# NINGALOO OUTLOOK

## Highlights Report 2015 - 2025

**Ningaloo Outlook has provided critical data on the health and trends of the region's natural assets, as well as detailed insights into the movements of key megafauna to and from Ningaloo.**

# INTRODUCTION

The Ningaloo (Nyinggulu) coast hosts one of the world's longest fringing coral reef systems which supports globally significant populations of large megafauna. Its ecological and cultural value led to its World Heritage listing in 2011, and it continues to attract hundreds of thousands of tourists annually, generating tens of millions of dollars of revenue to the region. However, Ningaloo's ecosystems are under growing pressure from global climate change and ever-increasing human use. Effectively addressing these challenges depends on robust scientific research to identify key pressures, understand their impacts and help find ways to mitigate them.

Ningaloo Outlook was a ten-year, $12.5M partnership between CSIRO and BHP (2015–2022), and later Woodside (2022–2025), focused on advancing scientific research to increase the understanding of the Ningaloo Reef and its iconic marine life. The program supported a range of research activities, funded seven PhD scholarships and encouraged active participation by industry staff and the Exmouth community, including local students and teachers.

The research included 65 expeditions and dozens of scientists, who collected a wide range of data using diverse tools, from autonomous underwater vehicles (AUV) to satellite tracking devices. Deep reef surveys, where diving is challenging, relied on a combination of remote video, autonomous vehicles and remote submersibles, while divers covered more than 100 km of shallow reef habitat. Researchers tagged more than 660 individual turtles, whale sharks and coastal sharks using methods ranging from simple metal tags to advanced acoustic and satellite tracking technologies. Over 2000 members of the public, including school children, local community members and tourists to the region, participated in the research and education activities, with more reached through public talks and online resources. Indigenous rangers were actively involved in the turtle tagging field activities.

Ningaloo Outlook has provided critical data on the health and trends of the region's natural assets, as well as detailed insights into the movements of key megafauna to and from Ningaloo. This information plays an important role in guiding conservation management strategies and policy decisions. It has been shared with government, industry and the broader community, who together will make critical decisions that affect Ningaloo in the future.

# CONTENTS

# SHALLOW REEFS

Ningaloo is one of the world's longest fringing reefs and is one of the few World Heritage listed coral reefs projected to avoid severe bleaching more than twice per decade by 2040. Research in Ningaloo Outlook sought to extend existing assessments of corals and fish close to shore and to provide new information on the ability of the reef to continue to grow in the face of rising pressures.



## Did you know?

On pace with rising seas: Sea levels are predicted to rise by between 0.4 m and 0.7 m in the Indian Ocean by the year 2100, with potential negative impacts on the reef and adjacent coastal areas. Our research currently suggests Ningaloo's reefs are capable of keeping pace with this sea-level rise.

Humphead parrotfish at Ningaloo: The humphead parrotfish (*Bolbometopon muricatum*) can reach lengths of up to 1.3 metres, weigh over 75 kilograms, and often forms schools of up to 100 individuals. However, despite its large size and schooling behaviour, it had never been recorded in scientific surveys at Ningaloo prior to our research.

**Figure 1.** Diver conducting coral surveys on the reef slope at Ningaloo Reef.

Ningaloo's shallow reefs (Figure 1) support over 200 species of coral and 500 species of fish. However, they are increasingly threatened by rising sea temperatures, which can cause coral bleaching and death, along with more intense storms and growing human activity. Effectively managing these pressures depends on having up-to-date information about the organisms that build and erode the reef, as well as the environmental factors that influence reef changes.

To gather this information, scientific divers from the Ningaloo Outlook team surveyed more than 100 km of reef, recording data on corals, fish, reef structure (complexity), and marine debris (Figure 1). These surveys contribute to one of the longest-running ecological datasets for an Australian coral reef, with records dating back to 2007. Drawing on 18 years of data, the team found that hard coral cover, the main contributor to reef growth, increased between 2015 and 2020, but declined during the periods from 2006 to 2015 and from 2022 to 2024 (Figure 2).

To better understand the factors driving these changes, the team measured coral abundance (cover), coral growth, coral survival, and juvenile settlement. Increases in coral cover were primarily linked to increases in both the number and size of fast-growing *Acropora* corals, with over 80% of existing corals surviving each year. Although coral (juvenile) settlement rates were too low to fully explain the increases in coral cover, smaller corals were found to grow faster than larger ones, and overall coral growth rates were higher in areas with lower wave energy. In contrast, periods of declining coral cover (2008–2015 and 2022–2024) were associated with outbreaks of coral disease and predation by the coral-eating snail *Drupella* (Figure 3), which together caused a reduction in both the number and size of *Acropora* colonies.

To better understand what drives reef erosion across different reef zones, the team measured the activity and abundance of both large and small reef eroders.

## Did you know?

Marine heatwaves: The 2025 marine heatwave was the most intense and widespread ever recorded. Sea temperatures rose more than 4°C above the long-term average, and for the first time, coral bleaching was observed on the reef slope at depths down to 20 metres.

Among the larger eroders, the team recorded the presence and distribution of *Bolbometopon muricatum*, the world's largest parrotfish species, which can grow up to 1.3 metres in length (Figure 4). This species is capable of removing significant amounts of reef carbonate through bioerosion. Including *B. muricatum* in erosion estimates increased total bioerosion rates by up to six times compared to earlier assessments at the same sites. At a smaller scale, the team also measured erosion by urchins, microborers (<35 µm) and macroborers (>35 µm), which contributed relatively little to overall erosion, approximately 22%, 4% and less than 1%, respectively. Total erosion rates were 3.07 ± 0.37 kg/m²/yr, representing some of the highest rates of reef erosion recorded globally.

The team investigated long-term trends in fish abundance and biomass both inside and outside sanctuary zones, as well as the role of habitat in shaping these patterns. They found that emperors (Lethrinids: Figure 5) were more abundant and had greater biomass within sanctuary areas compared to fished areas, suggesting that sanctuary zones are effective at protecting these species. Larger sanctuary zones located closer to shore were especially effective, likely due to the influence of nearby reef habitat.

Advanced three-dimensional modelling showed that reef complexity increases the availability of shelter for many fish, which appears to be a key factor driving higher abundance and biomass in some fish.

The team also surveyed the amount of debris found on beaches and reefs. Marine debris is a global issue, as it can injure or kill marine animals through suffocation, starvation, or poisoning. The surveys recorded low levels of debris (0.004–0.02 items m$^{-2}$: 48.5 km beach surveyed), with plastic making up 61% of the items. Land-based and locally sourced items accounted for nearly 90% of the debris. Interestingly, lower debris levels were found in areas with higher visitor numbers, suggesting strong environmental stewardship. Debris levels did not differ significantly between sanctuary zones and non-sanctuary zones.

Based on four key indicators of coral reef health (live coral cover, proportion of algae as macroalgae, herbivore biomass, 12-month change in live coral cover) the team concluded that the shallow reefs of northern Ningaloo were in poor to fair overall condition in 2025. Since 2022, ongoing coral losses due to predators, disease, and more recently bleaching, have led to a marked decline in coral cover and overall reef health. The full impact of the 2025 marine heatwave is unlikely to be known until later in the year.

