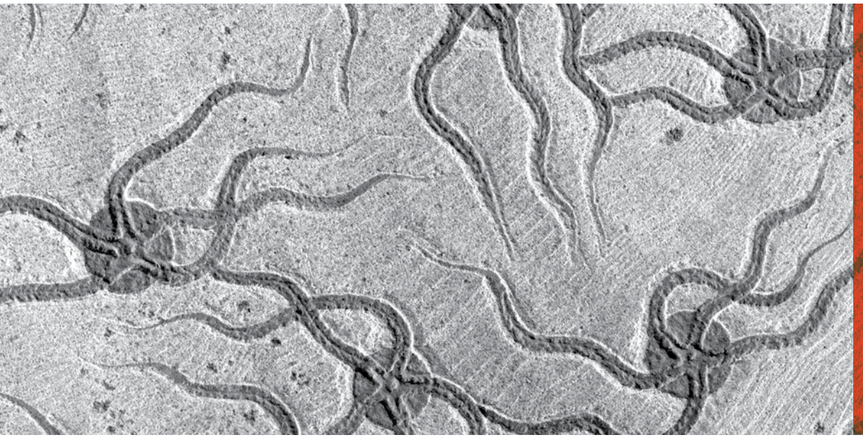
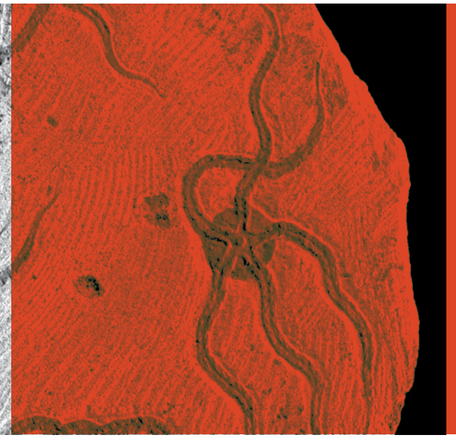
PAST AND PRESENT





Geological History

Ammonites were found in the oceans until 65 million years ago and were present when natural gas was forming in the region around Scott Reef.

The story of Scott Reef began many millions of years ago, with the geological processes that slowly formed the reef's foundations, and then the reef itself. Many changes to the planet have occurred during this time – continents have drifted, sea levels have risen and fallen, new species have evolved and others have become extinct. Since the reef formed, it has experienced times of being exposed by low sea levels, and times of growth to keep up with rising sea level. Examining the history of Scott Reef over geological timescales has provided scientists with an important understanding of how the reef responds to changing sea level and different climates.

Living on the edge

Scott Reef rises from depths of up to 800 metres on Australia's continental slope, some 270 kilometres off the current coast of north-western Australia. Seen from the air, it is made up of two large adjacent reefs. The pear-shaped North Reef is a continuous loop, broken only by two narrow passages, while the horseshoe of South Reef is open to the north. A channel, two kilometres wide and up to 700 metres deep, runs between them. To the north-east, about 30 kilometres away, is the smaller circlet of Seringapatam Reef, whose narrow reef rim surrounds a lagoon approximately nine kilometres across.

The reefs are atolls – coral reefs that enclose lagoons. Millions of years ago, they began to develop at a high point of the subsiding continental slope. As the sea floor slowly sank, coral and other marine organisms built up layers of reef. Today, the surrounding sea floor is deep underwater, but the coral reef continues to grow and change. Exploratory wells drilled more than 4700 metres into the rocks below Scott Reef reveal a sedimentary history dating back to the Late Triassic period some 220 million years ago.

