The Australian ghost shark's unusual 'nose' is covered in electroreceptors, which help it seek out hidden, hard-shelled prey.
Photo credit: Sheree Marris

CHASING GHOSTS

STORY BY **GARETH FRASER**

Delve into the deep secrets of the mysterious Australian ghost shark.

I'M IN MONASH University's Currie Lab, in Melbourne, pondering a batch of Australian ghost shark (*Callorhinchus milii*) eggs. With me is Dr Frank Tulenko, a research fellow in the lab, and we're both marvelling at how otherworldly the tough collagen capsules look – like something from the *Alien* film franchise. The embryo inside each is protected in a kind of cocoon that's surrounded by a frilled fringe, which helps it blend in and become securely attached to the seafloor. To lay eyes on these biological oddities is truly mind-blowing.

The Currie Lab, within the Australian Regenerative Medicine Institute, is one of few laboratories worldwide to study ghost sharks. Much of the natural history of these mysterious marine creatures – also known as elephant sharks or fish – is unknown to science. To have their eggs on hand is a rare privilege.

Elephant sharks are poorly studied because most species dwell in the deep sea. But a handful migrate to shallow waters to breed, and the Australian ghost shark is one of them. The species lives in the cold waters of the Southern Ocean and can be found along Australia's southern coastline – including Tasmania – and New Zealand. It has silvery skin, which makes it shimmer like an apparition in dark water. But the species' most unusual characteristic is a shovel-shaped 'nose' covered in electroreceptors that see it operate like a fleshy metal detector seeking prey. Each autumn, these odd fish migrate to a critical breeding and nursery ground for the species in the shallow waters of Victoria's Western Port Bay. Here, each female lays two large leathery eggs every few weeks during the March–May breeding season.

Made to withstand the ocean elements and predation, these cocoons secure the embryo ghost sharks that develop inside, separated from parental care, after they're deposited by females. The egg capsules keep the embryos safe during their long 6–8 month incubation, after which the young hatchlings emerge, self-sufficient and ready for the world.

Most species live in the ocean's dark depths and are inaccessible for study.

Western Port Bay is just 60km south of the Currie Lab, which has painstakingly, over many years of trial and error, figured out how to collect and harvest eggs from Australian ghost sharks. It's provided the opportunity for consistent study of the species' development and a rare opportunity to uncover the evolutionary secrets of these biological curiosities.

STRICTLY SPEAKING, GHOST sharks aren't sharks. Rather, they're part of an ancient group of related fish called chimaeras. These diverged from their shark cousins more than 400 million years ago and are as evolutionarily distant to sharks as sharks are to humans. They are, however, grouped in the same taxonomic class – Chondrichthyes, or cartilaginous fishes – as sharks, rays and skates.

The vast expanse of evolutionary time has concocted many oddball varieties in the ghost shark lineage, most of which are now extinct. The surviving 60 or so species are grouped into three families, each having a distinctive 'nose', or rostrum: long-nosed chimaeras (Rhinochimaeridae); short-nosed chimaeras (Chimaeridae); and shovel-nosed chimaeras (Callorhinchidae), which is evolutionarily the oldest group.

The Australian ghost shark is in the latter family. It's one of three known species in the family, all of which are found in the Southern Hemisphere. The other two are the American elephant fish (*Callorhinchus callorhynchus*) and South Africa's cape elephant fish (*Callorhinchus capensis*).

Research into sharks and their relatives is crucial for a complete picture of ocean ecosystem function; after all, these carnivorous fish are at or near the top of their food chains. The holy grail of cartilaginous fish research is locating breeding and nursery grounds, where adults congregate to mate and vulnerable young find refuge from predators to grow. Finding these places allows a better understanding of vital environments that are key to the conservation of threatened or vulnerable species – a category into which most sharks, rays and chimaeras fall.

Most chimaeras are understudied and therefore labelled as 'Least Concern' or 'Data Deficient' on international conservation lists. The Australian ghost shark has a stable population because it's not targeted by direct fisheries and is quota-protected for recreational fishing. It's listed as Least Concern on the IUCN Red List. In contrast, the American elephant fish is listed as Vulnerable because it's targeted by several fishing practices – such as gillnet, recreational and longline fishing – and is reported as the most common chondrichthyan caught in commercial shrimp fishing operations.