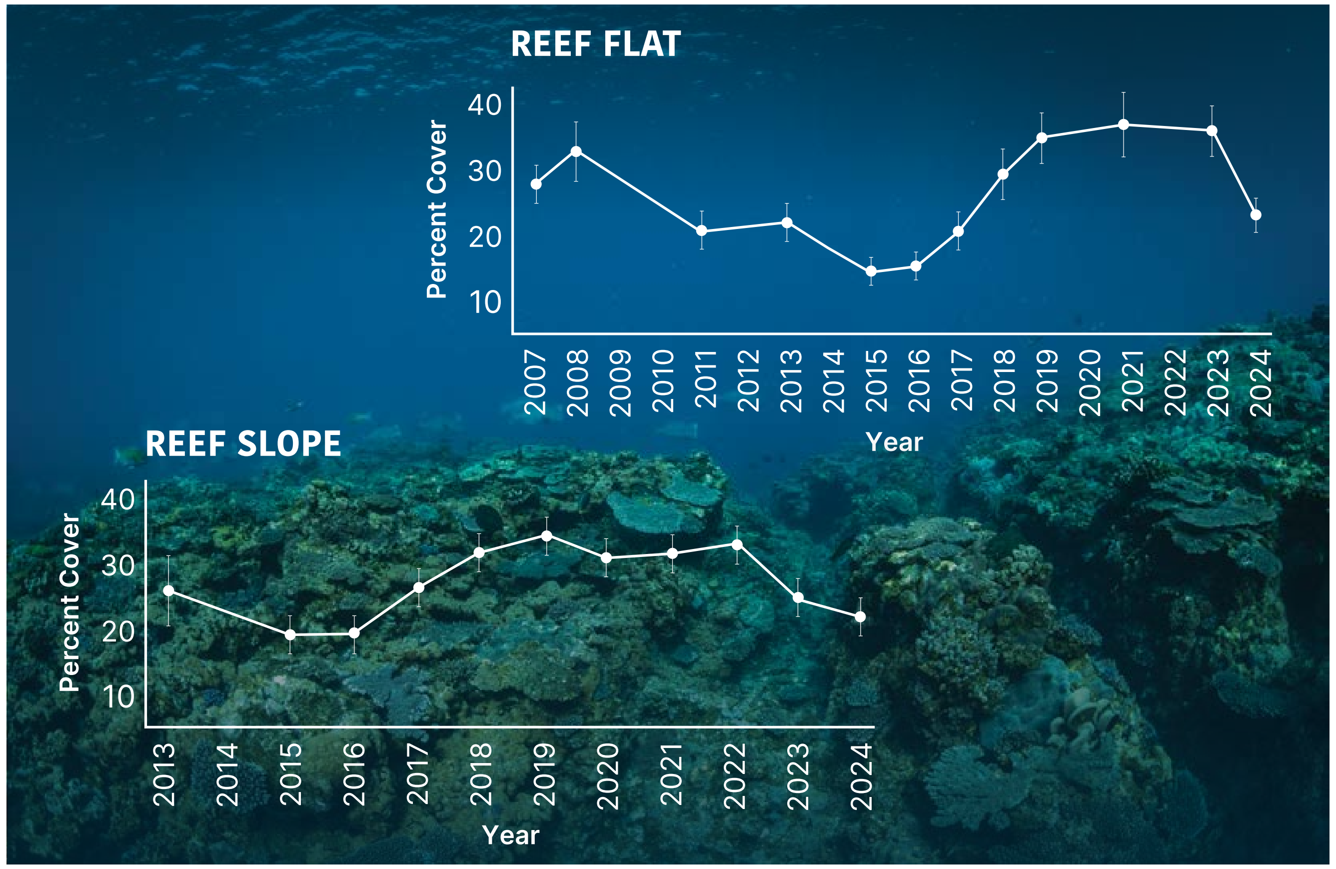


**Figure 2.** Percent coral cover (mean ± se) at northern Ningaloo between 2007 and 2024.



## NINGALOO OUTLOOK SHALLOW REEFS

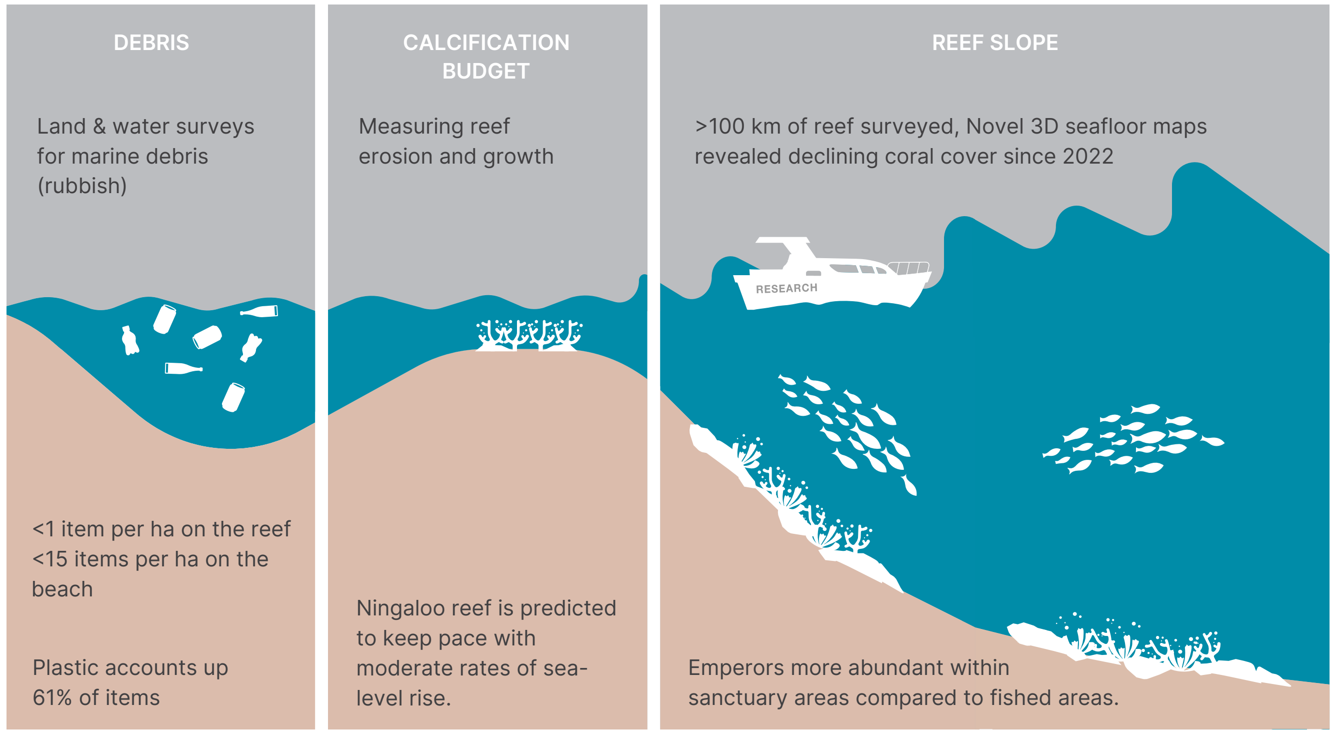


**Figure 3.** Fast-growing *Acropora* coral on the reef slope which has partially died due to feeding by *Drupella* snails.

**Figure 4.** Humphead parrotfish (*Bolbometopon muricatum*) at northern Ningaloo reef.

**Figure 5.** School of spangled emperors (*Lethrinus nebulosus*) at northern Ningaloo reef.

# DEEP REEFS

The deep reefs of Ningaloo, beyond the seaward edge of the reef slope, are home to deep-water coral communities, abundant and diverse filter-feeding communities of sponges and sea fans, as well as mushroom corals which form a dense carpet on the seafloor and a diverse range of fishes endemic to the area. Relatively little was known about theses habitats until the Ningaloo Outlook program and our research helped shape our understanding of how important these habitats are for fish assemblages and how they differ greatly between each habitat type. This valuable research, along with our new knowledge of the ecology of deep reef habitats, and their associated fish and invertebrate assemblages at Ningaloo, have provided a comprehensive baseline for the development of long-term management strategies for these unique ecosystems.



## Did you know?

Rich Deepwater Habitats: In deeper areas of Ningaloo, beyond 40 m depth, sponge and sea fan gardens form complex seabed structures that provide vital habitats for fish and other marine life in the absence of reef-building corals.

High Fish Diversity in Deep Coral Zones: Coral habitats at depths of 25–35 m support the highest fish diversity and abundance among all deep reef habitats surveyed out to 100 m.

We know much less about deep reefs, or mesophotic ("middle light") ecosystems which occur beyond the seaward slope of fringing coral reefs like Ningaloo, because they are harder to access and lack the spectacular corals present in shallow waters. However, these low light environments have their own amazing biological assemblages of colourful animals which form distinct three-dimensional structures creating important habitats for a vast array of fish and invertebrates (Figure 6).

Early in the Ningaloo Outlook program there was a necessary focus on how different assemblages of sessile invertebrates formed deep reef habitats and how these varied spatially. This was a critical first step in identifying what types of deep reef habitats existed at Ningaloo from the base of the reef slope (generally about 20–25 m), out to about 100 m deep.

Extensive imagery obtained from a submersible tow camera was used to identify these habitats and then the project developed innovative survey approaches using Starbug-X, an autonomous underwater vehicle or AUV, to collect underwater imagery. Other approaches, such as acoustic mapping which provide proxies or surrogates of habitat type over much larger areas than can be covered by video, were also used to predict habitat type and develop habitat maps for the area.

These approaches enabled researchers to determine the range of deep reef habitats and the assemblages that comprised them and standardise their categorisation.