Hydrocarbon formation

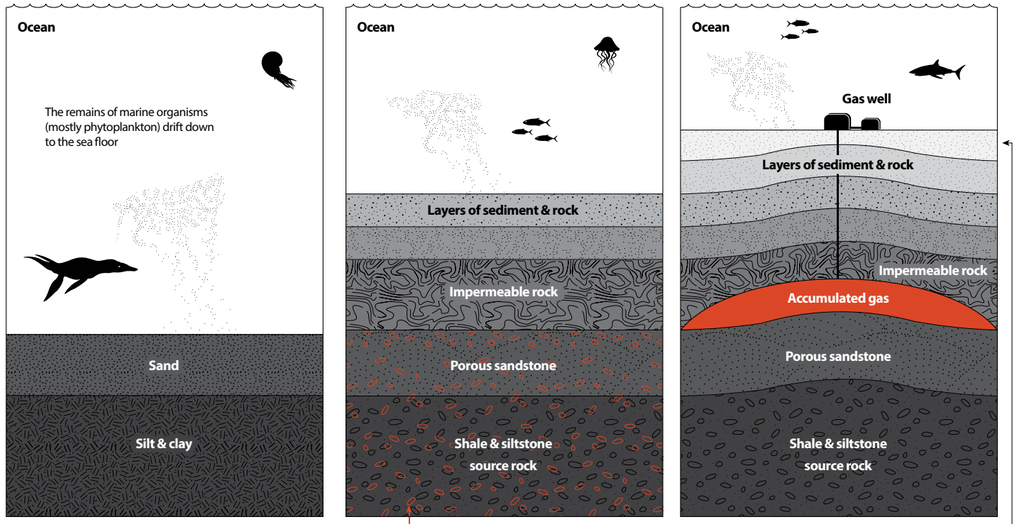
Two hundred million years ago, at the start of the Jurassic period and long before the reef itself existed, the area where Scott Reef is now was a broad flat plain near the northern edge of the ancient supercontinent of Gondwana. The landmass that is now India lay to the south-west, with an ocean to the north-west and north. Geological processes – which would ultimately lead to the breakup of Gondwana, with the opening of the Indian Ocean and the separation of what would become India and Australia – started to stretch this part of the Earth's crust.

Gradually, the sea encroached onto the ancient plain. Sand and silt carried by rivers were deposited in this shallow sea. The remains of many marine plants and animals, particularly tiny single-celled plankton, also drifted down to the sea floor. These sediments, and the organic matter they contained, were then buried by additional layers of sediment that accumulated above them. Eventually, compressed by the weight of the overlying sediment, they became sedimentary rock.

The thick band of sediment and rock overlying the organic-rich Jurassic rocks acted as a blanket, holding in heat that flows continuously from the interior of the Earth. Over time, this heat transformed the organic matter into hydrocarbon compounds – the components of natural gas. The hydrocarbon molecules, squeezed by immense pressure out of the shale and claystone 'source rocks' into porous rocks (such as sandstone), percolated upwards through the tiny pore spaces between the sediment grains until they encountered an impermeable rock layer. If the structural form of the impermeable layer was right, the trapped hydrocarbon molecules may have travelled large distances until they accumulated to form concentrated deposits of oil or gas.

At Scott Reef, the natural gas accumulation is located about four kilometres below the seabed, at temperatures of nearly 200 degrees Celsius, and is made up of gas molecules that formed 50 to 100 kilometres away.

Hydrocarbon formation beneath Scott Reef began 200 million years ago – long before the reef existed. An accumulation of natural gas now sits four kilometres below the sea bed.



A reef is born

The first tropical coral reef structures in the area we know today as Scott Reef began to form about 15 million years ago, during the Middle Miocene period. This was a time of relatively warm global climates and the oceans were home to a great diversity of cetaceans – the relatives of modern day whales and dolphins. The ancestors of many forms of marine life, including the reef-building corals, were also present.

Scientists have discovered evidence of these reefs within layers of rock now hundreds of metres below sea level. By the end of the Middle Miocene, a barrier reef, atolls and patch reefs existed along the continental margin near Scott Reef. However, by 10 million years ago, many of these reefs had become extinct, drowned by rising sea levels. The cooling climate may have reduced the growth rate of corals and other reef-forming organisms, which failed to match the rising sea level. Many ancient reefs were simply too far underwater for corals and other light-dependent organisms to survive.

In addition to the changing sea level, the edge of the continental shelf was also beginning to subside, carried deeper by the shifting of the continents. The reef continues to subside today, at around 30–40 centimetres every thousand years – a rate that is easily matched by the growth of this healthy coral reef.

Today, Scott and Seringapatam Reefs are the only atolls that remain in the area, having survived many changes in sea level and ongoing subsidence of the continental shelf. They are one of three oceanic reef systems in the wider region, the others being the reefs of the Rowley Shoals to the south, and the Ashmore Reef system to the north.

