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Sound in the sea

Tracking inshore fish

Whistlers of the waves

Deep-sea drumming

Listening to the seafloor

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Editorial enquiries
The Editor | e-mail: Quest-Editor@assaf.org.za

Advertising enquiries
Barbara Spence | Avenue Advertising
PO Box 71308, Bryanston 2021
Tel: (011) 463 7940 | Cell: 082 881 3454
e-mail: barbara@avenue.co.za

Subscription enquiries and back ssues
Tsepo Majake | Tel: (012) 349 6645
e-mail: tsepo@assaf.org.za

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Cover image
Divers check an acoustic receiver
by Ryan Daly

Sound in the sea

During COVID-19 lockdowns around the world, stories of wildlife venturing closer to human habitation or apparently thriving thanks to the reduction of human activity, traffic and noise have circulated in both the mainstream media and social media. The effect extends to the oceans too, and this has provided the perfect opportunity to conduct a project that was first conceptualised a decade ago. Called the International Quiet Ocean Experiment (IQOE), it aims to improve understanding of background sound in the sea – the 'soundscape' – and the effects of noise on marine life. By early February 2021, IQOE project leaders had coordinated a network of more than 230 hydrophones operated by various groups in different parts of the world. Software has been developed to standardise data analysis, allowing the project participants to contribute to a global database that can be used to investigate changes in ocean sound during the pandemic.

Sound in the sea was first intensively monitored during the 1950s, when the US Navy set up SOSUS – the Sound Surveillance System – to track Soviet submarines. A network of hydrophones was installed along the edge of the continental shelf on the east and west coasts of the United States and around Hawaii. These hydrophones listened in on sound transmitted via the 'deep sound channel', also known as the SOFAR (Sound Fixing And Ranging) channel. This is simply a layer in the world's oceans where low-frequency sound travels great distances because it is effectively trapped between warm water near the surface and the increased pressure of deep waters. It exists because the speed of sound decreases with temperature and pressure, so at the depth of the water column where both are relatively low, the speed of sound is at a minimum. Since sound waves are refracted towards the area of slower speed, those in the SOFAR channel bend back when they encounter the warm waters above or the higher-pressure waters below. By bouncing between these layers, sound waves can travel long distances with little loss of energy, or attenuation. The SOFAR channel varies in depth according to the local salinity, temperature and water depth, but its axis lies about 600–1200 m below the sea surface in low and mid latitudes.

By the end of the Cold War in 1991, the US Navy had started to allow some government and civilian research groups to use SOSUS to monitor undersea volcanic and seismic activity, whale migration and vocalisation, and later oceanographic conditions for climate change studies. Scientists were already using hydrophones moored in coastal waters or deployed from boats – Roger Payne famously discovered the songs of the humpback whales in 1967 – and underwater acoustics were also being widely used to map the seafloor and survey fish stocks.

The year 2021 marks the start of the Decade of Ocean Science for Sustainable Development (2021–2030) proclaimed by the United Nations. The 'Ocean Decade' provides a framework to ensure that ocean science can support countries in their efforts to reverse the decline in ocean health and achieve the 2030 Agenda for Sustainable Development. In celebration of this global event, this issue of *Quest* focuses on 'Sound in the sea', and features relevant research carried out by South African scientists.

Sue Matthews
Quest Editor

Lesisiqephu se *Quest* sibhekene nomsindo wasolwandle. Isivinini sinyuka kanye nezinga lokushisa Kanye nencindezi. Okusho ukuthi umsindo ushesha kakhulu emanzini angaphezulu afudumele ezindaweni ezishonayo bese uhamba ngesivinini esiphansi ezindaweni eziphakathi nolwandle.

Translated by Zamantimande Kunene

WHALE SONG

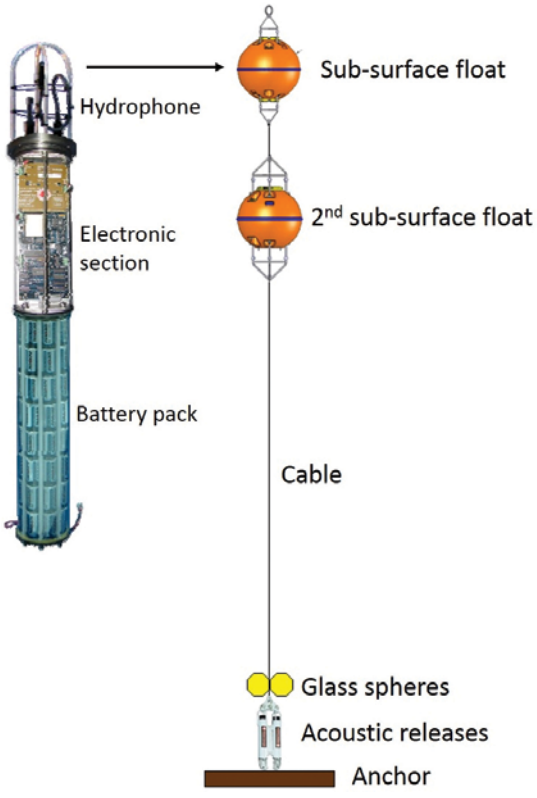
NOAA

Fannie Shabangu tells us about the underwater melodies of ocean giants

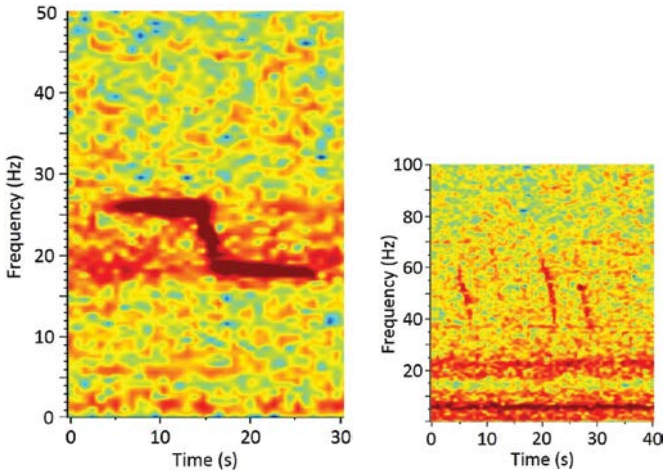
Reaching a maximum recorded length of 30 m, weighing as much as 148 000 kg, with a heart roughly the weight of a small car, and living more than 90 years, Antarctic blue whales are the largest animals on Earth. Fin whales come a close second, growing up to 27 m long. The two species are classified by the International Union for the Conservation of Nature (IUCN) as critically endangered and endangered, respectively.

Both used to be commonly encountered on the west and east coasts of South Africa, but many were killed during the whaling era, which began in the 1790s and ended in the 1970s. Whale blubber and baleen were used for products such as lamp oil, margarine, cooking oil, candles, soaps, cosmetics, corsets, umbrellas and tennis racquets, while whale meat was sold for human consumption, animal feed and fertilizer. As a result, these two whale species were reduced to precariously low population sizes, and it is now rare to see them along the South African coast.

These and other baleen whales, or mysticetes, which filter food through baleen plates, produce some of the loudest sounds ever recorded. The sounds, which are species- and region-specific, can be produced as individual, often repeated, calls or merged into sequences as songs that last from minutes to hours, days and sometimes weeks. For example, humpback whales are known for singing rhythmic songs throughout their distribution range. Most baleen whale sounds have a frequency below 100 Hz (100 sound wave cycles per second), and can be detected by underwater



Not-to-scale diagram of a hydrophone attached to the top sub-surface float of an oceanographic mooring. The hydrophone is equipped with a battery pack allowing autonomous recording of acoustic data for more than a year.



Spectrograms showing a Z-call (left) and D-calls (right) by Antarctic blue whales recorded off the west coast of South Africa. Spectrograms are visual representations of the spectrum of a sound changing through time.

instruments called hydrophones from tens to thousands of kilometres away. Distances travelled by these sounds depend on water temperature, ocean noise and sea bottom type, among other things.

The study of listening to and recording sounds produced by animals is called bioacoustics, and the method of conducting such listening and recording is called passive acoustic monitoring (PAM). The main advantage of using PAM to study these animals' occurrence is that it is a non-invasive and non-lethal method that can be conducted at low cost, independent of weather and daylight conditions. Furthermore, sound is an important component of these ocean giants' life as they use it for short- and long-range communication, navigation and avoidance of sounds associated with danger. They produce sounds underwater using specialised vocal cords, other body parts or unknown mechanisms.

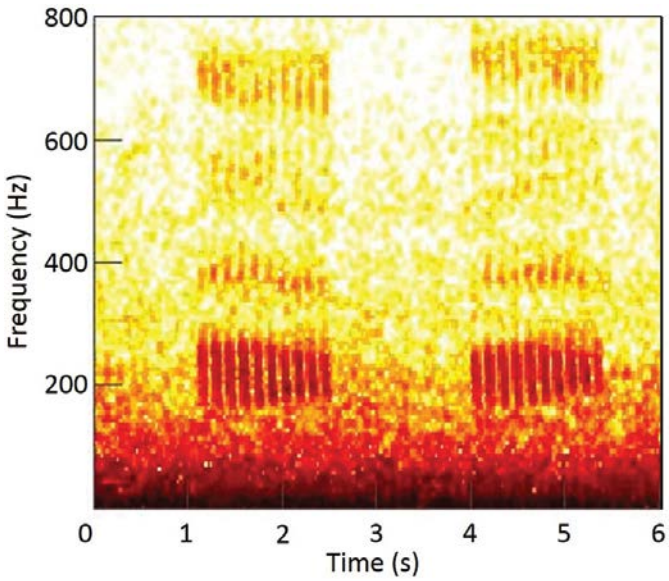
Since these whales are rarely seen during traditional sighting surveys aboard research vessels, their recovery post-whaling remains uncertain, but their sounds are useful for telling us about the behaviour and seasonality of these animals in their important and preferred habitats. My colleagues and I monitored these ocean giants in Antarctic and South African waters using hydrophones deployed on moorings. Antarctic blue whales produce two types of calls: D- and Z-calls. D-calls are produced by both sexes for short-distance communication during feeding and for antagonistic interaction during mating. Z-calls (so-called due to their resemblance to the letter Z on a spectrogram – a visual representation of a sound signal) are characteristic of Antarctic blue whales and produced only by males for long-distance communication as individual units or in song form to attract females. Fin whales also produce two types of calls: the 20 Hz pulse used by males for communication (it can also be produced in song form), and the 40 Hz pulse probably used during feeding.