The result was the identification of several distinct deep reef habitat types including low diversity, low light tolerant reef building corals (mostly 25–35 m), spectacularly colourful sponge and octocoral sea fan gardens (mostly 30–50 m), and algae dominated habitats (about 30 m). The importance of inter-reefal and deep sandy habitats (40–100 m) was also identified because of the large area they occupied. Most surprising however, was the discovery of the largest aggregation of a single species of mushroom coral, *Cycloseris distorta*, ever discovered. This aggregation, running in a longshore direction at about 38 m, was so large that it formed an important deep reef habitat of its own. Like most corals, mushroom corals get their energy from the sun through single-celled algae that live within the corals and photosynthesise. This means that they can't survive in water that is too deep, otherwise not enough light would reach them. But if they were too shallow, they would not be able to compete with other corals and might be susceptible to rough sea conditions, especially at Ningaloo Reef where tropical storms are common. So, it seems that this community of mushroom corals has found the perfect 'Goldilocks Zone' to prosper, not too deep, not too shallow, but just right.

Having identified the dominant types of deep reef habitats, the latter stages of the Ningaloo Outlook deep reef program has focused on understanding aspects of their ecology, in particular how they are used by different groups of fish and invertebrates, to determine their overall importance to the Ningaloo reef ecosystem.

**Figure 6.** Deep reef sponge garden off Ningaloo and red-throat emperor.

**Figure 7.** *Cycloseris* bed of mushroom corals in the deep reefs of Ningaloo.

In order to do this, the team applied new and existing approaches to the collection of underwater imagery. These included the use of remote underwater vehicles (ROV), stereo baited remote underwater video (BRUV), and stereo unbaited long-run (ca. 24 hour) remote underwater video (LRUV).

These methodologies allowed important habitats to be mapped, determined differences in habitat use by fish, examined aspects of the behaviour and ecology of different reef species, and examined the effectiveness of some marine park management approaches.

Using the ROV, the team were able to map in detail the location and extent of the *Cycloseris* mushroom coral bed (Figure 7) off Helby Bank in the northern part of the Ningaloo Marine Park (Figure 8). The mushroom coral bed extends 2.6 km parallel to Ningaloo Reef and is 670 m at its widest point. Mushroom corals on the seabed form a dense carpet with maximum densities exceeding 1200 per $m^2$. The total population size was determined to be 652 million ± 124 million. The population appears to reproduce mainly through asexual reproduction with lobes of the corals breaking off to form new corals. The size of the corals varied from 11–65 mm. Each individual coral starts as a single lobe or petal shaped corallite and grows by adding more lobes. Some of the individual corals had as many as 13 lobes.

Among the animals living in the mushroom coral beds is the short-spined crown of thorns starfish (COTS), a close relative of the starfish responsible for extensive coral destruction on the Great Barrier Reef. The Ningaloo Outlook program discovered that these short spined COTS were eating the mushroom corals (Figure 9); the first record of this species of starfish predating on corals.

Examining fish populations among deep reef habitats revealed more than 400 species of fish using these habitats among 33,000 fish recorded by ROV and BRUV methodologies.

Fish species assemblages differed greatly between all the different habitats with certain species typical of some habitats and not others. Stereo-ROV based transects allowed for identification of fine scale fish habitat associations, while BRUVs, increased the observations for key recreational targeted species and ecological important species often missed by other methods. Environmental data obtained helped understand the functional differences of these habitats. While many species occurred in all habitats, fish were most abundant in the deep coral habitats. These include many of the highly mobile large species of snappers, emperors and cods which make up an important component of the recreational fish catch at Ningaloo.

The deep reefs program was also able to survey a deep-water sanctuary zone established in 2018 off Point Cloates in the central section of the Ningaloo Marine Park and compare fish populations with adjacent areas open to fishing. The survey revealed that for species targeted by fishing, abundance was higher inside the sanctuary than outside the sanctuary. New sanctuary zones typically take many years for fish populations to recover to an unfished level so we can expect to see further improvement in years to come. The survey data has created an important baseline of data on fish diversity, abundance and biomass that can be compared against future surveys to establish whether the sanctuary zone is meeting its conservation objectives.

The LRUVs developed as part for the Ningaloo Outlook project, provided an insight into behaviours of fish and invertebrate species not previously possible. Among the work carried out at Ningaloo using these cameras, the team was able to determine the diurnal feeding and movement habits of sea urchins and sea cucumbers. Also, the movement of rarely seen schools of hump head parrot fish was discovered and the cameras enabled the team to observe how some fish species' behaviour changes naturally at night during a complete solar eclipse.

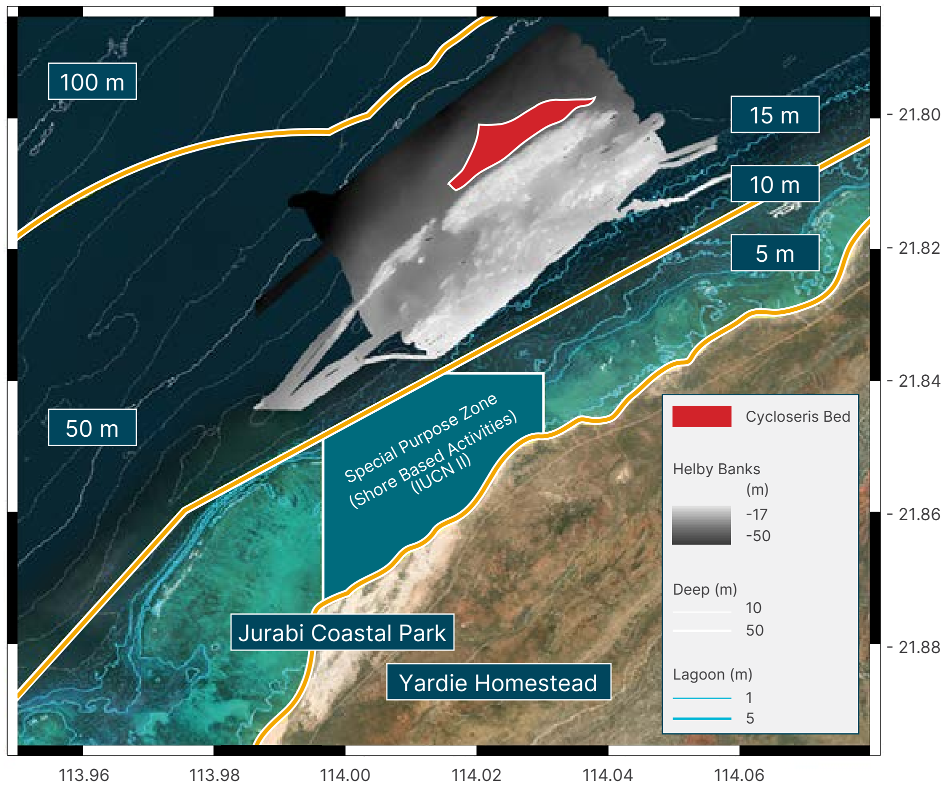


**Figure 8.** Map showing location of the mushroom coral (*Cycloseris*) bed off the northern section of Ningaloo reef. Bathymetry and marine park zoning in the area is also shown.

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## NINGALOO OUTLOOK DEEP REEFS