Reef growth

Like all coral reefs, Scott Reef is built from the skeletons of a range of plants and animals, predominantly hard (scleractinian) corals and plants such as calcareous algae. The hard calcium carbonate skeletons these organisms produce remain behind long after they have died.

Corals are the best-known reef-building organisms, although their biological characteristics are not always easily understood. The organism we recognise as a coral is, in fact, thousands of tiny individual polyps, similar to sea anemones. The polyps grow together in a colony, building a hard skeleton around themselves. To survive and grow, reef-building corals rely on tiny symbiotic algae that live within their tissues and convert sunlight into energy.

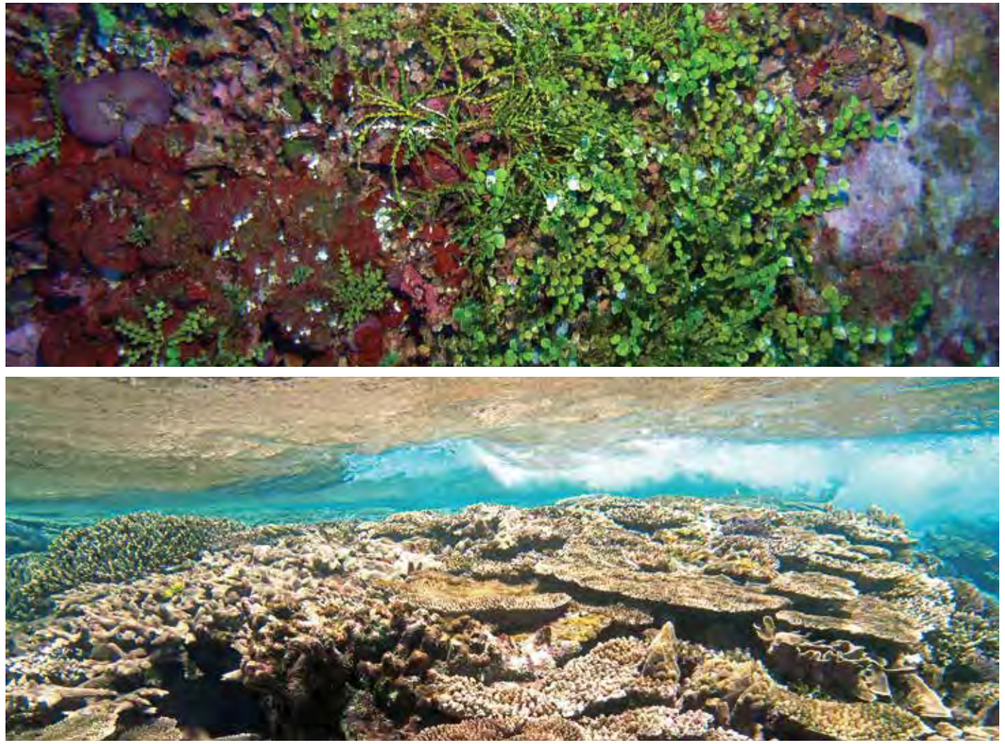
As each generation of coral dies, its remains contribute to the growing reef structure, forming a limestone base upon which new generations grow. This layering process allows reefs to keep pace with changes in sea levels that occur over thousands of years, remaining near the ocean's surface where there is plenty of sunlight.

By extracting long cores from the reef and examining the layers within them, scientists have investigated Scott Reef's growth more closely. The cores have revealed that during the past 400,000 years the reef has gone through five significant phases of reef growth, each 30–40 metres thick, responding to rising sea levels during periods when the Earth's climate was warmer.