Our research indicated that these whales are in South African waters from May to November. This finding is very important in informing local and international management and conservation efforts of a useful habitat of these species. Results of our studies also suggest that these whales might be feeding off the west coast, which enables them to remain in our waters for extended periods, up to the entire year. Some of the whales migrate between Antarctica to feed during summer and the low latitudes of southern Africa, Australasia and Patagonia to overwinter, breed or calve. Most whales move out of Antarctica when the sea surface is frozen in winter, although some animals remain there in winter, most likely by staying on the edge of the sea ice or using open waters surrounded by sea ice, called polynyas. Warmer waters of the low latitudes, such as South Africa's west coast, provide nursery areas for these whales as they promote fast growth of calves.

Southern right whales calve mainly on the south-east coast of South Africa, and can be commonly seen during the famous Whale Festival in the coastal town of Hermanus in September. The adult whales can grow up to 17 m in length, weigh more than 80 000 kg and have an estimated lifespan of up to 80 years. These whales produce up to 13 call types depending on the behavioural state – resting, swimming, mating, feeding, etc. My colleagues and I recorded the 'gunshot' sound of southern right whales off the west coast of South Africa, mainly in October when most whales are expected to be in this area. These sounds, which sound like a rifle being fired, are broadband (30–34 000 Hz) sounds believed to function as an antagonistic signal between males, as communication between mother–calf pairs and also as an echolocation method. However, it is not known

Pavel Spindler, CC BY 3.0

Southern right whales can be seen in Walker Bay from the cliffs of Hermanus and De Kelders from July to November.



A spectrogram showing the new subcall type of Antarctic minke whale, bioduck B2, which the research team discovered in Antarctic and South African waters. Bioduck B2 calls consist of 10 pulses.

how this sound is produced. Our PAM results showed that years with low gunshot sounds corresponded well with low whale counts from aerial surveys conducted by the Marine Research Institute Whale Unit of the University of Pretoria, indicating that PAM can be successfully used to monitor species of concern in South African waters.

Our PAM research also showed that Antarctic minke whales in Antarctic and South African waters have similar call types. These calls range in frequency from 60 Hz to 311 Hz, and are called bioducks because the researchers who first heard them underwater thought they sounded like duck quacks. Additionally, our PAM results suggest that there could be two acoustic populations of Antarctic minke whales, the first one from the western Antarctic Peninsula and the second one from the eastern Weddell Sea. Such work shows that it might be possible to tell where Antarctic minke whales originate based on recorded call type. Antarctic minke whales are one of the smallest baleen whale species, growing up to 10.7 m, weighing a maximum of 9 100 kg and living between 50 and 70 years.

MRI Whale Unit, University of Pretoria

A sperm whale shows its tail flukes before going for a long, deep dive.

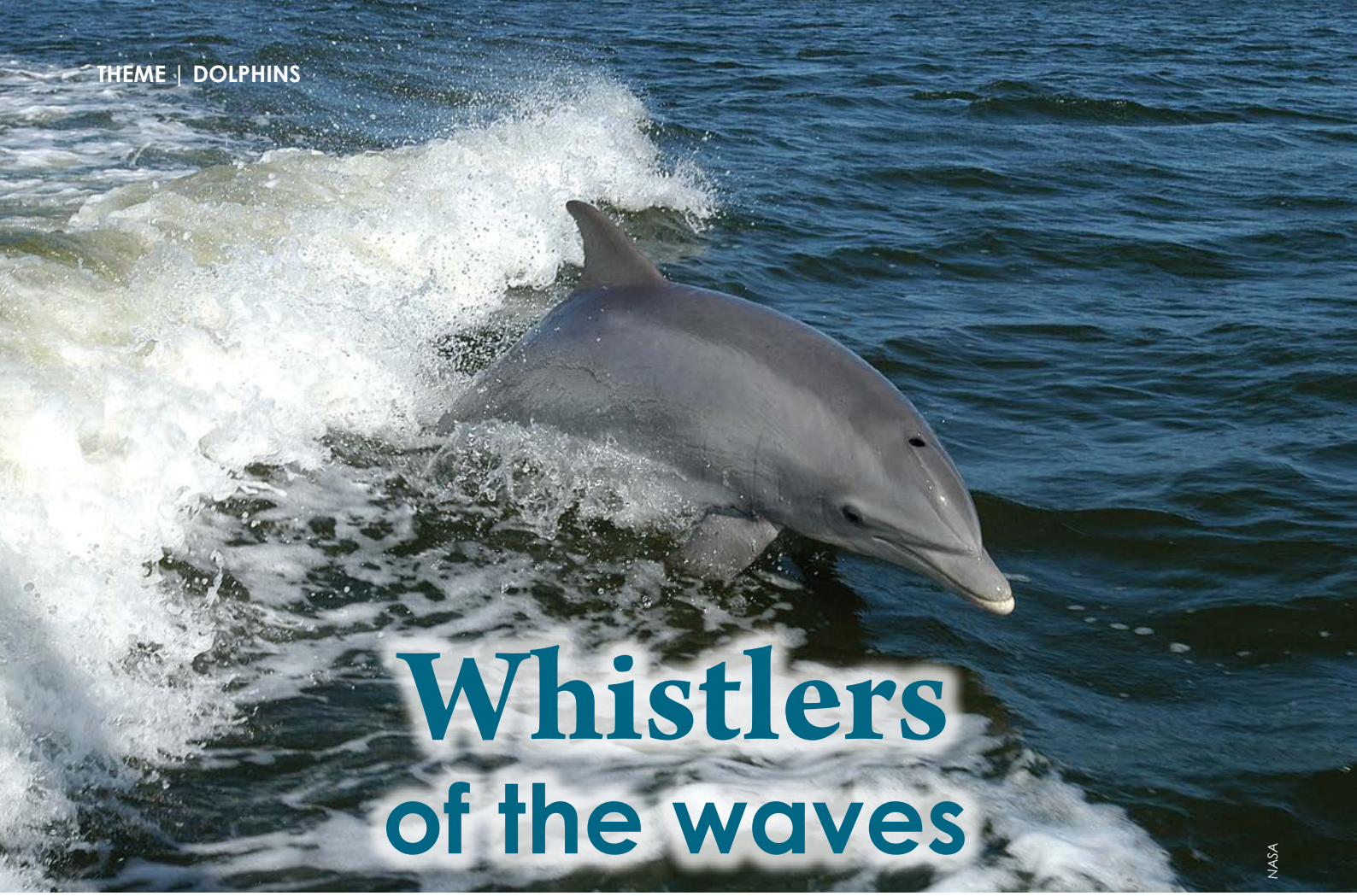
Sperm whales are the largest of the odontocetes – the toothed whales – growing up to 19 m, weighing up to 57 000 kg and living to at least 70 years. They produce the second loudest sounds to those of blue whales, and their sounds are called clicks. These powerful, broadband (10–32 000 Hz) clicks were first thought to be used for stunning or disorienting prey, predominantly giant squid. However, recent research has revealed that clicks are used purely for echolocation. My own research shows that sperm whale clicks are present throughout the year off the west coast of South Africa, probably because of the year-round availability of prey and suitable environmental conditions. Sperm whales can dive to an estimated depth of 3 200 m, spending two or more hours underwater without breathing. This deep-diving behaviour makes them difficult to study with other observation methods, but a suitable species for PAM as they are continuously clicking throughout their dives.

The ocean is a noisy environment, where noise is produced by multiple sources including marine organisms, weather conditions, earthquakes and human activities. Some of the noise is tolerated by the ocean giants and other marine organisms, whereas certain noise types are harmful to them, as they lead to physiological damages and behavioural changes. Some of my PAM research quantifies ocean noise levels in relation to whale acoustic occurrence and behaviour, with the aim of providing baseline information needed to advise management and conservation authorities on how to curb animals' disturbance by noise produced through human activities. Such activities include gas and oil exploration, ecotourism and shipping in our oceans.

Given that human activities are increasing, and oceans are becoming noisier, it is very important that PAM be conducted to gauge impacts of our actions on marine organisms. Since PAM research is still in its developing phase in South Africa, more expertise in this field is needed to help us fully understand the functioning of our marine system.

- Visit the 'Discovery of sounds in the sea' website to listen to recordings of various whale and dolphin species: https://dosits.org/galleries/audio-gallery/

Dr Fannie Shabangu has been employed at the Department of Environment, Forestry and Fisheries (DEFF) since 2009, the same year that he completed his master's degree at the University of Bergen in Norway, following honours and undergraduate degrees at the University of Limpopo. In 2018 he was awarded his PhD by the University of Pretoria for his thesis on acoustic assessment of the seasonal occurrence and behaviour of Antarctic blue whales in the south-eastern Atlantic and Southern Oceans.