As well as their anomalous appearance, what makes ghost sharks particularly intriguing is that most species live in the ocean's dark depths, which makes them very hard to research. Scientists are usually limited to studying adult and juvenile specimens collected as bycatch from deep-sea trawl fisheries, or preserved specimens in museum collections such as the Australian National Fish Collection at the CSIRO Marine Laboratories in Hobart.

But adult specimens provide only limited information on the biology and morphological diversity of these fishes. To understand how these weird deep-sea wonders and their alien-like features form, we need eggs, which offer a window into their embryonic development.

Access to eggs and embryos of any ocean fish is difficult, and in these mostly deep-water animals, finding eggs is often impossible. Most chimaera eggs are lost to the ocean's depths and hardly ever seen by human eyes. Occasionally, deep-sea trawlers will capture empty egg cases; or, rarer still, they wash up on beaches. Locating ghost shark egg-laying sites is also difficult, even within known breeding grounds in the shallow tidal bays of southern Australia and New Zealand. There are often conflicting – sometimes historic – reports that ghost sharks lay either wherever is convenient or in mass egg deposits. The truth is ghost sharks continue to be a biological mystery, and we clearly need a better strategy to find and sustainably collect eggs to uncover the secrets of their unusual development.

SCIENTISTS AT THE Currie Lab, being just a stone's throw from Western Port Bay, have rare access to one of the Australian ghost shark's breeding and nursery grounds. Professor Pete Currie and his team have been successfully acquiring Australian ghost shark eggs for study for the past few decades. But rather than taking isolated eggs out of the environment, researchers go straight to the source: adult females carrying fertilised eggs.

Fisherfolk and collectors working in and around Western Port Bay – or Corner Inlet to the east – collect gravid females for the lab. That includes Steve McLeod, director of Oceanreef Aquaculture in Rosebud on the Mornington Peninsula. Steve releases females back to the wild after they lay eggs in his aquaculture facility. The eggs are then collected by the lab team and grown to the desired developmental stages for study.

My own collaboration with the Currie Lab has made it possible for me to gain rare access to these incredible ►

Few people have ever seen the egg capsules (left) that ghost sharks develop, let alone an embryo (above). This rare image was captured by Monash University's Currie Lab and has only been made possible thanks to intensive efforts to procure and study the eggs.

PHOTO CREDITS, FROM LEFT: FRANK TULENKO AND BEC DALE; COURTESY MONASH UNIVERSITY

A FOREHEAD WITH BITE

The head and cartilaginous skull of the Australian ghost shark is a very unusual structure – and this X-ray computed-tomography (CT) scan by the Florida Museum of Natural History (right) shows just how bizarre it is. Here you can see the strange skull and forehead jaw – the tenaculum (inset) – of this fish. You can also see the teeth that surround the strange appendage and the opposing second set of teeth, which are crucial for mating 'bites' used by males to secure females during copulation. Only chimaeras – not sharks or rays – have this odd forehead jaw protruding from the skull between the eyes. Studies are focused on understanding how this structure develops.

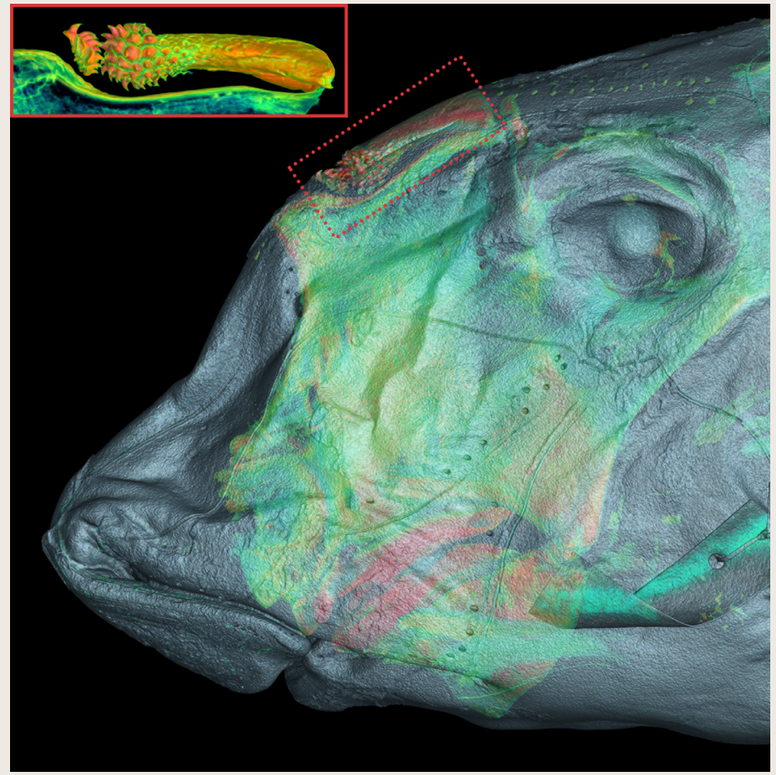

PHOTO CREDITS: GARETH FRASER AND ELLA NICKLIN

Ghost shark heads have a number of peculiar features that truly set them apart from all other vertebrates.