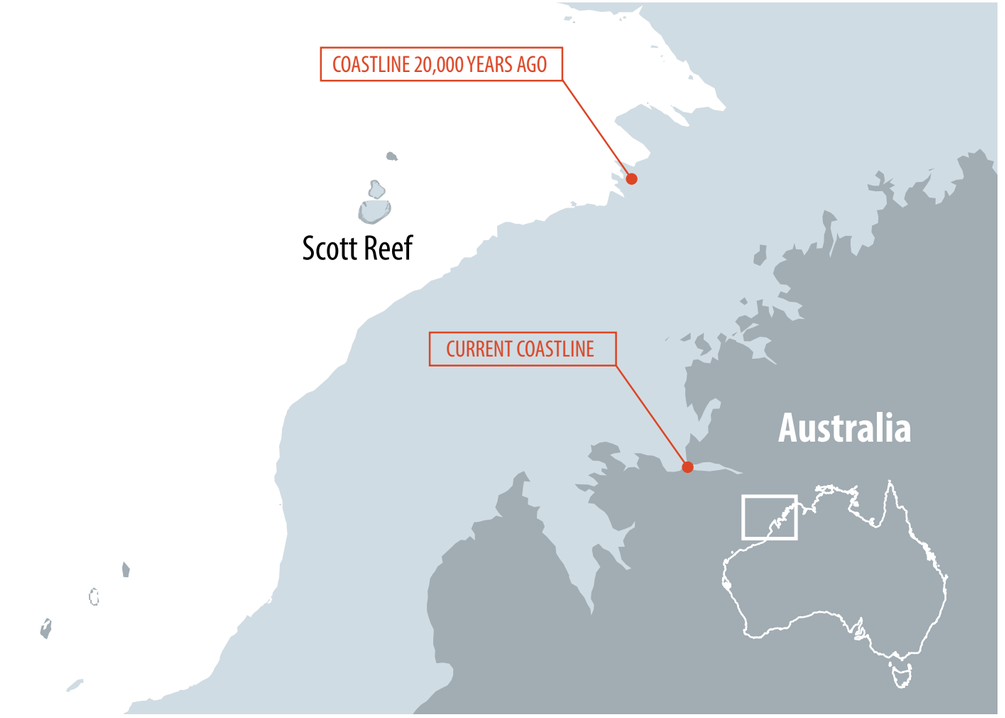
During colder, glacial periods in the Earth's climate history, when ocean levels were lower, the surface of the reef platform was exposed above water. In fact, for thousands of years the reef was a steep-sided rocky island, standing between 50 and 125 metres above the sea. Researchers have found evidence of these times – thin layers of hard, cemented limestone that formed over the reef, along with a pause in coral growth while the reef was not under water.

Twenty thousand years ago, at the peak of the last 'glacial maximum', sea levels around Australia were approximately 125 metres lower than they are today. At that time, the coastline would have been hundreds of kilometres further offshore than its current location, although the plants and animals would have been similar to those we know today. The reef would have been less than 100 kilometres from the shore – today it is around three times that distance.

The cores also revealed rapid periods of growth, more evidence that Scott Reef has kept up with rises in sea level. Since the start of the warm interglacial period 11,000 years ago, Scott Reef has grown about 35 metres.



The skeletons of millions of calcareous algae (top) and corals (bottom), deposited in layers, form the basis of Scott Reef.



Around 20,000 years ago, sea levels were 125 metres lower than today. At this time, Scott Reef stood high above the sea as a steep-sided rocky island, and experienced a pause in growth that scientists have observed in the layers within the reef structure.

The reef today

Altogether, North Reef, South Reef and Seringapatam cover some 650 square kilometres of potential coral reef habitat, at depths down to 70 metres. After millions of years, these reefs stand as monuments to changing climate and sea level over geological time scales. Their ability to withstand these changes also highlights the resilience that coral reefs have historically exhibited to climate and sea level fluctuations over these periods. Undoubtedly, Scott Reef will continue to change, although how it will keep pace with future rises in sea level remains to be seen.

Human History

Many traditional fishing vessels make the voyage to Scott Reef from Indonesia each year, using technology that has remained relatively unchanged since the 1600s.

Hundreds of nautical miles from land and without vegetation or fresh water, Scott Reef has never been the site of a permanent settlement. Yet for more than 300 years, humans have been regular visitors to the reef – first in search of food and mother-of-pearl, and more recently for exploration and research. Fishing vessels have travelled from Indonesia for hundreds of years, eventually joined by European ships exploring the region. In recent decades, visitors have had a different purpose – to explore the natural gas reserves in the area, and to investigate the reef's diverse biological communities. Today, a range of vessels converge on Scott Reef, drawn together by its natural wealth and beauty.