Whistlers of the waves

NASA

Tess Gridley reports on her team's research on dolphin communication

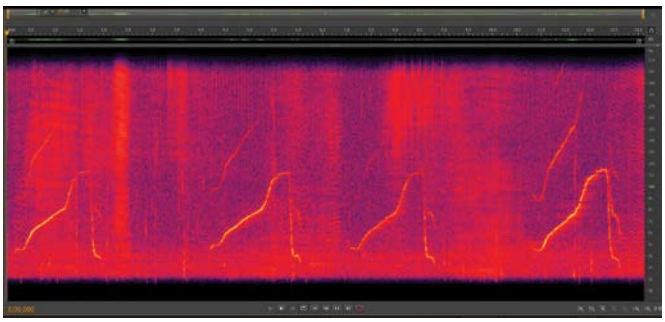
From the day they are born, dolphins produce high-pitched whistles. At first the whistle contours are quite varied and unclear, but within a few months calves develop an individually distinctive whistle contour, through learning and practice. These whistle contours are used by each dolphin when communicating with other dolphins, so they act somewhat like a name in human society. Called 'signature whistles', they remain very stable over time, with the result that dolphins recorded on separate occasions decades apart have been found to still be using the same whistle contour.

Dolphins may recognise each other's signature whistle for a similar time span. This communication system helps dolphins develop important relationships within the population, as well as ensuring that mothers and calves or affiliated males can stay together in the dynamic underwater environment. Such relationships continue over long periods, and communicating with signature whistles allows strong bonds between individuals to be formed and maintained.

More than 50 years of research has been carried out to understand how dolphins develop and use these signature whistles, with a wealth of information collected around the world from captive, temporarily restrained and wild dolphins. In southern Africa, our team members from Sea Search / Namibian Dolphin Project – associated with Stellenbosch University but hosting postgraduates from other local and foreign universities too – have been studying the behaviour of wild dolphins for over a decade.

In Namibia, we have recorded bottlenose dolphins (*Tursiops truncatus*) under different behavioural settings and catalogued over 50 signature whistles from a population of around 100 individuals. In research published in the *Journal of Mammalogy* in 2020, we were able to calculate a population abundance estimate using signature whistles by applying a statistical method called mark-recapture. The resulting estimate was very similar to that calculated using the standard method, which relies on photo-identification of the dolphins' dorsal fin.

Further research using this passive acoustic monitoring (PAM) technique is planned in both Namibian and South African coastal waters. By recording the signature whistles produced by dolphins as they move around in their natural habitat, the team will document individual dolphins in space and time. This will allow the number of



Sea Search

A spectrogram (sometimes called a sonogram) of bottlenose dolphin whistles.

Clicks and acoustic crypsis

Simon Elwen

Heaviside's dolphins don't whistle, but probably use clicks for communication.

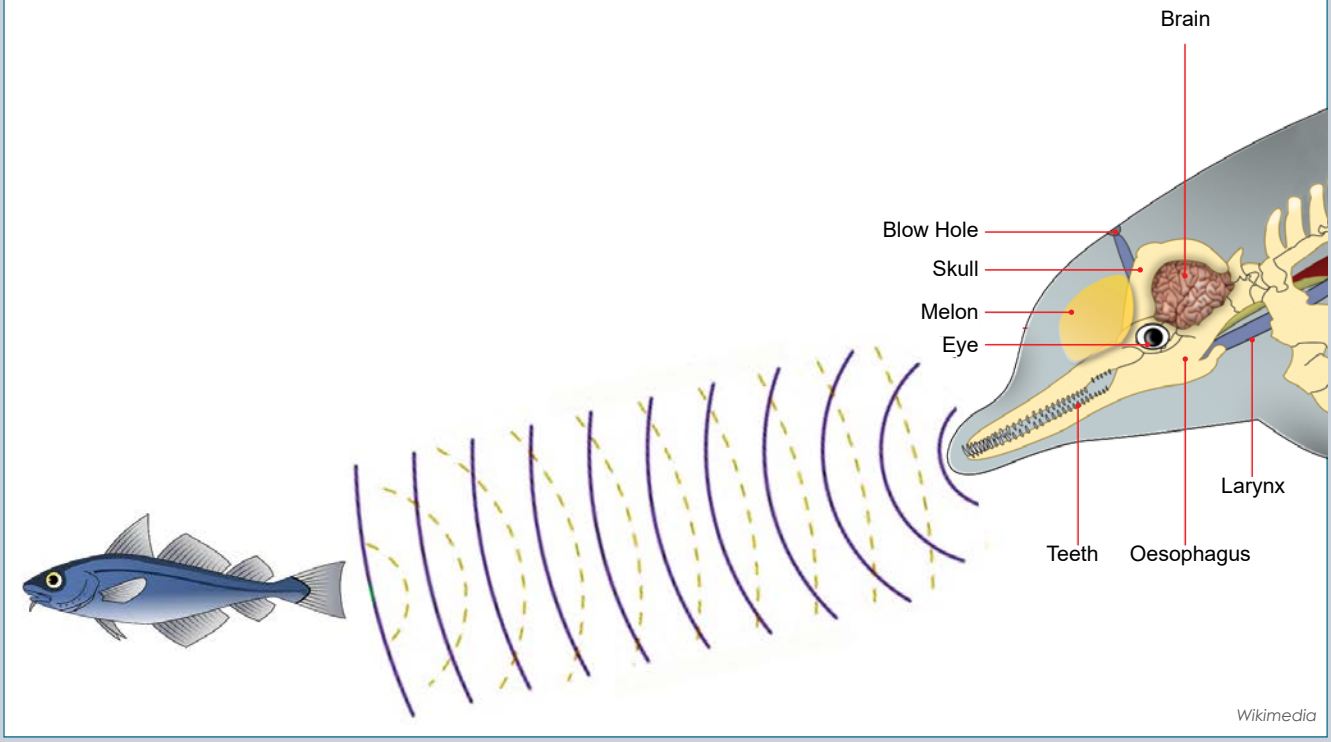
All dolphin species use echolocation to help 'see' the underwater world around them. By producing loud clicks and then processing the returning echo, dolphins can avoid obstacles and detect prey, for example. When they find a prey item, they tend to speed up the clicking so that they can home in on it. As the clicks are produced at faster rates, the interval between individual clicks is shortened, turning the sound into a feeding buzz that allows the dolphin to track and capture its target.

Heaviside's dolphins (*Cephalorhynchus heavisidii*) are small dolphins found only in the Benguela Current ecosystem along the south-western coast of Africa. Together with other members of the genus, these dolphins do not whistle, and have long been thought to produce clicks only for echolocation, but we suspect they use clicks to communicate too.

When foraging, Heaviside's dolphins produce very high-frequency echolocation clicks at 125 kHz. These ultrasonic clicks are beyond the range of human hearing, which at its best extends up to 20 kHz. Killer whales, also called orcas (*Orcinus orca*), can't hear these clicks either, and we think this is a great advantage for the dolphins as they can forage without being detected by the predators, sometimes referred to as the 'wolves of the sea' because they hunt in groups like wolf packs. The behavioural adaptation of modifying the structure of calls to avoid detection by eavesdropping predators, such as changing the volume or pitch, is known as acoustic crypsis, and is practised by many whales and dolphins.

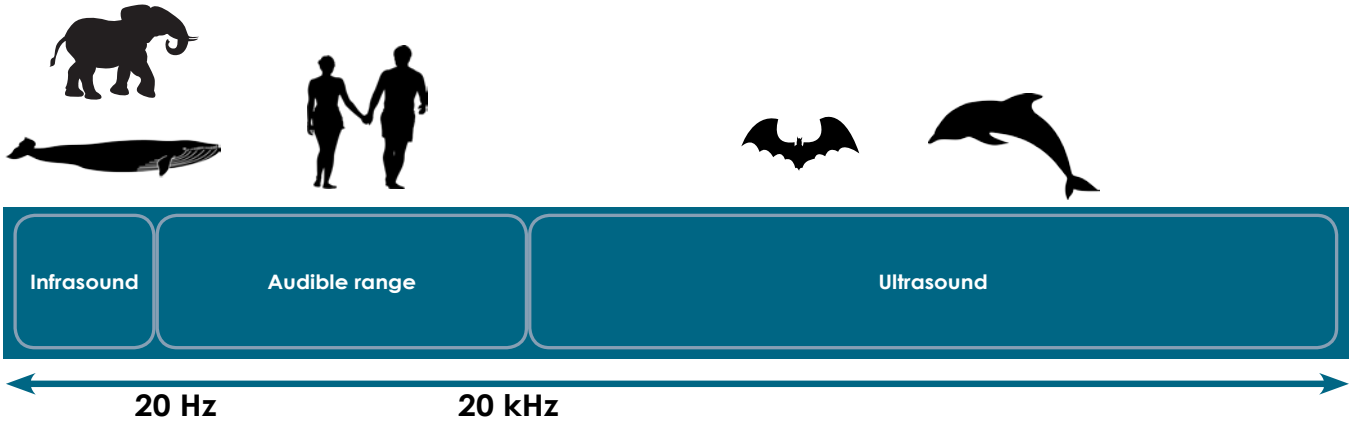
When communicating with each other, though, Heaviside's dolphins produce lower-frequency sounds that apparently overlap with the hearing range of killer whales. The dolphins arrange the clicks at these times in a different way, producing them very quickly, with different sound properties, and also in patterns, like a sort of Morse code, which all helps to communicate different information.

In this instance, they appear to have relaxed the acoustic crypsis in order to communicate with other animals in the area – but this can be costly as predators can overhear the 'dolphin chatter'.



Wikimedia

Dolphins use echolocation clicks to detect underwater objects, including prey items. The outgoing sound waves from these clicks – produced by air movements in the nasal passages – are focused into a beam by the melon, a mass of fatty tissue in the forehead.



