biological communities, with an abundance of corals, sponges and algae. Since corals depend on light for nutrition, those in the deep waters of the lagoon have developed a range of adaptations that enable them to survive in the low light conditions.



Adapted for the depths

After conducting detailed investigations into the physiology of corals living in deep water communities, researchers found evidence of multiple adaptations to the darker habitat – at a range of scales.

The most obvious adaptation is the flat, spreading growth form adopted by many of the deep corals, a shape that maximises the amount of the colony's surface exposed to light. In the shallows, strong waves or currents would easily break this delicate growth form, but in the deep these forces are far less powerful.

The other adaptations are less obvious and more complex. Within the colony, the mechanisms by which corals and their symbiotic algae harvest light and convert it to energy are also adapted to the deep environment. For some coral species, the types of algae change with depth, while in other instances the density and efficiency of the photosynthetic pigments within the algae are adapted to maximise energy provided to the coral.

In general, corals may possess efficient and flexible strategies that allow them to adapt to high or low light environments – strategies that are primarily based on their vital relationship with the tiny symbiotic algae that live within them.

Even so, with increasing depth corals will eventually become limited by light. The deep corals in South Reef lagoon are near their limit of adaptability and any addition of suspended matter that further reduces light penetration may also reduce their growth and survival. As such, high water clarity is vital to the persistence of these unique communities.

Clear, clean water at Scott Reef allows light to penetrate to the deepest parts of the South Reef lagoon. This excellent water quality is critical to the survival of the unique, deep water coral communities.