Sharks, sea cucumbers and mother-of-pearl

The tall, angular sails of traditional Indonesian fishing boats are a familiar sight to scientists who visit Scott Reef. Dozens of these small wooden vessels make the voyage from Indonesia between July and October each year. The boats set a southern course using local landmarks before navigating over the open ocean to Scott Reef, using little more than a rudimentary compass and the stars.

Often their first destination is Ashmore Reef, where they stop to replenish their stocks of water before continuing south. On reaching Scott Reef, the fishers gather trochus shells – whose iridescent interiors are used to make mother-of-pearl buttons – sea cucumbers, and the shark fins that are a prized delicacy in parts of Asia.

Each of these tiny wooden vessels carries a crew of around 10 fishermen. These men spend weeks at the reef, living on rice and water carried from home, and the fish they catch each day to cook over fires on the deck. During the peak season, up to 80 boats may visit the reef, and the number of fishers reaches into the hundreds.

Every day, they collect their catch by walking over the reef at low tide or free-diving to harvest prized species of sea cucumber and trochus. In doing so, they are carrying on a way of life that has changed little in more than 300 years.

For centuries, such fishermen or trepangers – 'trepang' is the Indonesian word for sea cucumber – were the only regular visitors to Scott Reef. In 1974, Australia and Indonesia entered into a Memorandum of Understanding that recognised this long history, acknowledging rights of access for traditional Indonesian fishers in a small area of Australian waters.

The voyage from Indonesia to Scott Reef is not without its risks, including dehydration and deadly storms and cyclones. The simple graves of several trepangers on Ashmore Reef and on Sandy Islet at Scott Reef bear testament to these dangers. But the benefits of these fishing expeditions are clearly considered to outweigh the risks. Dried sea cucumbers and shark fin sell for a high price, and by surviving at sea, fishermen ease the pressures on meagre food resources at home during hard times.

Sea cucumbers (left) and trochus (right) are harvested by fishermen who have been visiting Scott Reef for hundreds of years. A variety of sea cucumber species are processed and sold as food, while trochus shells are valued for the iridescent interiors of their shells.

Mutineers, smugglers and international tension

While Indonesian trepangers have long seen value in journeying to Scott Reef, the same cannot be said for Western sailors. The lack of fresh water on the reef meant that, generally speaking, it was a place best avoided.

The first accurate recording of the reef's position seems to have been made in 1801, by HMS Vulcan, under the command of Captain Peter Heywood. Heywood had been aboard the HMS Bounty during the infamous mutiny against William Bligh some 12 years earlier, but was pardoned by King George III. With that behind him, Heywood went on to become a respected charter of the oceans, the career that eventually saw him record Scott Reef's position.

A decade later, the Scottish hydrographer James Horsburgh reported that Heywood named the reef after the man who was at the masthead on Heywood's vessel at 1pm on February 22, 1801 when he saw the breaking waves amid the open ocean. For his part, Horsburgh thought the famed English explorer William Dampier had actually sighted the reef much earlier, but historians suggest it was in fact Seringapatam Reef, some 23 kilometres further north, that Dampier had sighted.

During the 19th and 20th centuries, the status of the reefs and islands of the Timor Sea became increasingly important. In the 1840s, American whalers discovered that there were large deposits of guano on islands in the north-west Kimberley region, and within decades the valuable substance was being taken from a number of offshore islands, including Ashmore Reef and Browse Island.

With money to be made, American and British interests negotiated the sovereignty of the reefs, with Britain eventually annexing Ashmore in 1878 and Cartier Island in 1909. According to one report, the crew of the British cruiser Cambrian hoisted their flag at Ashmore Reef, singing the national anthem and firing a 21-gun salute.

In the early 1900s, newspapers reported on claims of illegal poaching in the region. In 1911, a gunboat commissioned to carry out patrols of the north-west waters apprehended two schooners fishing at Scott Reef. The captains were charged with smuggling and their schooners released once they had paid their fines by selling their catch of trochus shell. The fines were apparently refunded later because Scott Reef had not yet been declared part of Australian waters – it was not until 1924 that the reef was declared part of Western Australia.

The wreck of the Yarra

Roughly 70 metres from the edge of Scott Reef, and visible at low tide, is the wreck of the Yarra, a 490-tonne iron barque built in 1870. Today, from a distance, the wreck can barely be distinguished from the reef. Over the 120 years since the ship was wrecked, it has slowly rusted away and been broken apart by waves.