Whistles produced by humpback dolphins have a frequency of about 35 kHz, while echolocation clicks produced by Heaviside's dolphins during foraging are in the region of 125 kHz. These sounds are in the ultrasonic range, and cannot be heard by humans.

Chantel Elston

The Indian Ocean humpback dolphin is considered South Africa's most endangered marine mammal.

Sea Search

Sea Search team members study the behaviour of wild dolphins, record their sounds and estimate their numbers.

dolphins in a population as well as dolphin density (the number per unit of area) to be determined, and provide information on the size of an individual's home range.

The South Africa-based project focuses on the locally endangered Indian Ocean humpback dolphin (*Sousa plumbea*), which has an estimated population size of 250 to 500 individuals in our waters. The population is threatened by human activities including noise pollution, overfishing, boat interactions, shark nets and coastal construction. Data collection will therefore be invaluable to inform conservation action and management options for the species, allowing for improved protection.

Although signature whistle use is well documented in bottlenose dolphins, much less is known about humpback dolphin vocalisations, so a first step is to record and document the vocal repertoire of the South African population. Since 2019 we have been collecting recordings at multiple locations around the coast. This has revealed that humpback dolphins make very high-pitched whistles, with frequencies up to 35 kHz (much higher than bottlenose dolphins), as well as lots of interesting clicks, grunts and burst-pulse sounds.

Preliminary analysis of existing data suggests that humpback dolphins also use signature whistles. These will be identified using SIGID, a signature identification technique developed by Janick and co-authors in 2013. It analyses the timing of whistles in the acoustic recordings and if very similar whistles are produced close together – repeated every 10 seconds of raster – it's very likely the individual is calling its signature whistle. These calls are then catalogued and matched over time so that we can create 'capture histories' of when different individuals were in an area. The SIGID technique offers a cost-effective and low-impact method for studying dolphins.

Although several studies have documented signature whistle use in humpback dolphin species, there are no published reports of the acoustic behaviour of our study species, *S. plumbea*, so this is an exciting project that will provide important information on the whereabouts of this endangered species.

- For more information, see the Sea Search Research and Conservation website http://seasearch.co.za or YouTube channel.
- Report your sightings of humpback dolphins and other marine mammals on the SeafariApp or via the website http://www.seafariapp.org/

Dr Tess Gridley is Co-Director of Sea Search and the Namibian Dolphin Project. In March 2018 she initiated the African Bioacoustics Community, which convened its second international conference in November 2020, held online. She was awarded her PhD by the University of St Andrews, Scotland, in 2011.

CURRICULUM CORNER

PHYSICAL SCIENCE: GRADE 10
Sound: pitch, frequency, ultrasound

DEEP-SEA DRUMMING

Dave Japp and Kerry Sink explain whether something fishy is going on

On the edge of the continental shelf at the south-eastern tip of Africa, a rocky ridge rises from the ocean floor in the murky depths some 750 m beneath the surface. Beyond this submarine feature, which is no more than 500 m wide, 300 m high and 40 km long, the shelf falls away steeply and the warm Agulhas Current rushes past. On the landward side, the ridge forms a natural amphitheatre, and here the kingklip take 'centre stage', their calls booming out across the seascape.

Dave Japp with a kingklip caught during the longline experiment in the 1980s.

This is how we imagine the 'Kingklip Kingdom', which lies more than 30 nautical miles off the coast between Port Elizabeth and Cape St Francis.

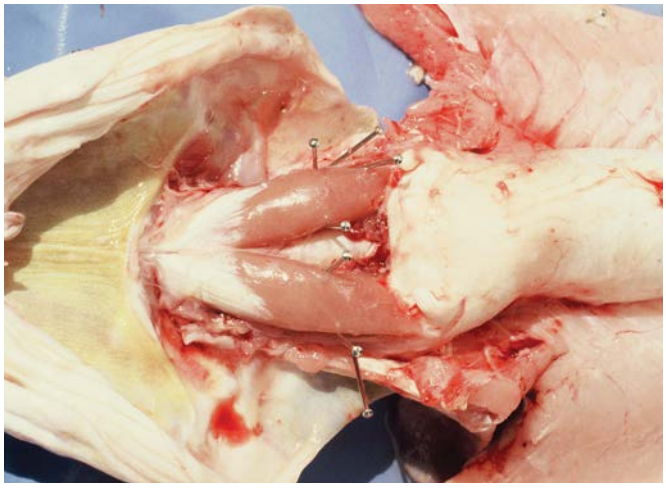
Kingklip, or 'king of the rocks', were caught even before trawling began in South Africa's seas in the early 1900s, and they remain one of our most valuable seafoods. They are part of a large group of bony fish known as cusk-eels or Ophidiiformes, a name derived from the Greek word for 'snake' – *ophis* – because of their eel-like appearance. Although rather ugly, slimy fish, they are among the most delicious to eat, providing a tasty and firm white fillet on the plate.

The genus *Genypterus* is only found in the southern hemisphere and the species known as kingklip, *Genypterus capensis*, occurs only in the waters off southern Africa, its range extending from Namibia, around our three Cape provinces, into KwaZulu-Natal and possibly even southern Mozambique. Adult fish can reach a length of 1.5 m during their approximately 40-year lifespan, and they are ferocious predators, active mostly at night. Since they in any case live mainly in deep, dark bottom waters, they have physical and behavioural adaptations for finding food in the dark, including whisker-like barbels for feeling seafloor organisms, and a 'sit-and-wait' approach to ambush and stalk passing prey. The most interesting part of their biology, though, is that they are underwater acoustic champions, and this is how they probably find one another for something akin to an orgy at particular times of year.

Kingklip sound production

Sound is used by many fish species as a means of communication, whether to signal to competitors, scare intruders away from eggs or young, send alarm calls or attract mates. Different mechanisms of sound production are used, but most either involve the swim bladder or stridulation – the rubbing together of teeth or bones, such as the spines in the pectoral fins.

In kingklip, sounds are produced using sonic muscles located on or near the swim bladder, in a mechanism



A dissection of a male kingklip showing the large sonic muscles.

known as drumming. Both males and females have tough swim bladders – so tough in fact that they are only possible to cut with strong, well-sharpened blades. Both sexes have sonic muscles too, but they are significantly larger in males than in females, particularly at peak spawning time from July through to September.

The sonic muscles attach directly to the swim bladder and insert firmly on the vertebrae with ligaments at a position directly adjacent to a large pair of otoliths, the fish ear bones that are essential for hearing. The muscles, swim bladder, otoliths and bone attachments (rocker arms) form a sophisticated and complex acoustic structure used for both the production and reception of drumming sounds. Tank-based studies of similar ophid species have shown that the males and females may produce sounds of different frequencies. In the kingklip's natural environment, where visual cues are not likely except at close range, this would clearly be an advantage in finding a mate.

Some other fish species also engage in drumming, and have similar seasonal and spatial patterns of sound production. Identifying such patterns can provide useful information for managing certain fish stocks or the different habitat types they occupy. What makes kingklip particularly interesting is that we have been exploiting them for over a century, but remained largely oblivious to the importance of the biological and behavioural mechanisms they evolved over millions of years, and the significance this might have for their management as a commercial fishery.

The kingklip fishery

Kingklip are caught in the bottom-trawl fishery, which primarily targets Cape hake. Early studies on kingklip focused on basic stock dynamics of the species such as trawl catch rates, age and growth, and reproductive biology. That changed in the 1980s, when an experimental fishery was conducted over six years using a completely different fishing method – bottom longlines. This entailed setting lines on the seafloor, each containing up to 15 000 hooks spaced at 1.5 m intervals. Initially intended for hake, fishers soon found that the longlines were perfect for catching kingklip.

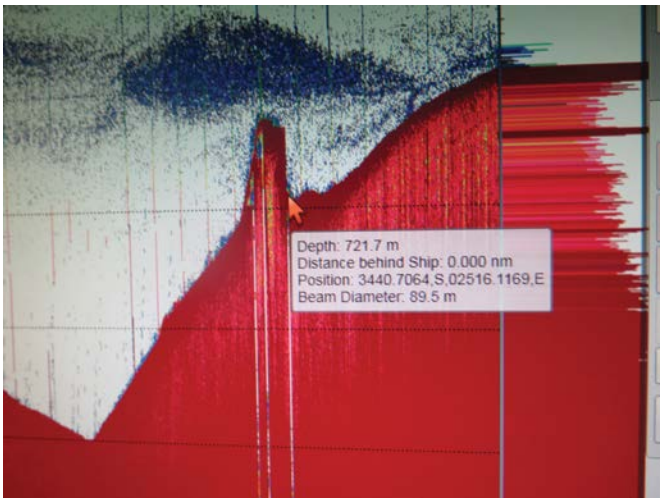
In such 'offshore' fisheries, little is often known about the life histories of the many different fish species that occur in deep waters. When exploiting these deep-sea species, a cautious approach should be followed, at least until sea-based studies can be done to assess the impacts of the new fishery. The 'kingklip experiment' therefore focused on getting the information needed to determine the potential of establishing a sustainable longline fishery for kingklip. Managers controlled how many boats could fish, and for the duration of the experiment kingklip were more intensively sampled than ever before. While kingklip were caught around the entire coast from Namibia and southwards towards Port Elizabeth, the fishery very quickly focused where catches were highest – on the eastern side of the Agulhas Bank in an area that has since been called the 'Kingklip Box'. In this area, the longline skippers discovered large seasonal aggregations of kingklip.