Australian ghost sharks can be found in shallow tidal bays across parts of southern Australia from March to May.
Photo credits: Sheree Marris

embryos. This follows years of studying juvenile and adult short-nosed chimaeras in the Pacific Northwest of the US, coupled with the disappointment of a consistent lack of embryos.

All this rare insight into ghost shark development has provided incredible new discoveries, revealing how the strange anatomies of these chimaeras emerge during the early stages of embryonic form to later become the adult structures that characterise this most bizarre group. This embryonic window is essential for understanding not only the development of this group of understudied fishes but also the evolutionary diversity that has resulted from their phylogenetic past (evolutionary history). Knowledge like this is crucial for building a complete picture of vertebrate evolution.

As well as their unusual 'noses' (rostral projections), ghost shark heads have a number of peculiar features that truly set them apart from all other vertebrates. For one, their teeth are nothing like shark teeth, but they instead have a set of tooth plates on their jaws. Their head shape, odd rodent-like teeth and rat-like whip-tails have earned them common names such as 'rabbitfish' and 'ratfish'.

Even more bizarre is the tenaculum (see breakout, page 43), an appendage on its forehead between its huge eyes. The appendage can extend erect from its head, and then return to its forehead pouch on demand. This feature is found only in males, and we think it's used during mating, providing the male with an extra 'bite' to grip the female's pectoral fins during copulation. Interestingly, real sharks mate in a very similar way to ghost sharks – males use jaws and teeth to gain purchase of female fins. Ghost sharks, with their awkwardly small mouths and beaked dentition, cannot 'bite' in the same way as real sharks, so over millions of years of evolution they've adapted and refined their truly bizarre forehead jaws for this possibly singular function.

Just take a second to think about how truly outlandish this structure is: a cartilaginous rod sticking out of the forehead, covered in teeth. (Work in my lab has classified these tooth-like embellishments as teeth, more closely related to oral teeth based on genetics and fossil evidence.) Ghost sharks are the only animals to have an opposable set of tenaculum teeth – just like a jaw – on the inside of their forehead pouch, separate from the actual mouth used for feeding.

The obvious question, of course, is why do we need to study embryonic development if these structures are only present in adult males? The answer is a common one for developmental biologists: there's an embryonic source for all skeletal elements.

With regard to the tenaculum, we use embryos to chart the developmental origins of these odd structures. The male-only adult appendage first arises in early-stage embryos – the same embryos hidden within their alien-like egg cases. The early embryonic head develops with an enormous bulge, like an inflated balloon on top of the developing head. This structure then 'deflates' during several weeks of growth before it condenses into a spot on the forehead, which we call the 'pimple'. This is the site of the future tenaculum. Importantly, we see this in both young males *and* females, suggesting that only later in its development does a male grow a tenaculum, while a female loses it.

These discoveries of morphological novelty would be lost if we didn't have access to eggs and embryos – plus, we might not know as much about this important group of shark relatives and their role in the story of vertebrate evolution. Finding ghost shark eggs is tricky, especially with a changing planet and habitat shifts. But when we do find them and preserve their delicate breeding grounds, we benefit from learning more about these otherwise hidden and important inhabitants of the Southern Ocean.

In recent years, Western Port Bay has experienced a massive reduction in seagrass as part of overall habitat loss due to turbidity – sediment pollution – and nutrient pollution from its catchment. This has hugely impacted the animals that call the bay home. The number of ghost sharks, along with other migrating visitors, has dwindled. Local sightings and fishing reports help inform where else these already hard-to-find fish visit during breeding. Sites around Australia's south coast offer science a rare opportunity to study ghost shark biology, and so the preservation and conservation of these Australian habitats are vitally important for all the inhabitants of this delicate ecosystem. ■

Dr Gareth Fraser, from the University of Florida, in the US, is currently based at Monash University, in Melbourne.