The ship came to grief in January 1884, en route from Lakes Island in the Gulf of Carpentaria to England, with a cargo of guano. The vessel struck Scott Reef during a cyclone, and in the midst of the storm, all aboard had to abandon ship. Given that the gale had washed away the ship's boats, they were forced to lash together a makeshift raft. Remarkably, after 13 days at sea they reached Browse Island some 170 kilometres to the east. Even more remarkably, all survived.

Since the 1800s, many sailing ships (inset) have visited Scott Reef, both for exploration and while collecting guano at other reefs in the region. The Yarra was wrecked on the reef in 1884 and its remains can still be seen at low tide.

Scott Reef's human visitors

Humans have been visiting Scott Reef for more than 300 years. Over the centuries, people have come to the reef for many different reasons – some for food, some for exploration, and others for research. Today, a diverse range of people and activities can occur together at the reef.

1993 to present
AIMS research vessels have been visiting Scott Reef for two decades, including the RV Solander since its maiden voyage in 2008. Scientists aboard these, and other research vessels, use a wide range of equipment and methods to study the reef's environment and organisms.

1970s to present
Natural gas reserves were discovered beneath Scott Reef in the 1970s, and since then seismic surveys and exploratory drilling have been carried out to determine the extent of the resource.

1970s
The first scientific voyages to Scott Reef occurred in the 1970s, with visits by research vessels from the then-USSR and USA.

1800s
Scott Reef's position was first charted by Europeans in the early 1800s. At the time, the islands off north-western Australia were commercially important sources of guano for fertiliser.

1600s to present
Indonesian fishing vessels have made the journey to Scott Reef for over 300 years, and were the first known human visitors to the reef. Today, each vessel has a crew of around 10 fishers, and may tow several dugout canoes that are used for fishing and transport among the fleet.

Diving is an important method of investigating coral reefs. In the last two decades, researchers have spent thousands of hours under water studying the corals, fish and associated organisms.

Recent technological advances have enabled scientists to explore parts of the reef not readily accessible to divers. Remotely operated vehicles (ROVs) like this one are a valuable scientific tool for collecting samples and video footage from deep waters.

Resources and research

Until the late 20th century, only sporadic scientific attention was paid to the rich ecosystems of Scott Reef and the other reefs, banks and shoals that dot the broad continental shelf off north-western Australia.

In 1963, Woodside, an Australian-based oil and gas exploration company, was awarded exploration permits over 367,000 square kilometres of ocean off Western Australia's north-west coast. This included what is now known as the Browse Basin.

Initial seismic surveys in the late 1960s identified the area near Scott Reef as a prospective site. A drilling campaign just off Scott Reef in 1971 led to the discovery of the Torosa gas and condensate field. The field lies in part beneath Scott Reef, and over the decades Woodside, as operator of the Browse Joint Venture, has conducted a range of seismic surveys and drilling campaigns in the area to further appraise the Torosa resource.

Meanwhile, the first taxonomic collections from Scott Reef also took place in the 1970s. Scientists aboard the US Research Vessel Alpha Helix and the USSR Research Vessel Kallisto both catalogued specimens from the reef. In 1984, researchers from the Western Australian Museum carried out extensive surveys to sample fauna on the reef flats, lagoon and outer reef slopes of Scott and Seringapatam Reefs.

In 1993, the Australian Institute of Marine Science (AIMS) conducted a comprehensive survey of coral and fish communities at Scott and Seringapatam Reefs. The following year it established a long-term monitoring program designed to assess changes within the reef's shallow water coral and fish communities. The monitoring program continues today, with co-investment by the Woodside-operated Browse Joint Venture, and is one of the longest and most comprehensive coral reef monitoring programs in Australia. From 2008 to 2011, AIMS and other research institutes conducted a much more detailed and multidisciplinary research program at Scott Reef, with the goal of gaining a deeper understanding of the processes influencing the ecology of the reef, and the relationships between different habitats.

In the past 20 years, research at Scott Reef has involved a dozen organisations, hundreds of scientists and many years of cumulative ship time. Today, Scott Reef is among the most intensively studied coral reefs on the planet.

Exploration by the oil and gas industry began at Scott Reef in the 1970s, and has continued in parallel with scientific research.