Speaking to the 'old salts' of the trawl fishery is enlightening too, though, because many skippers knew of the ridge and amphitheatre we call the Kingklip Kingdom, but which they called the Chalk Line Grounds. They knew that kingklip could be caught there in large numbers at certain times of the year. It was said that if they 'hit the gold pot', up to 40 tonnes of kingklip could be caught in a single trawl. Likewise, skippers participating in the longline experiment knew that if they set their lines in one particular depth and area, it was possible to catch a kingklip on every hook.

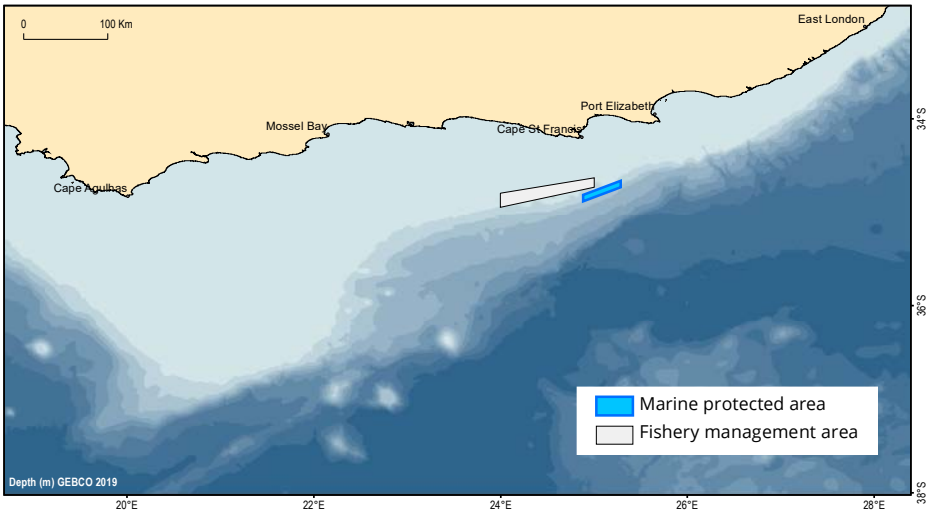
By the end of the 1980s, this intensive fishing caused a sharp decline in kingklip catch rates, so the experimental fishery was stopped and precautionary catch limits were introduced for the trawl fishery to rebuild the kingklip stocks. In an effort to protect spawning aggregations, a seasonal closure of the Kingklip Box was implemented, representing South Africa's first offshore fishery management area (FMA). Today, kingklip continue to be caught as bycatch in a small longline fishery for hake and in the much larger hake trawl fishery, and kingklip catches are back to where they were before the experimental longline fishery began, at around 4 000 tonnes per year.

Protecting the Kingklip Kingdom

The importance of the Kingklip Kingdom from a biodiversity perspective was first recognised in 2016, when sonar



A single-beam echosounder image showing a cross section of the ridge and amphitheatre where kingklip aggregate to spawn on the continental shelf off Port Elizabeth. The image depicts a 'cloud' of plankton and fish (blue) above this bathymetric feature on the seabed (red).



The Port Elizabeth Corals MPA protecting the 'Kingklip Kingdom' lies close to the 'Kingklip Box' FMA that is closed to fishing during the spawning season.

mapping of the area was conducted during the search for deepwater ecosystems warranting protection, including habitats, species and ecological processes. After the ridge and a series of underwater hills were detected on echosounder images, a towed camera was deployed for a closer look. This revealed that the ridge is covered in deepwater corals, including calcareous stony coral species that build complex three-dimensional reefs much like shallow-water coral reefs in tropical and subtropical waters.

A 270 km^2 marine protected area (MPA) was proclaimed in 2019 to protect part of the ridge, and encompasses depths ranging from 300 m to 1 000 m. The area is also recognised as an ecologically and biologically significant area (EBSA) because of its importance in the life history of a wide variety of marine species, including kingklip. The MPA protects the seabed and the reef structure of the deep corals, which provide habitat for plants and animals and probably a nursery area for young kingklip and other juvenile fish, as they offer hiding places and suitable food sources. The MPA also excludes activities like seismic surveys for oil and gas exploration and habitat-damaging fishing practices that could not only disrupt the calls and aggregations of kingklip gathering to spawn, but might also result in their injury or death.

While sensitivity of marine mammals to noise is fairly well understood by scientists, the same cannot be said of fish. Their responses to sound is a growing area of research, but there have been clues in the past that kingklip could be negatively affected by the pressure waves associated with noise-related impacts. For example, an earthquake in the early 1900s on the south coast apparently resulted in many kingklip washing up on beaches, presumably due to seismic waves in the seabed causing injury or sudden changes to their surroundings. And crew working on the support vessels for oil and gas rigs on the Agulhas Bank report that 'stunned' kingklip often rise to the surface when activities with a high-acoustic signal are undertaken – no doubt providing fresh fish fillet for their dinner!

Kingklip future

Fishery science has evolved into the realm of computer modelling, much of it beyond the skills of traditional fishery managers, who in the past relied largely on a combination of biological knowledge and experience related to the historical performance of the fishery. Management decisions were often made without fully understanding the general ecological and biological impacts of the fishery. Fishing gear has been used over centuries (bottom-trawling dates back to about 1350 in England, for example) with little regard for the habitat it may be damaging. Managers did not comprehend the implications this might have on fish stocks, such as disturbing the vulnerable life history stages, let alone other components of the ecosystem. Increasing noise in the oceans is adding another dimension to the cumulative effects on our marine resources. The impact this may be having on natural biological characteristics of many fish species, as well as the habitats they occupy, should not be underestimated.

The global adoption of the Ecosystem Approach to Fisheries (EAF) has in recent years been promoted as an alternative solution to the sustainable management of fisheries. This EAF approach in fact underpins the current management of South Africa's most valuable fishery – hake trawl – through certification by the Marine Stewardship Council (MSC). While the MSC indirectly supports the management of kingklip as a bycatch, there remain many unanswered questions about the long-term sustainability of the kingklip stocks in our waters.

The story behind the kingklip resource is just one example of our need to change our approach to fisheries management to better account for habitat and life history, in addition to monitoring stocks and catches.

Dave Japp is an international fisheries consultant and Marine Stewardship Council reviewer. He undertook research on the kingklip longline fishery while previously employed at the then Sea Fisheries Research Institute, later absorbed into what is today the Department of Environment, Forestry and Fisheries (DEFF).

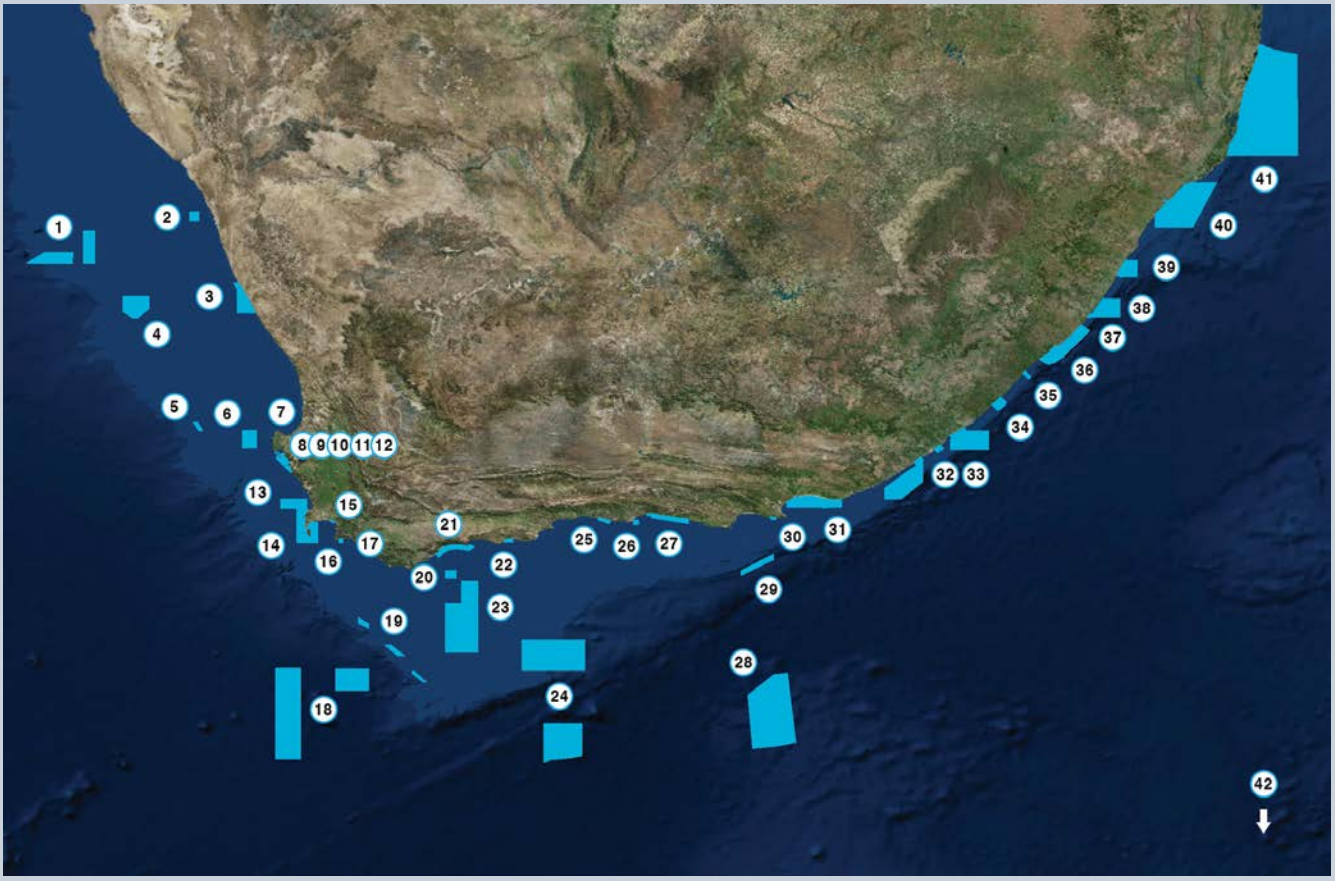
Kerry Sink is a scientist who leads the marine programme at the South African National Biodiversity Institute (SANBI), and is a professor at Nelson Mandela University. Her research conducted as part of the NRF-funded African Coelacanth Ecosystem Programme's Deep Secrets and Deep Forest projects revealed the Kingklip Kingdom and led to its protection within the Port Elizabeth Corals MPA.