**Figure 9.** Short spined crown-of-thorns starfish shown consuming a mushroom coral from Ningaloo Reef.

### Did you know?

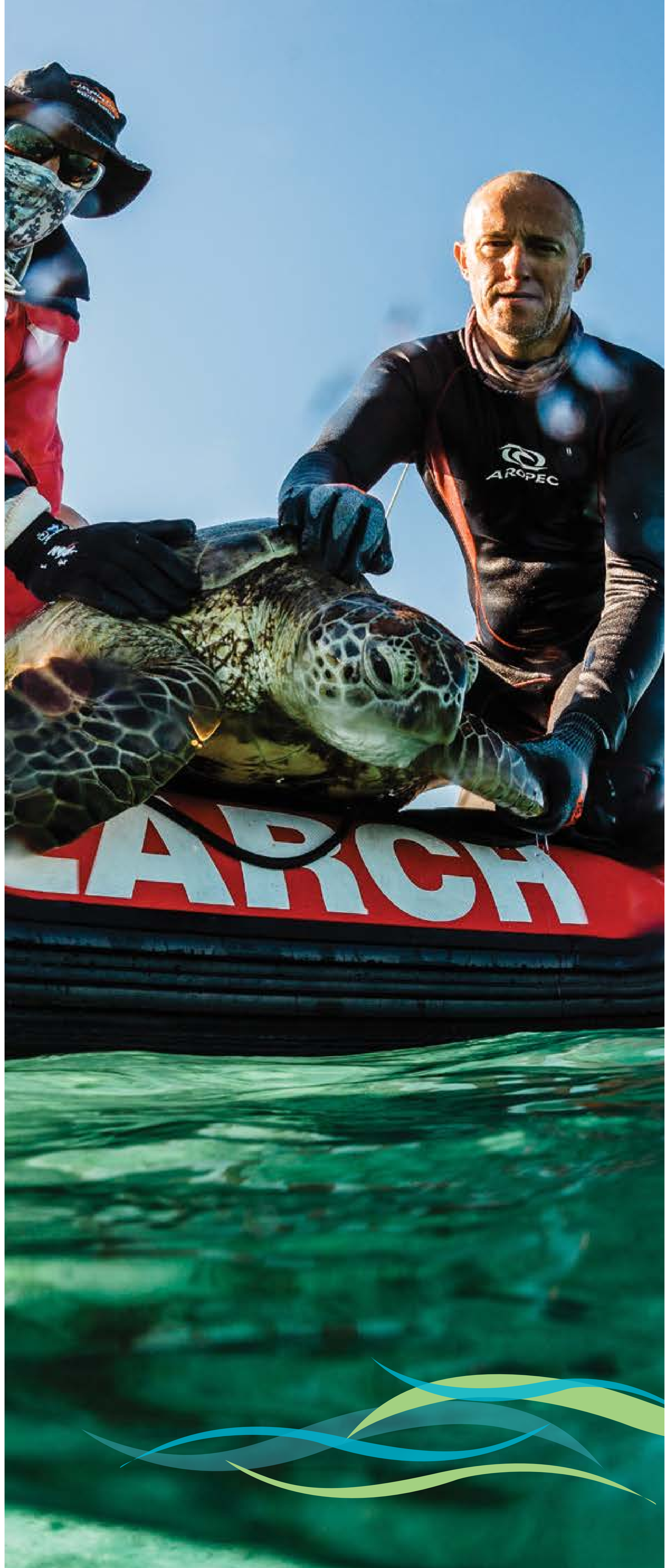
Mushroom Coral Aggregation: The world's largest known aggregation of a single species of small mushroom coral species occurs off northern Ningaloo, where 652 million corals form a dense coral carpet 2.63 km long and up to 0.67 km wide—now known to be preyed upon by a short-spined crown-of-thorns starfish.

# TURTLES

Green turtles that nest at Ningaloo arrive from as far away as Shark Bay and the Kimberley, sometimes over 1,000 km away. Meanwhile, Ningaloo green turtles typically nest several hundred kilometres away in the islands of the Pilbara, making nesting voyages that last for several months.

Aerial drone surveys revealed surface densities of around 10 turtles per km². Accounting for the fact that they spend most of their time below the surface where they cannot be seen from above, this translates into approximately 25 turtles per km². This was consistent across sites spanning over one hundred kilometres, meaning that Ningaloo's lagoons are home to thousands of resident green turtles, making it one of the world's most important turtle conservation areas.





## Did you know?

Common visitors: Six of the world's seven species of sea turtles occur in Australia. All visit Ningaloo, but only three (green, hawksbill and loggerhead) are common.

The green turtles which inhabit Ningaloo are part of a population which is distributed around north-western Australia, and is one of the largest in the world. Many live in the lagoons within the reef, or nest on the beaches during summer. The Ningaloo Outlook team sought to find out whether these turtles stayed at Ningaloo or roamed more widely, as well as how many there are in the lagoons at Ningaloo, and how fast they grow.

To answer questions about movement, the team used different types of tags. Fifty green turtles were tagged with satellite tags during the program (13 of these were nesting females tagged while on the beach, the remaining 37 were captured in the water), generating almost 100,000 locations. Nesting turtles returned to feeding grounds between Shark Bay and the Kimberley up to 1,250 km away, and most did not stay within the Ningaloo World Heritage Area (Figure 10), while turtles captured in the water in known feeding areas tended to remain very close to where they were tagged, typically moving just a few kilometres at most.

To detect females that were likely to nest, large female turtles were captured in the water at the onset of mating season, and a portable ultrasound machine was used to assess whether vitellogenic (yolk-forming) follicles were present. The team detected these yolk-forming follicles in seven females, and successfully tracked four of them for their entire nesting migration, from feeding grounds to nesting beaches and back (Figure 11).

All four turtles nested on Barrow Island or in the Montebello Islands, more than 200 kilometres from where they were tagged, then returned to Ningaloo (in one case the last transmission after 283 days was a mere 400 metres from where she was first captured). Another nested on North West Island in the Montebello Islands, but then established itself off West Lewis Island in the Dampier Archipelago after a torturous post-nesting journey in which it travelled all the way to Point Samson (Figure 12). Finally, one nested in the Lacepede Islands over 1,000 km from Ningaloo, and after nesting stayed in the vicinity of Cape Baskerville on the Dampier Peninsula.

The study revealed the wide extent of movements by green turtles, with those from Ningaloo residing in small areas but leaving Ningaloo to nest in the Pilbara or even the Kimberley, and those nesting at Ningaloo arriving from far afield.

The team also attached flipper tags to 483 turtles during the program (477 to green turtles and three each to loggerhead and hawksbill turtles). Of the 477 green turtles, 32 were recaptured at least once, with some recaptured up to three times. The team also recaptured six individuals that had been tagged during other programs. Combined, this gave 43 measurements of growth, with durations between measurements spanning from 123 to over 11,000 days. Understanding growth is fundamental to effective management, but it can be very difficult to do. The team wanted to compare how rates of growth of Ningaloo green turtles compared to turtles that have been kept in captivity, where they are cared for and fed.

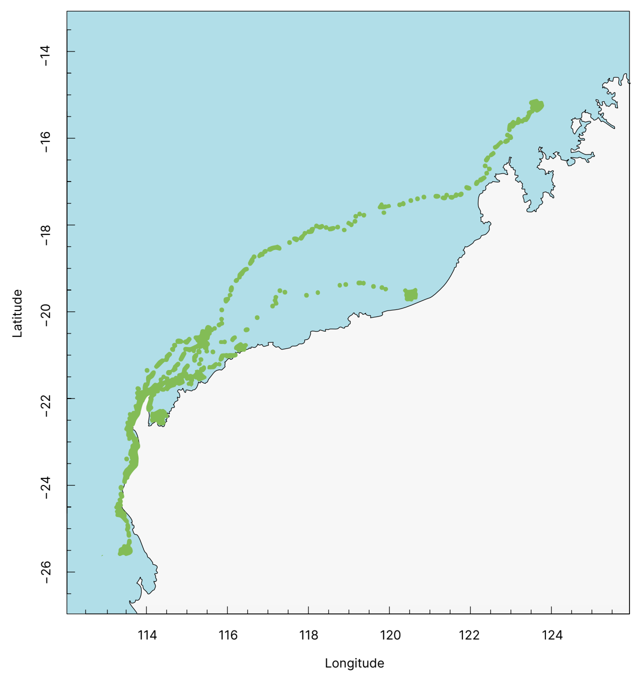



**Figure 10.** Map showing tagged nesting turtles that returned to feeding grounds between Shark Bay and the Kimberley.

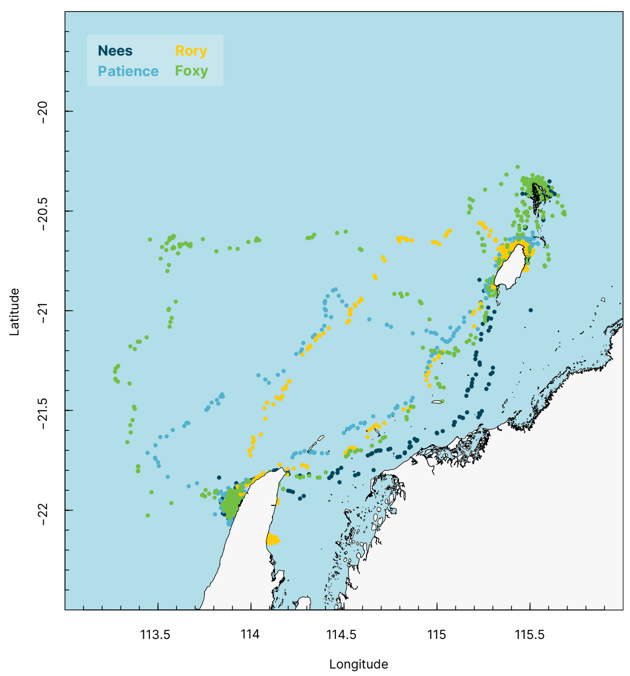



**Figure 11.** Map showing the movement of four tagged female turtles that were tracked during their entire nesting migration from Ningaloo to nesting beaches and back.

Analyses of the recaptured turtle growth revealed that Ningaloo's green turtles grow very slowly—even small (and so young) turtles did not grow more than 2.5 cm per year (Figure 14).