Operational Challenges

A full day's steaming from the nearest port, Scott Reef's remote location makes it one of the most spectacular, and most difficult, coral reefs to study.

Scott Reef's remote location is a powerful draw for scientists wanting to study a coral reef system that is isolated from the effects of modern society. However, that same remoteness poses logistical difficulties and safety concerns. Scientists have conducted many surveys of the reef, using research vessels, aeroplanes and instruments deployed for months at a time, to study a multitude of organisms in vastly different environments. Each of the research methods they use – from visual observations to satellite tags – comes with its own challenges.

First things first

Getting to Scott Reef is never easy. Most research trips begin with a flight into Broome, where scientists board the vessel that will carry them to the reef and be their workplace for several weeks. Four or five hours after departing, the Kimberley coastline disappears from view. Night falls and passes, the sun rises again, and still the boat steams through the open ocean.

Around 24 hours after leaving the dock at Broome the engines finally slow. A few waves breaking on the shallows of the reef and an area of paler green water are the first clues that the destination is at hand. Broome is now about 425 kilometres to the south and the closest mainland 270 kilometres to the south-east. The horizon all around is flat and blue. For the scientists on board, it is time to get to work.

Of course, the journey to Scott Reef really began months before boarding the research vessel. Working in such a remote and potentially hazardous location requires extensive planning and experience. Research vessels can spend up to four weeks at the reef, requiring a significant list of provisions and scientific equipment. Even freighting pallet-loads of equipment to the wharf in time for departure can be a challenge in itself, with delays due to road closures a relatively common occurrence in this remote region. Forgotten supplies must be done without, as the round trip back to civilisation takes more than two days.

The researchers themselves also need considerable training before travelling to such an isolated place, including qualifications in first aid, diving and survival at sea. Thorough evacuation and emergency response plans are also critical to trip preparations. A commitment to safety is vitally important at Scott Reef, where advanced medical care is many hours away. This commitment to safe science has earned the Scott Reef Research Project two Commonwealth safety awards.

Even with all the preparations undertaken before visiting the reef, no qualification can guarantee that a visitor is suited to long periods at sea. The idea of spending weeks diving in tropical waters may sound wonderful, but it is not unheard-of for people to join a research trip only to discover – too late – that they suffer from seasickness. Others may struggle with working for hours on the back deck in tropical heat or with being immersed in water, day after day.

Life at the reef

Once at the reef, researchers use a variety of techniques to collect their valuable data. Some work relies heavily on scientists venturing underwater, using SCUBA (self-contained underwater breathing apparatus) or SSBA (surface supplied breathing apparatus), which require a small mountain of equipment and careful preparation. Compressors, air cylinders, breathing apparatus, communication units, buoyancy control devices, hundreds of metres of air hose, and myriad personal dive equipment must be maintained in optimal condition, checked and certified to minimise the risks of breathing underwater.

Scientists and their support crew use small boats to access the shallow areas of the reef. Each afternoon, they return to the research vessel to process the samples and data collected during the day's work.

In many situations, diving is not an appropriate method of research. Divers are generally restricted to shallow depths and can spend only limited time each day underwater, so studying deep water corals or collecting data over long time periods require different approaches.

In these situations researchers rely on alternative methods, including the use of remotely operated vehicles (ROVs) to collect samples from deep water organisms, and towed cameras to describe their communities. Environmental conditions are also monitored with instruments mounted on the research vessel's hull or deployed on the reef.

To make the most of a visit to Scott Reef, scientists will often deploy instruments that stay on the reef for months at a time, automatically recording data. This is one way to overcome the challenge of studying an isolated place, but is not without its own problems.

Electronic equipment can develop faulty connections in the harsh marine environment, or there may be difficulties in recovering instruments from the depths if their release mechanism fails. Equipment may disappear following severe storms and cyclones, or may be souvenired by other visitors to the reef, human or otherwise; reef fish have been known to bite off coral tags and sharks have damaged noise loggers. Given the effort required to deploy this equipment, considerable foresight is required to ensure sufficient data are obtained.

ROVs are used to describe and sample deep water communities, such as those as deep as 70 metres in the South Reef lagoon. ROVs transmit real-time video data back to the surface and have a moveable arm which can be used to collect samples.