Marine protected areas

A marine protected area (MPA) is an area of coastline or ocean that is protected to some degree for the long-term benefit of both people and nature. The role of MPAs as a tool to conserve and rebuild fish stocks has been demonstrated worldwide. Prior to 2019, South Africa had 25 formally declared MPAs (24 around mainland South Africa and one around the Prince Edward Islands). The 24 MPAs around South Africa covered only 0.43% of the total ocean area, of which only 0.16% was considered 'no-take', where no fishing is allowed. In May 2019, 20 new MPAs were gazetted, increasing the protection of South Africa's mainland ocean territory to 5%. As a result, 87% of the 150 marine ecosystem types identified around South Africa now have some protection.

For more information, see https://www.marineprotectedareas.org.za

1 Orange Shelf Edge
2 Namaqua Fossil Forest
3 Namaqua National Park (NP)
4 Childs Bank
5 Benguela Mud
6 Cape Canyon
7 Rocherpan
8 Malgas Island
9 Marcus Island
10 Jutten Island
11 Langebaan Lagoon
12 Sixteen Mile Beach
13 Robben Island
14 Table Mountain NP
15 Helderberg
16 Betty's Bay
17 Walker Bay
18 SE Atlantic Seamounts
19 Browns Bank Corals
20 Agulhas Mud
21 De Hoop
22 Stilbaai
23 Agulhas Bank Complex
24 SW Indian Seamounts
25 Goukamma
26 Robberg
27 Tsitsikamma
28 Agulhas Front
29 Port Elizabeth Corals
30 Sardinia Bay
31 Addo Elephant NP
32 Amathole
33 Amathole Offshore
34 Dwesa-Cwebe
35 Hluleka
36 Pondoland
37 Trafalgar
38 Protea Banks
39 Aliwal Shoal
40 Uthukela Banks
41 Isimangaliso
42 Prince Edward Islands



https://www.marineprotectedareas.org.za

Tracking inshore fish

Ryan Daly

Rebecca Vuyolwethu Mxo tells us how sound is used to understand the movements of coastal fishery species

As a young African woman, the thrill of going to sea is sometimes hard to put into words. At the back of my mind, I often hear my brother's voice saying, "why this kind of work, can't you do something less dangerous?" when we set off from shore. But watching the land slowly fade away, and hearing the seabirds' beautiful harmony, brings a wonderful sense of calmness. Most of all, falling asleep while listening to the waves bashing on the boat after a long day of work is incredibly rewarding. I cannot recall the first day I undertook a sea-going field trip, but each time I go I feel so refreshed and fortunate.

The purpose

South Africa is home to more than 2 000 species of marine fish. Of those, approximately 250 species are caught in recreational, commercial and subsistence fisheries along the coastline. The stocks of many coastal fishery species are overexploited, and their future sustainability relies on improved management measures. Studies on the migrations and longshore movements of such species are important for the fisheries managers to consider new ways to protect them. Knowledge of movement patterns is also needed for the effective design of marine protected areas.

Unlike many terrestrial animals that are strongly associated with certain habitats or areas, or even confined to game reserves by fences, marine fish have unrestricted potential to move. Some important fishery species are known to occupy small home ranges while others migrate long distances. Their effective protection depends on answers to questions such as:

- where do they spend most of their time?
- are they dependent on critical habitats?
- where do they go when they move?
- do they return to favoured areas?

Researching the movements and behaviours of animals that live underwater poses different challenges due to the physical characteristics of water. For example, direct observations by divers, cameras or even remote underwater vehicles can only be performed for short periods – usually during daylight hours – and are restricted to small areas. Various approaches have been used to infer fish movements, each with their advantages and limitations. For example, fisheries catch data can be used to reveal seasonal trends in abundance as fish stocks move from one area to another. At the individual level, dart tagging has been widely used, where a uniquely numbered tag is attached to a fish that is then released back into the water. Anyone who subsequently catches the fish is meant to report it, giving the tag details as well as the size of the fish. The tag-recapture method is relatively cheap but requires many individual fish to be tagged to obtain meaningful data. Furthermore, the whereabouts of the fish between the release and the recapture site remains unknown.

Paul Cowley

Prof. Paul Cowley with an adult white steenbras.

Acoustic Tracking Array Platform

There are many large-scale acoustic telemetry arrays in the world, including the Integrated Marine Observation System – Animal Tracking Facility in Australia, the Florida Atlantic Coast Telemetry working group in the United States and the European Tracking Network throughout Europe, among others. South Africa has its very own network called the Acoustic Tracking Array Platform (ATAP), which is managed by the National Research Foundation-South African Institute for Aquatic Biodiversity (NRF-SAIAB) in Makhanda (formerly Grahamstown), Eastern Cape. The network is made up of more than 200 acoustic receivers deployed in the sea and estuaries along 2 200 km of the South African coastline, from the Berg Estuary in the Western Cape, through to Ponta do Ouro on the South Africa–Mozambique border, allowing the movements and migrations of aquatic animals to be monitored.

Paul Cowley

Instrument scientist Dr Taryn Murray holds a juvenile leervis before it is tagged with an acoustic transmitter at the Kowie Estuary. Its movements will be monitored by an array of receivers moored in the estuary.

Acoustic telemetry

One tool that has become extremely popular and has proven successful in studying the movement behaviour of fish is acoustic telemetry. 'Acoustic' relates to sound and 'telemetry' is the remote transfer of information from a transmitting to a receiving device, which in this case is via the transmission of sound waves. The acoustic transmitters, or tags, are surgically implanted inside the fish, while the acoustic receivers, or listening stations, are moored at fixed locations in the sea or in estuaries. Each tag has a unique identification code, and a battery life of up to 10 years. Once deployed inside a fish, the tag continuously gives off signals, which are picked up and recorded when the fish swims past an acoustic receiver. Along with the unique identification code of the fish, date and time are also recorded, so this allows researchers to track the movements of tagged fish as they swim around within a network of receivers. Amazing!

White steenbras and leervis

The research that I am currently conducting at the South African Institute for Aquatic Biodiversity (SAIAB), under the supervision of Prof. Paul Cowley, Dr Taryn Murray and Mr Matt Parkinson, aims to investigate the longshore movement patterns of two important coastal fishery species – white steenbras and leervis.

Why study these two species? Overexploitation combined with ineffective traditional management measures, such as size and bag limits, have resulted in the collapse of stocks of both species; it is thought that only 5% of spawning adult white steenbras and only 14% of spawning adult leervis remain. In addition, they have similar life histories in that the juveniles of both species are dependent on estuaries. While considerable past research has focused on the movements of juveniles of both species in estuaries using acoustic telemetry, and large-scale movements of adults have been studied using dart tagging, detailed tracking of their coastal movements using acoustic telemetry is yet to be explored.

Paul Cowley

An acoustic transmitter is surgically implanted into a juvenile white steenbras.

With this in mind, our study aims to determine where the adults of these two species are throughout the year, whether they undertake annual spawning migrations and if all the adults migrate each year, and how important estuaries are for the adults of both species.

To answer these questions, data from 34 white steenbras and 79 leervis, which were tagged with long-life acoustic transmitters between July 2010 and February 2018, will be used. To date, more than 112 000 detections of white steenbras and more than 740 000 detections of leervis have been recorded on acoustic receivers in the ATAP. This means that there is a lot of work to do and a lot of data to analyse, but we cannot wait to learn more about what these animals have been getting up to!

Rebecca Vuyolwethu Mxo is an MSc candidate at Rhodes University. She has a BSc Biological Sciences from Walter Sisulu University and a BSc Honours in Zoology from Nelson Mandela University.

Rebecca Mxo with instrument technician Matt Parkinson after a receiver retrieval.