Uncrewed aerial vehicles (UAVs, aka drones) were used to conduct aerial surveys using still photographs. A Phantom 4 RTK was flown at a consistent height of 75 m above sea level, with images overlapping. The images were processed in a modified version of the software 'labelme' and processed with code written in Python. Multiple sightings of the same turtle (which occurred because images overlapped) were filtered out. Over 70,000 images from over 8,000 ha of surveys were manually analysed and turtles identified (see example image, Figure 16). These manually identified turtles are being used to develop a Convolutional Neural Network object detection (YOLO) model. This has been tested and is currently being improved.

Surveys of around 300 ha each (range 276 to 341 ha) were done outside nesting season across Ningaloo from Jane's Bay to Graveyards Beach (Figure 13). On average, about 10 turtles per km² were observed, although fewer were counted in some places (such as the southern part of Jane's Bay). Multiple surveys over several years were done at Mangrove Bay and Tulki to understand how counts might vary across the year (for example, during nesting season when some leave and others arrive) or from day to day because of weather conditions making surveys easier or more difficult.

At Mangrove Bay, counts varied from 1.3 to 11.0 turtles per km², while at Tulki counts varied from 2.8 to 11.4 turtles per km².

UAV surveys can detect turtles at or near the surface but is not reliable for detecting turtles in deeper water. To help understand the proportion of time that turtles could be detected by UAV, acoustic tags with depth sensors were attached to 24 green turtles. The tags returned over 400,000 records of location and depth from October 2022 to May 2024, and 13 turtles provided sufficient data for analysis. The recorded depths were mostly shallower than 6 m. On average, turtles were near the surface (<0.5 m) about 40% of the time.

Extrapolating the UAV counts with this information, we expect the actual number of turtles in an area to be about 2.5 times the number we can see. Our estimates of total turtle density across Ningaloo are therefore approximately 25 turtles per km².

Outstanding participation by local community members and school students proved critical to the team's turtle research. More than 40 volunteers helped with tagging during the program—many returning several times. The research also incorporated yearly visits by Year 9 students, with more than 250 students joining the research team for science classes on the beach over the course of the program. Students looked after, measured and tagged turtles while learning about the physics underpinning satellite tags, the chemistry underlying the methods the researchers use to study diet, and the biology of turtles.

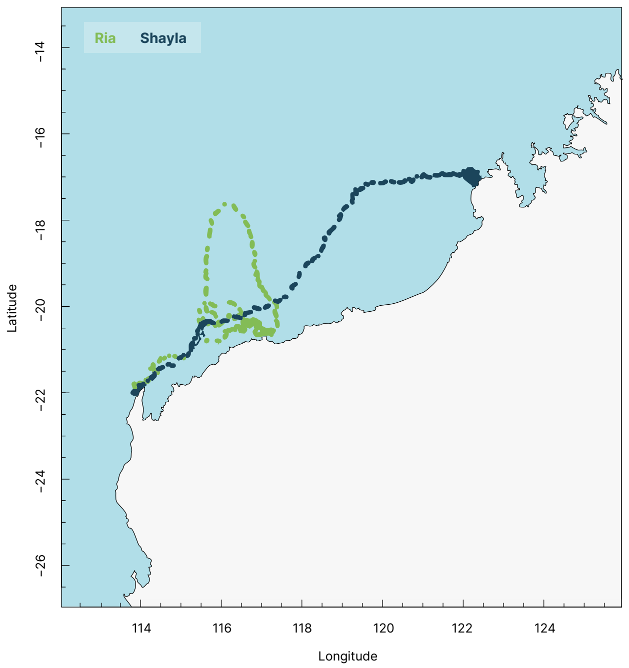



**Figure 12.** Map showing the movement of two tagged females turtles that didn't return to Ningaloo following their nesting migration.

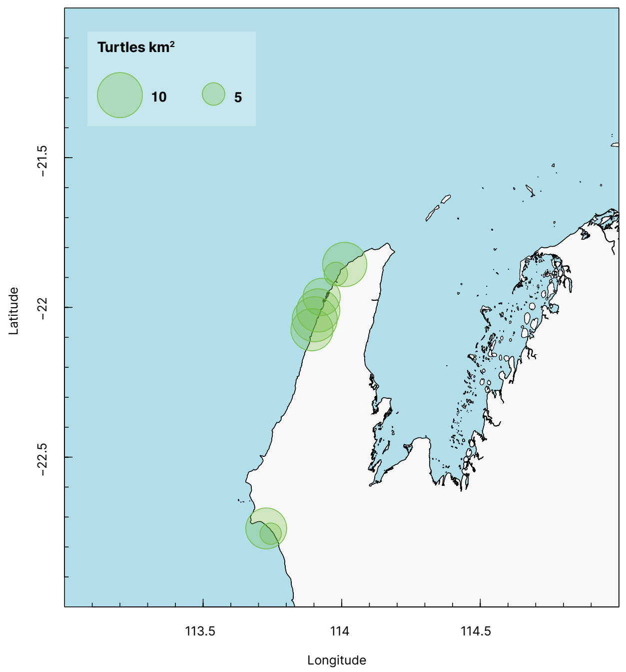
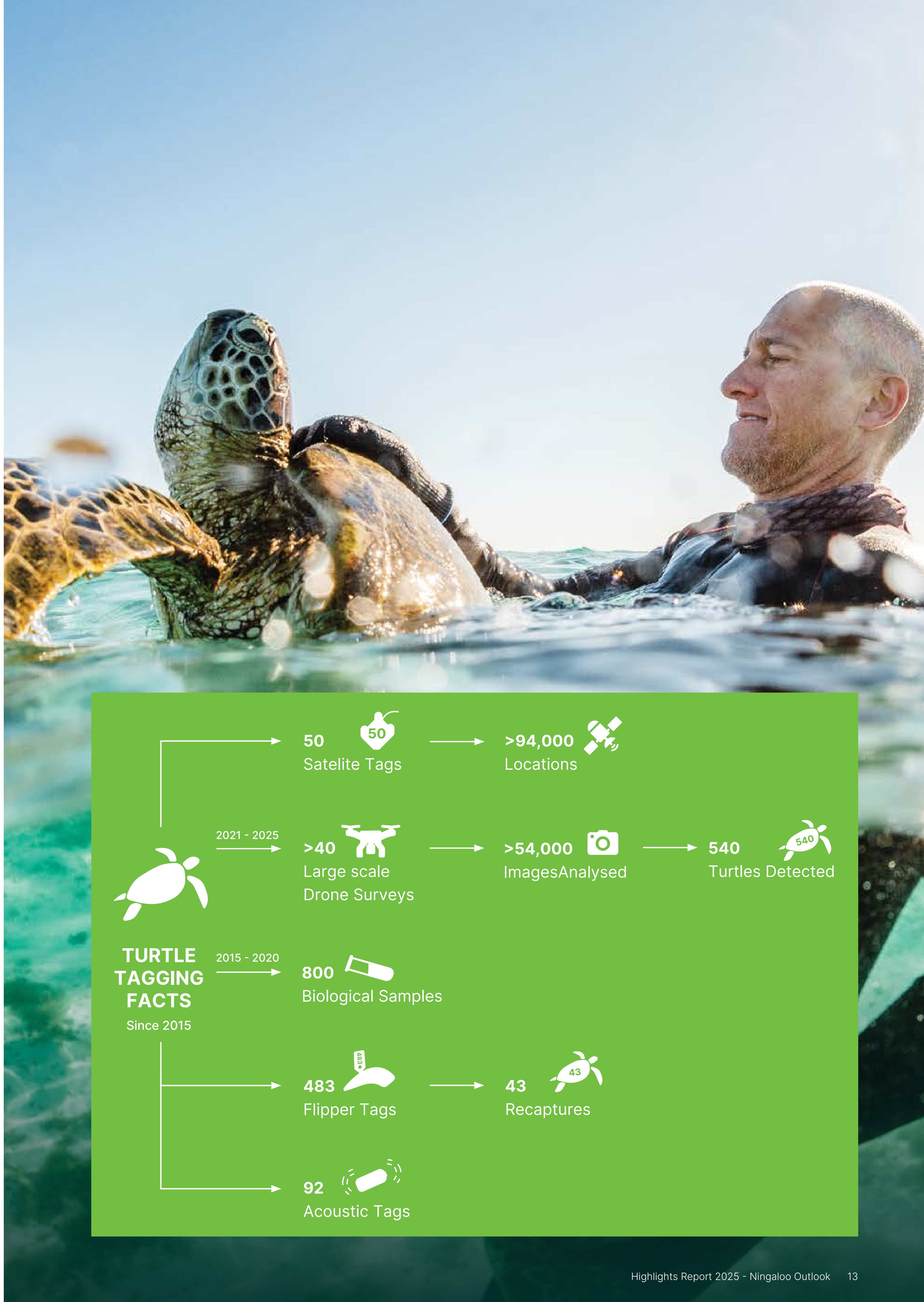