Weighted metal frames carrying various scientific instruments are lowered to the sea floor, where they record data continuously for several months before being retrieved for data collection and maintenance.

Battling the weather

Scientists at Scott Reef live by the daily weather forecasts delivered through satellite email or fax, and the skipper's intuition. Work is shut down during periods of rough weather, so teams must be ready to adjust their work plan according to the prevailing conditions and make the most of calm periods. Currents, tides, wind and swell all require consideration. Working on the moving platform of a vessel or under the water in rough seas can make the simplest tasks difficult or even dangerous, so efficiency and safety considerations are paramount.

Moderate weather can make certain tasks impossible, but severe weather events like tropical cyclones are best given a wide berth. Tropical cyclones are common in the region around Scott Reef between November and April. Historically, many shipwrecks occurred during cyclones, and they remain a serious threat to modern mariners. Early warning services are closely monitored while at Scott Reef and early action is taken to avoid the path of tropical cyclones.

Diving operations are shut down during rough weather, but crew must be constantly vigilant. Squalls of wind and rain can hit within minutes of first sighting, and cause sudden changes in working conditions.

RV Solander

Since 2008, the Australian Institute of Marine Science has undertaken more than 25 voyages to Scott Reef aboard the RV Solander, a purpose-built, steel hulled research vessel. The vessel provides a home and workplace for up to 18 researchers and support crew, enabling them to work in remote areas like Scott Reef for weeks at a time.

Equipped with a 'moonpool' tunnel that allows instruments to be mounted below the hull to collect data while underway, four-tonne capacity winches and an eight-tonne capacity A-frame for deploying large equipment into deep waters, the RV Solander is a 35 metre floating laboratory and workstation.

Working from the RV Solander are four inflatable boats with outboard motors, which take teams of scientists into shallow reef areas where diving operations take place.

Operating and maintaining the vessel is the job of the six crew members who take care of navigation, winch and crane operations, stores of food and fuel, and mechanical maintenance, while also assisting the researchers in their tasks. The skills of the marine crew are vital for the safety and efficiency of the expedition. They can spend six months of the year on board so the RV Solander becomes a home away from home – they are constantly welcoming a new team of scientists. The crew know their vessel inside and out and without their skills, research would be impossible.

Diving safely

There are inevitable dangers when humans venture out of their natural environment to explore beneath the sea. Diving has evolved over many years since the days when basic equipment meant divers often had short life expectancies. Today, diving is a precise science in itself, with researchers well aware of the risks and equipped to avoid them.

Today, the use of modern equipment and dive tables minimises the risk of diving. These allow researchers to stay underwater for several hours a day without harm, but they must also consider other factors to avoid diving-related illnesses.

Researchers can now expect to dive safely for many years without accidents or health problems. Nevertheless spending time underwater still carries risks of decompression illness or 'the bends', which results when bubbles of nitrogen gas form within the diver's body as he or she ascends to the surface.

The risk is minimised by using conservative dive tables that provide guidelines for safe dive times at a range of depths. However, every person is different and divers can still get the bends while following the guidelines. Treatment for this illness is re-compression within a specialised chamber for several hours, allowing the bubbles to be absorbed back into the body tissues and then slowly cleared from the system. A re-compression chamber with accompanying medics and technicians is aboard the research vessel, ready to administer such treatment.

One of the first questions divers are asked by friends or family is 'aren't you afraid of sharks?' Most divers are wary of marine creatures – particularly those with sharp teeth – but usually have positive experiences with sharks. Reef sharks inhabit the Scott Reef area, but they are generally timid and less than two metres long. Most divers enjoy a sighting of these perfectly adapted creatures in their natural environment.

Other creatures have a lower profile but can be just as deadly. The sea snakes that are abundant at Scott Reef are venomous, but bites to divers are rare. Sharp-toothed moray eels, venomous stonefish and other dangerous creatures also live on the reef. However, divers cover themselves in protective gear, knowing to avoid rather than provoke such creatures. In thousands of dives at Scott Reef, no-one has ever been bitten or stung.

Sea snakes are common at Scott Reef, and have a venomous bite. Fortunately for divers, they are often inquisitive but rarely aggressive. Six species of sea snake have been found at Scott Reef.