Sound science for counting fish

Janet Coetzee explains the role of hydroacoustics in fishery surveys

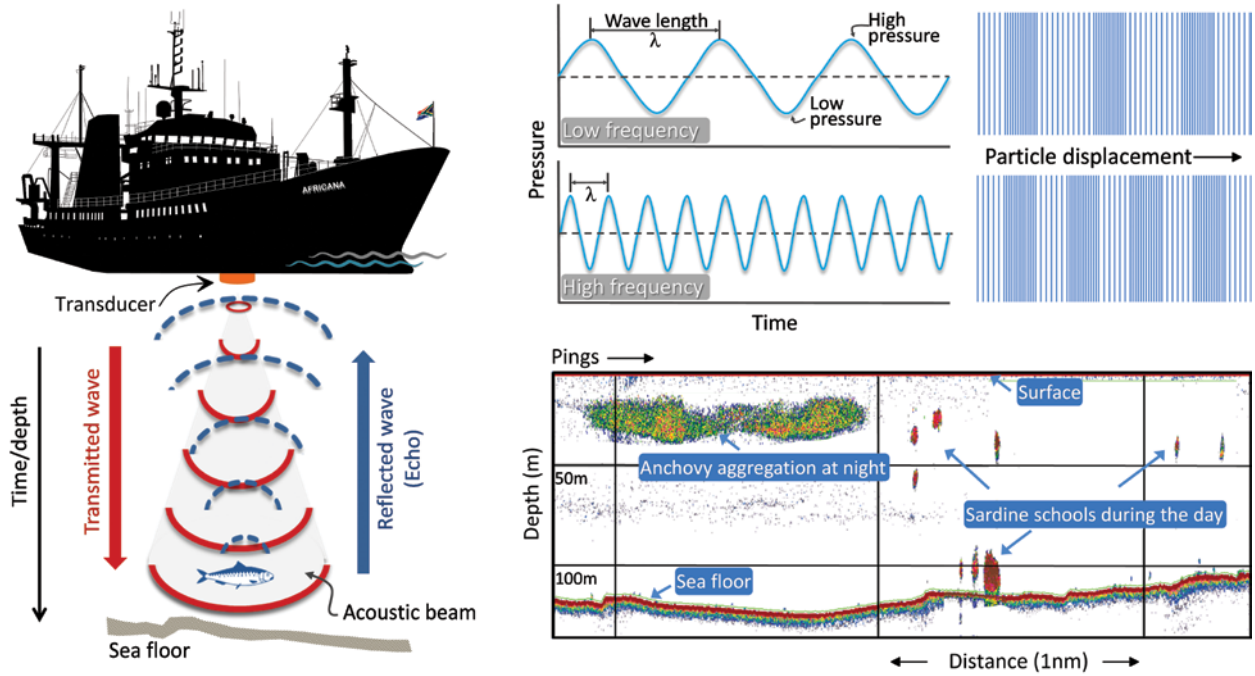
Imagine an area of almost 200 000 km^2 of ocean, stretching up to 150 nautical miles offshore (about 280 km) at its widest point and extending down to a depth of 200 m – now imagine counting the number of fish in that vast, mostly dark and inaccessible body of water. Impossible? No. Just listen....

This ocean space, referred to as the South African continental shelf, slopes gently offshore from the coastline to the shelf break, from where it descends quickly towards the deep ocean floor. This is one of the most productive areas on Earth and has a rich biodiversity of marine resources, many of which are exploited for their economic and nutritional value. The most valuable, in terms of revenue to the country and employment opportunity, include the deep-sea hake trawl fishery, the sardine and anchovy purse-seine fishery, the inshore squid jig fishery and the rock lobster fishery.

The purse-seine fishery is the largest in terms of landed volumes, netting an average of 350 000 tonnes each year. Large nets with floats at the surface and weighted rings at the bottom are dropped like a curtain in a circle around a school of sardine or anchovy and then drawn closed from the bottom, much like a purse, to enclose the fish. These fish species, which occur in the upper 50–100 m of the ocean in the epipelagic zone, are also known as forage fish (because they are an important food source for larger fish and other marine animals) or small pelagic fish (to differentiate them from the larger pelagic fish such as tuna and swordfish). They are an essential component of the coastal continental shelf ecosystem, transferring energy from phytoplankton and zooplankton to upper trophic level predators such as seabirds, linefish, seals and whales.

Fluctuations in the size (or biomass) of these fish populations not only have important consequences for the ecosystem, but also for the local economies where these fisheries are based, and for the communities that depend on them for employment and food security. It is therefore imperative that these fish species are carefully managed to prevent overfishing and ecosystem collapse. Sustainable use of our marine resources, however, depends on having reliable estimates of how many fish there are to start with. This information is essential for determining how many fish can be harvested and how many should be left in the sea to grow and reproduce. So how do we count them?

Whereas light, at the wavelengths of human vision, cannot penetrate more than a few metres below the sea surface,



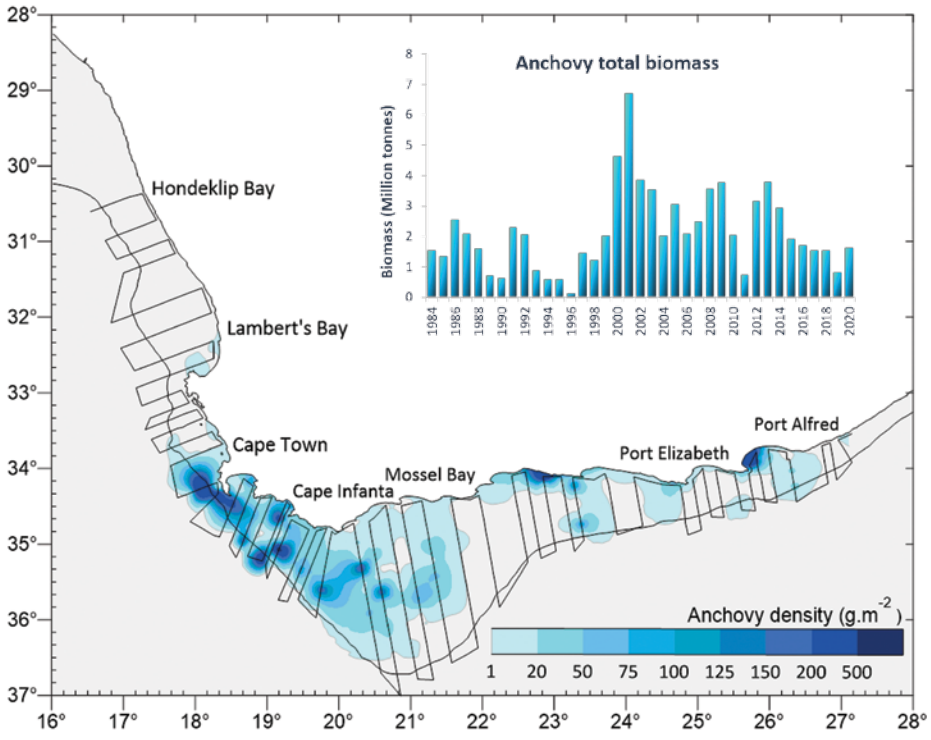
Applying an electrical signal to a transducer creates a mechanical sound wave that propagates through the water by displacement of water molecules. This pressure wave travels down through the water column and is reflected back towards the sea surface by targets such as fish or the seafloor. The returning echoes are displayed on an echogram, which is analysed by the hydroacoustic scientist on board.

and low-frequency radio waves some tens of metres at best, sound waves can travel much further and faster in water. The speed of sound in seawater is approximately 1 500 m/s compared to 340 m/s in air, and sound waves at frequencies in the range of 10–200 kHz are able to travel hundreds of metres in water. The lower the frequency, the longer the wavelength and the further the sound wave can propagate through water, and vice versa. These properties of sound are exploited in the field of hydroacoustics, in which underwater sound transmission and reception is used to detect marine organisms below the sea surface – much like bats do in air and dolphins do in water when they use echolocation to find food and navigate in the dark.

Every year in May/June and again in November/December, a team of 12 to 15 scientists and technicians from the Department of Environment, Forestry and Fisheries sets out from the Cape Town harbour on the research vessel *Africana* for a period of up to six weeks to conduct a hydroacoustic survey of the small pelagic fish stocks. The *Africana* is equipped with several scientific echosounders, comprising a series of transducers varying in frequency between 18 kHz and 200 kHz, with corresponding transceivers and processors for each of them. Through the conversion of electrical energy into mechanical vibrations, these transducers send short pulses of sound, known as pings (with a typical duration of 1/1 000th of a second, or one millisecond) into the water column. This results in the periodic compression and expansion of water molecules, or a pressure wave, which travels downwards and outwards from the transducer to form a cone-shaped acoustic beam (rather like the beam from a flashlight). Some of the sound energy is lost due to absorption and spreading – the loss increasing in proportion to the distance travelled and the frequency. Higher-frequency sound waves suffer greater absorption losses, and as such cannot penetrate as deep into the water column as lower-frequency sound waves.

The research vessel *Africana*, commissioned in 1982, provides fisheries managers with the data required for managing our commercially important fish stocks, but is nearing the end of service. She can accommodate 15 scientists and 35 crew.

A proportion of the incident sound energy is reflected off organisms (or targets) in the water column or off the seafloor, resulting in a new secondary wave (echo, or backscattered sound) that is detected by the transducer and converted back into electrical energy. The time taken for the echo to be detected by the transducer is used to measure the distance of the target from the transducer. For example, if the transducer detects an echo from the seabed one second after the pulse was transmitted, and we know that the speed of sound in seawater is approximately 1 500 m/s, then we know that the incident sound wave and the returning echo travelled 1 500 m in total. Given the same travel time in both directions, the seafloor depth is calculated to be 1 500/2, or 750 m.



This map shows the survey track followed by the *Africana* during the November/December 2020 hydroacoustic biomass survey, as well as the distribution and relative density of anchovy, derived from analyses of fish-school echoes detected during the survey. The inset shows the time series of hydroacoustic estimates of anchovy biomass since the inception of the survey programme in 1984.

The strength of this returned electrical signal depends on the proportion of the original (incident) sound wave that was reflected by the target as an echo, which in turn depends on the frequency of the sound wave and physical properties of the target such as its size, shape and material composition, as well as its orientation relative to the acoustic beam. Typically, smaller organisms such as zooplankton reflect more energy at higher frequencies than at lower frequencies, and most organisms have specific frequency-dependent acoustic signatures that can be used to distinguish different types.