**Figure 13.** Map showing numbers of turtles visible during drone surveys (per square kilometre).



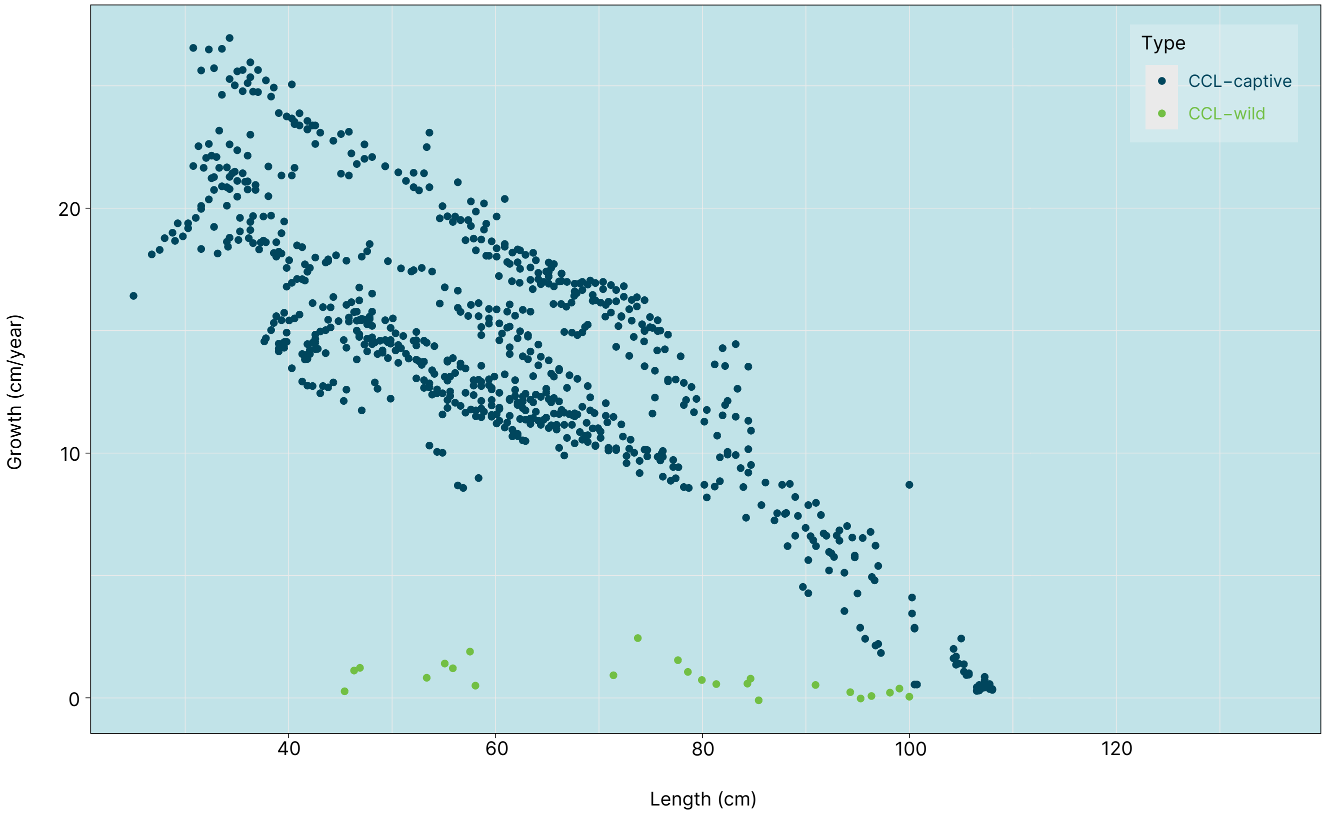



**Figure 14.** The growth rates of wild, Ningaloo green turtles (green dots) compared to captive turtles (blue dots).

**Figure 15.** Released green turtle with satellite tag attached.

**Figure 16.** Example of turtle extracted from UAV image.

### Did you know?

Green turtles: Green turtles are the most common turtle species at Ningaloo, and the North West Cape is one of Western Australia's most important nesting areas. The Ningaloo green turtles are part of a broader population that is distributed around north-western Australia.



# WHALE SHARKS

The Ningaloo Outlook project has provided the first evidence that whale sharks at aggregations >8000 km apart share the same parents. We found clear evidence from DNA sequences that whale sharks in Madagascar and Tanzania share parents with the Ningaloo sharks. Preliminary analysis suggests there is a single adult population of whale sharks in the Indian Ocean, with around 5000 individuals—this is the first estimate of breeding population size of a whale shark population. Previous genetic analysis did not have the resolution to confirm how connected the aggregation sites were. Photo identification methods have never shown animals moving between aggregation sites. So, this Ningaloo Outlook kinship data provides the first information on how connectivity really works within the population.

## Did you know?

Deep Dives Tracked: Satellite tags placed on 38 whale sharks at Ningaloo revealed their movements and depths, with one individual diving to a remarkable 1,906 metres.

Ningaloo Reef has globally significant abundances of large marine fauna which was an important contributor to its inscription as a World Heritage Area. The whale shark aggregation at Ningaloo is one of the largest known aggregations in the world with the predictable nature supporting an eco-tourism valued at over $25 million. While the peak season is between March–July, whale sharks have been recorded year-round at Ningaloo. This research has provided data on the movement, connectivity and population size of whale sharks at Ningaloo and the broader Indian Ocean.

Between 2016 and 2023, the Ningaloo Outlook Whale Shark team conducted annual field trips in the first 10 days of June to sample whale sharks. Sampling included obtaining a length estimate, sex, photographs of both sides for identification purposes, collecting stereo video to measure the exact length of the sharks (Figure 20) and obtaining a genetic sample (Figure 19). In addition to this, 38 whale sharks were tagged with satellite tags to track their movement (location and depth) over time.

Data from 35 satellite tagged whale sharks (ranging in size from 4–9 m) was used to investigate movement patterns. No difference could be detected in the movement, depth use and temperature use across animals tagged. Between July and November, both males and females moved north as far as Indonesia, the Timor Sea and Papua New Guinea (Figure 17)—females on average moved further away and departed Ningaloo earlier than males. Females also spent slightly more time in offshore waters (>200 m deep). By November, both sexes began to move south, with some animals remaining around Ningaloo/Shark Bay and others moving further south to Perth in the summer. There was evidence that in late Spring, females occupied areas with lower SST (<24 °C) than males (>28 °C). Additional data are required to determine if this result represents a preference for cooler temperatures in females, which differs from the widely accepted temperature preferences of whale sharks (26.5–30 °C). Both males and females dived to deeper, cooler water more frequently in areas with higher sea surface temperature.

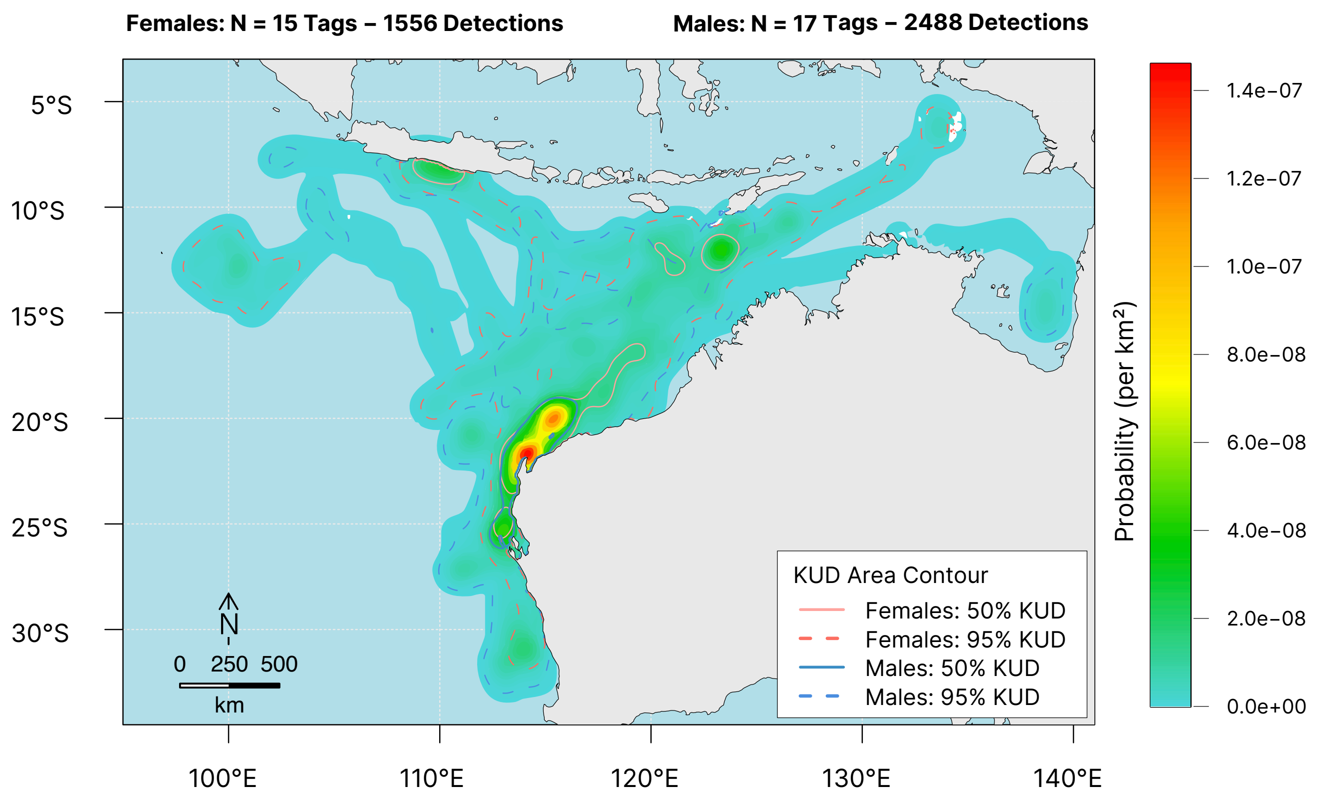



**Figure 17.** Distribution of 32 whale sharks tagged during the Ningaloo Outlook project.



## Did you know?

Global Family Links: Genetic studies showed Ningaloo whale sharks share half-siblings with individuals from Madagascar and Tanzania, over 7,000 km away.

Both genetic data and photo identification of the whale sharks sampled, facilitated the identification of individual whale sharks. Over the course of the Ningaloo Outlook project, 305 whale sharks were only seen once and 146 individuals had been seen more than once—one of which was seen on 5 separate field trips. The proportion of “resighted” whale sharks sampled, allows a population estimate of the total number of whale sharks that visit Ningaloo annually. While the whale sharks sampled for this project are primarily juveniles (and mainly males), they also include adult sharks with 19 mature male sharks sampled during over this timeframe. We estimate that around 500 individual whale sharks visit Ningaloo annually. These estimates are similar to previous records of around 300–500 sharks visiting annually, during the time of our sampling.

There are several documented aggregations in the Indian Ocean, however, to date, no evidence exists of movement between sites more than 2000 km away. Kin relationships (half sibling pairs (HSP)and full sibling pairs (FSP)) were examined as part of this project, using genetics from biopsy samples collected in the project’s field trips and from imported, overseas samples. A genetic whale shark library now exists with 392 samples from Ningaloo, 47 from Madagascar and 20 from Tanzania.

From these samples, 31 HSPs within the Ningaloo samples, 1 FSP within Ningaloo samples, 6 HSPs between Ningaloo and Madagascar, 2 HSPs from within the Madagascar samples, 5 HSPs between Tanzania and Ningaloo and 2 HSPs and 1 FSP between Tanzania and Madagascar were identified (Figure 18). Although, 19 mature males were sampled at Ningaloo, no parent-offspring pairs were detected in the samples.

These results suggest that there is significant mixing of adults in the greater Indian Ocean and that their shared offspring travel to different aggregation sites. Madagascar is ~7000 km from Ningaloo and Tanzania is >8000 km from Ningaloo, so the most plausible reason for juveniles sharing parents between these sites is that adults move widely with females either dropping pups at or near geographically isolated aggregation sites or juveniles dispersing long distances. Very few whale sharks smaller than 3 m have been reported anywhere, suggesting that sharks below this size may be more migratory.

Based on the samples collected during this project and the number of HSP and FSP pairs, our preliminary estimate is that there are approximately 5000 adult whale sharks contributing offspring to the Indian Ocean aggregation sites that we sampled. These results will be revised as additional samples from other aggregation sites are included and once a full model based on paternal and maternal relationships of the sibling pairs is developed.

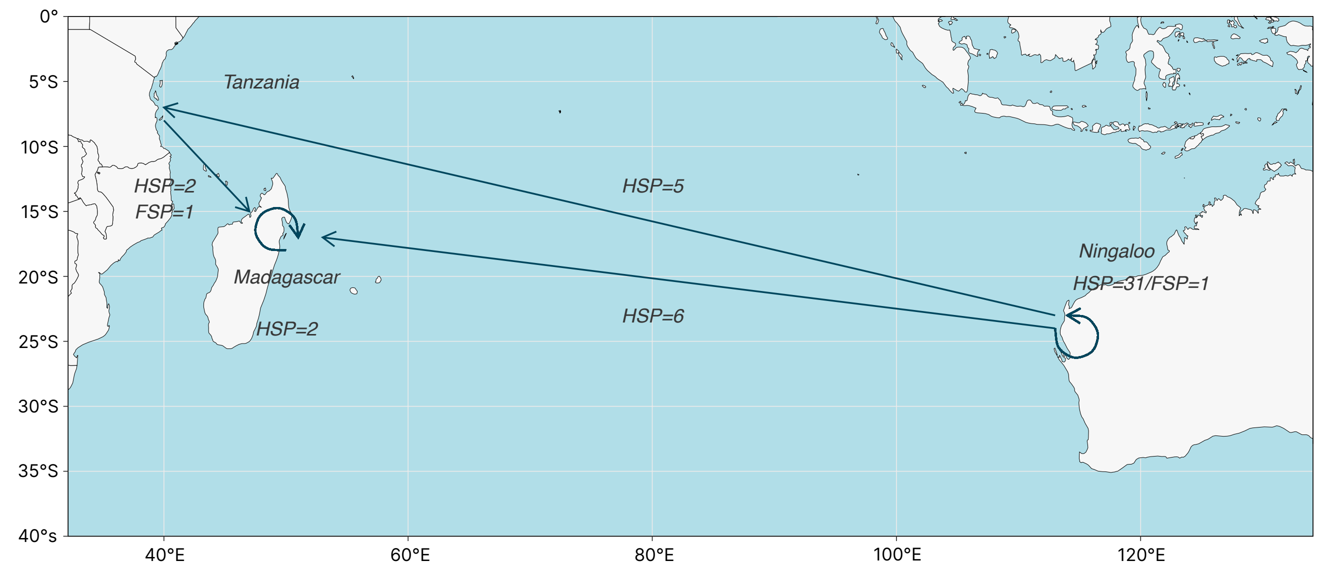



**Figure 18.** Kinship data from modern DNA sequencing shows the connectivity of whale shark aggregation sites around the Indian Ocean. FSP = Full Sibling Pair; HSP = Half Sibling Pair.

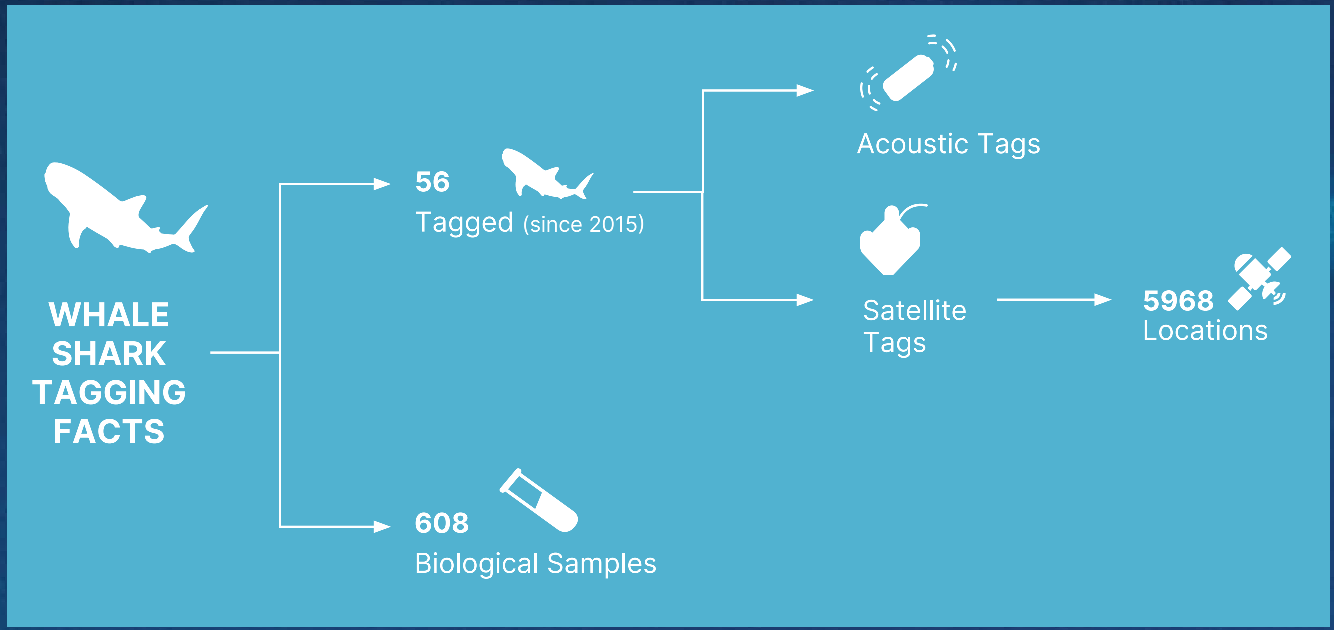





**Figure 19.** A modified Hawaiian sling and biopsy punch were used to collect tissue samples from individual sharks.

**Figure 20.** Researchers in the water with a whale shark, collecting vital information on length using a stereo video camera system (left diver) and identification photographs (right diver).

## Did you know?

World-First Mating Sighting: The first-ever photographed whale shark mating was captured at Ningaloo by a local aviation pilot.

Record-Breaking Pregnancy: The only known pregnant female whale shark, "Megamamma," measured 10.6 m and carried 300 pups, the largest litter ever recorded for any shark or ray.

Over the course of Ningaloo Outlook, 19 male and 19 female whale sharks were satellite tagged. The longest deployment of a tag was 340 days, but on average, the tags remained attached for 130 days providing data on horizontal and vertical movement. Whale sharks typically swam north after tagging with animals moving as far as Java (Indonesia), Papua New Guinea, Timor Sea and the Gulf of Carpentaria. Females departed Ningaloo earlier than males with both sexes moving back towards Ningaloo as sea surface temperatures in the tropics increased. Some whale sharks moved as far south as Perth in December/January with a few individuals tracked for nearly a year and all of these returned to Ningaloo.

# ENGAGEMENT

**Figure 21.** A CSIRO scientist talks to Exmouth District School students about the Ningaloo Outlook whale shark project and how these unique animals are now better understood from this research.

The team established strong collaborations with teachers at the Exmouth District School, and together they created hands-on STEM ('science, technology, engineering and mathematics') activities that brought real-world marine science into the classroom. The team worked directly with Years 3, 4 and 5 students, helping them explore how marine debris effects ocean ecosystems. In one activity, each student collected a piece of debris from their local beach and became a marine detective: investigating what it was, where it might have come from and how it could impact marine life. These discoveries sparked lively discussions about the "Three R's" (reduce, reuse, recycle) and inspired students to take action in their own lives to help protect the ocean.

During the annual Ningaloo Outlook turtle tagging surveys, year 9 and 10 science students observed scientists as they measured, tagged and took biopsies from turtles (Figure 22). They also attended lectures explaining how biology, physics and chemistry are used to answer complex ecological questions that inform conservation managers. The students also learnt about whale shark biology and the network of acoustic receivers located on the reef which monitor the movement of tagged animals (Figure 21).

Other students studying digital information technology built their own OpenROV (Remotely Operated Vehicle) at school and tested it in the local pool. Through this hands-on project, students learnt engineering principals whilst assembling their ROVs and discovered how to create three-dimensional images from "structure from motion" techniques. The activity highlighted how physics, engineering and technical skills play a vital role in marine research.

STEM activities expanded into "STEAM", through inclusion of the arts, when Dr Suzie Starfish visited younger primary school students with her unique blend of art and science (Figure 23). Her creative hands-on sessions engaged students' imaginations whilst building essential creative and critical thinking skills. From shark themed artworks to turtle storytelling, students explored visual learning techniques that highlighted the importance of the marine environment for both marine animals and people. These interactive lessons also demonstrated how science and technology is used to protect and manage the Ningaloo Marine Park.



Partnerships with numerous universities helped build scientific capacity. The team successfully guided six* PhD candidates through their research projects, supporting them in developing key skills in research, planning fieldwork and science communication. By working closely with Ningaloo Outlook researchers and academic supervisors, these students gained valuable experience presenting their findings to a range of audiences.

The engagement extended into the partners' own organisations. BHP and Woodside staff participated in tagging (and naming!) turtles, and Ningaloo Outlook researchers visited their offices in Perth to tell staff about what they had found, providing an opportunity to discuss the work together.

Sharing research with the scientific community is essential for validating findings, and the Ningaloo Outlook team took this responsibility seriously, delivering more than 100 presentations at scientific conferences and meetings across Australia and internationally, and also published over 40 peer reviewed journal articles.

The Ningaloo Outlook program aimed to deepen the understanding of the iconic Nyinggulu Reef and its unique marine life, and to share that knowledge with decision-makers responsible for its protection and sustainable use. Community involvement, youth education, and training were central pillars of the program.

The result was a comprehensive, integrated research effort focused on four core themes: Shallow Reefs, Deep Reefs, Turtles, and Whale Sharks. The team generated millions of data records that offered new insights, ranging from the composition of little-known deep-sea communities to the long-distance movements of whale sharks and green turtles. Shallow reef surveys were combined with historical datasets to build unique time series of coral and fish, revealing how these dynamic ecosystems have changed over more than two decades.

To uncover these insights, the team conducted dozens of field expeditions, applying innovative technologies and flexible approaches to tackle complex research questions. Their work prioritised delivering knowledge to those who would benefit most: policymakers, the Exmouth community, and especially the younger generation who will one day become the custodians of this remarkable place.

Ultimately, Ningaloo Outlook has shown that caring for this World Heritage-listed reef is a shared responsibility, one that belongs to researchers, industry, local communities, and resource managers. The program represents a lasting contribution to the ongoing effort to manage Nyinggulu wisely and protect it for generations to come.

* Although 7 PhD scholarships were funded, one candidate had to withdraw.

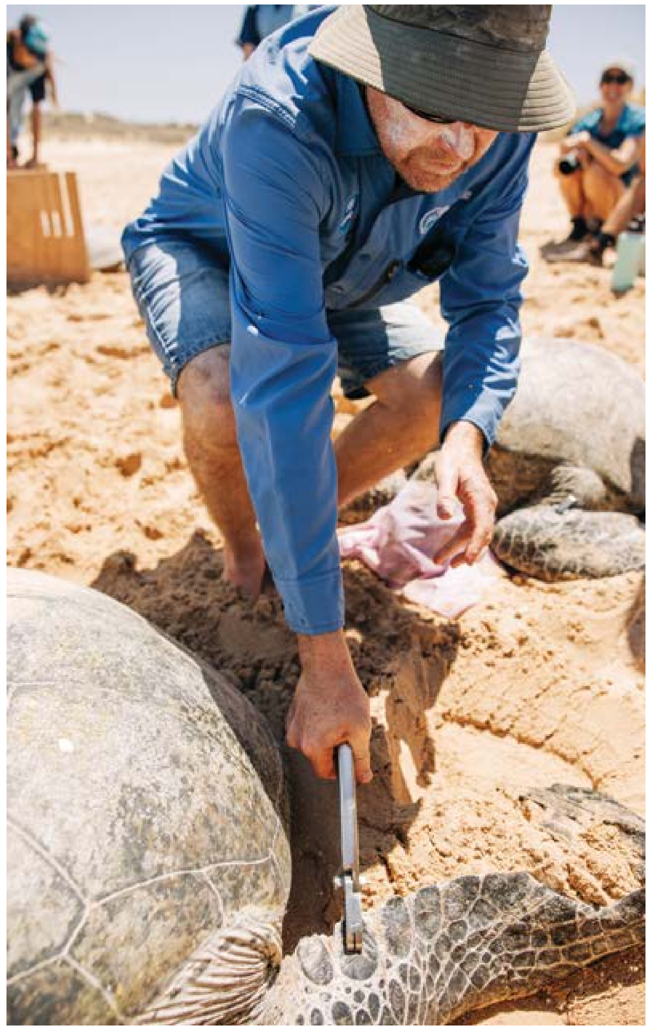


**Figure 22.** A CSIRO scientist explains to Exmouth District School students how the annual turtle tagging program has helped improve our understanding of turtle populations at Ningaloo Reef.

**Figure 23.** Dr Suzie Starfish and Exmouth District School students making turtle heart art during National Science Week.


## FOR MORE INFORMATION

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https://research.csiro.au/ningaloo/outlook/

This research is funded by Ningaloo Outlook (a strategic marine research partnership between CSIRO and Woodside Energy to better understand Ningaloo Reef and its important ecological values).

Images taken by Blue Media Exmouth, CSIRO, Dr Sue Pillans, Nick Thake Photography.