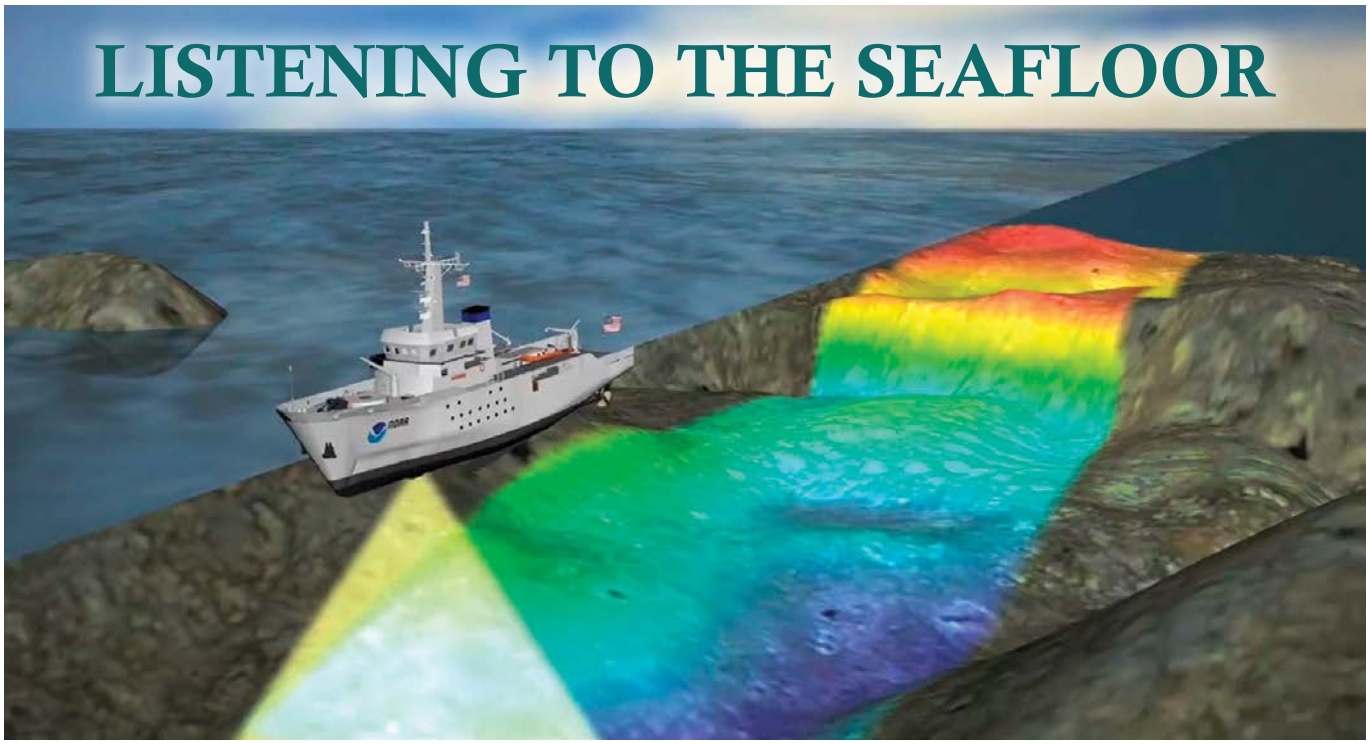
In general, fish that have air-filled swim bladders will reflect more sound than those that don't have swim bladders. This is due to the large change in density between seawater and air. Larger fish of the same species will also have stronger echoes than smaller ones. Therefore, if the target strength (reflective property) of a fish species is known, the number of fish contributing to an echo – or group of echoes in the case of a school of fish – can be calculated by simply summing the backscattered energy of those echoes (through a process known as echo integration) and dividing that summed energy by the average target strength of one fish.

Both the depth and echo strength information is depicted on an echogram that is interpreted and analysed by the hydroacoustic scientist. An echogram is a special graph that shows the strength of the echo in colour steps where blue or grey marks, or echo traces, represent weak echoes and red or black marks represent strong echoes. The vertical extent of marks indicate the height of the targets detected. By lining these echo traces up according to the time it took them to be detected, a two-dimensional image of the water column emerges once numerous transmissions (pings) are arranged in succession. The vertical axis represents depth (as derived from the time taken for an echo to be detected) and the horizontal axis represents distance along the track that the ship is following. Features that are attributed to fish schools and their behaviour, or even to differences in schooling patterns between schools of different species, soon become apparent. Experienced acoustic scientists use this information to partition the echo energy (backscattered energy) between species to estimate their density (number of fish per km^2). These surveys follow standard sampling designs that allow for extrapolation of the fish density estimated along the vessel's track to the full survey area (km^2) so that the total biomass of fish (tonnes) in the surveyed area can be determined.

This programme was initiated in 1984 and since then South African hydroacoustic research has been at the forefront of many internationally recognised technological advances in this field. The winter surveys cover the inshore areas of the continental shelf between the Orange River on the west coast and Cape Infanta on the south coast, out to a distance of about 40 nautical miles. These surveys provide estimates of the number of young fish recruiting to the populations. The summer surveys cover the entire continental shelf area out to a depth of at least 200 m between Hondeklip Bay on the west coast and Port Alfred on the east coast, and estimate the number of adult fish in the population. The *Africana* typically steams in the order of 5 000 to 6 000 nautical miles (~10 000 km) during a November/December survey – similar to the distance from Cape Town to Cairo – at a top speed of 19 km/h, while stopping along the way to conduct oceanographic sampling and trawl sampling of fish..... now that's a journey!

Janet Coetzee started her career as a marine scientist in Swakopmund, Namibia, in 1991 after obtaining a BSc Honours degree from Stellenbosch University. After informal training in hydroacoustics through Norwegian and Icelandic aid agencies, she completed her MSc thesis on this topic through UCT in 1997. She joined the Department of Environment, Forestry and Fisheries in 1997 and currently leads the 'surveys and fish behaviour' group that is tasked with conducting hydroacoustic surveys and advancing methods for applying this technology to answering other ecological questions.

LISTENING TO THE SEAFLOOR



NOAA

Andy Green tells us about the use of sound in marine geological mapping

Despite many years of marine mapping effort, initially for charting and safe navigation purposes and later for scientific and commercial reasons, we still know more about the surface features of Earth's neighbouring planets than the seafloor. The sheer depths of the ocean and the inability of light to penetrate water beyond a few metres, particularly in turbid seas, make it impossible to visually inspect the seabed from the sea surface with any degree of accuracy or precision.

Sonar – an acronym for sound navigation and ranging – overcomes these challenges, and can be used to map seafloors from the shallows of the surf zones to the deepest ocean trenches. Sonar entails directing sound pulses to the seafloor and measuring the time taken from the emission of a pulse to its return after it bounces off the bottom. When coupled with a knowledge of the sound velocity of the water column, this makes for an effective means of measuring depth, and hence understanding the changing elevations of the seabed. Like a bat's echolocation, sonar echosounding establishes a precise distance to a point on the seabed where the depth = time taken from emission to return, multiplied by the speed of sound in water divided by two (to remove one part of the sound pulse's journey, either to or from the seabed).

Our modern understanding of plate tectonics in many ways derives from the earliest maps made using sonar. Marie Tharp of the Lamont-Doherty Geological Observatory in the USA was the first to recognise patterns in the changing seafloor depths, especially over the centres of the ocean basins, and to hypothesise that these were related to movements of the Earth's crust. This pioneering work of the 1950s and '60s led to a technological revolution in the way in which the seabed is mapped.

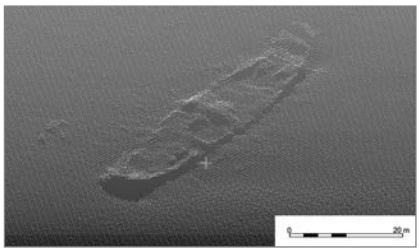
Early sonars used a single, downward-'looking' transducer to emit and then listen for the sonar pulses, termed single-beam echosounding. This was mounted and triggered aboard a ship whilst the vessel sailed back and forth in parallel lines, leaving a breadcrumb trail of soundings, or depth measurements. The ship's position was established using a sextant so the latitude, longitude and depth information could be compiled into a bathymetric chart, where depths were contoured or interpolated between each measured depth point. Naturally, the inferences made between points, especially if the parallel lines of the vessel path were very wide, would introduce some unusual and erroneous readings, and only broad, low-resolution maps of the ocean bottom could be made.

Multibeam echosounders

Today, we have increasingly accurate technology relying on a multibeam approach. With multibeam echosounding, known as MBES, sound pulses are emitted from multiple (up to 512!) individual transducers, creating a fan of sound beams that map a swath of seafloor. This swath can be as much as three times the water depth, essentially creating corridors or swaths of soundings that can be overlapped by successive passes of the ship. As the vessel sails in parallel lines, the seafloor is in effect painted with sound, creating 100% coverage of the bed and allowing for a three-dimensional visualisation of the terrain. When coupled to extremely sophisticated equipment that can compensate for the ship motions (heave, sway, surge, roll, pitch and yaw), as well as tidal changes and varying sound velocity of the water column due to temperature and salinity, the result is an accurate image of the seafloor derived from millions of depth measurements. Sextants have been replaced by differential global positioning systems (GPS) that provide the latitude and longitude of the vessel within

one-metre accuracy, making the ability to resolve the seafloor even better. In shallow waters, features of a few centimetres or larger can now be visualised with a great degree of confidence.

Such accurate maps are important for offshore mapping where intricate features on the seabed need to be resolved. This includes, for example, mapping special marine habitats like submarine canyons, conducting seabed exploration for mining, searching for shipwrecks and debris from aeroplane crashes, and identifying safe navigation pathways. The costs, relative complexity of the operation and of the system, and the labour-intensive data-processing that results from the generation of such large quantities of data mean that relatively few institutions have access to multibeam echosounders. The result is a relatively poor, albeit increasingly better coverage of the seabed by higher-resolution multibeam mapping, especially in the territorial waters of countries where this technology is only now becoming more readily available, such as South Africa.



A point cloud representation of multi-beam data showing a shipwreck off the KwaZulu-Natal coast.

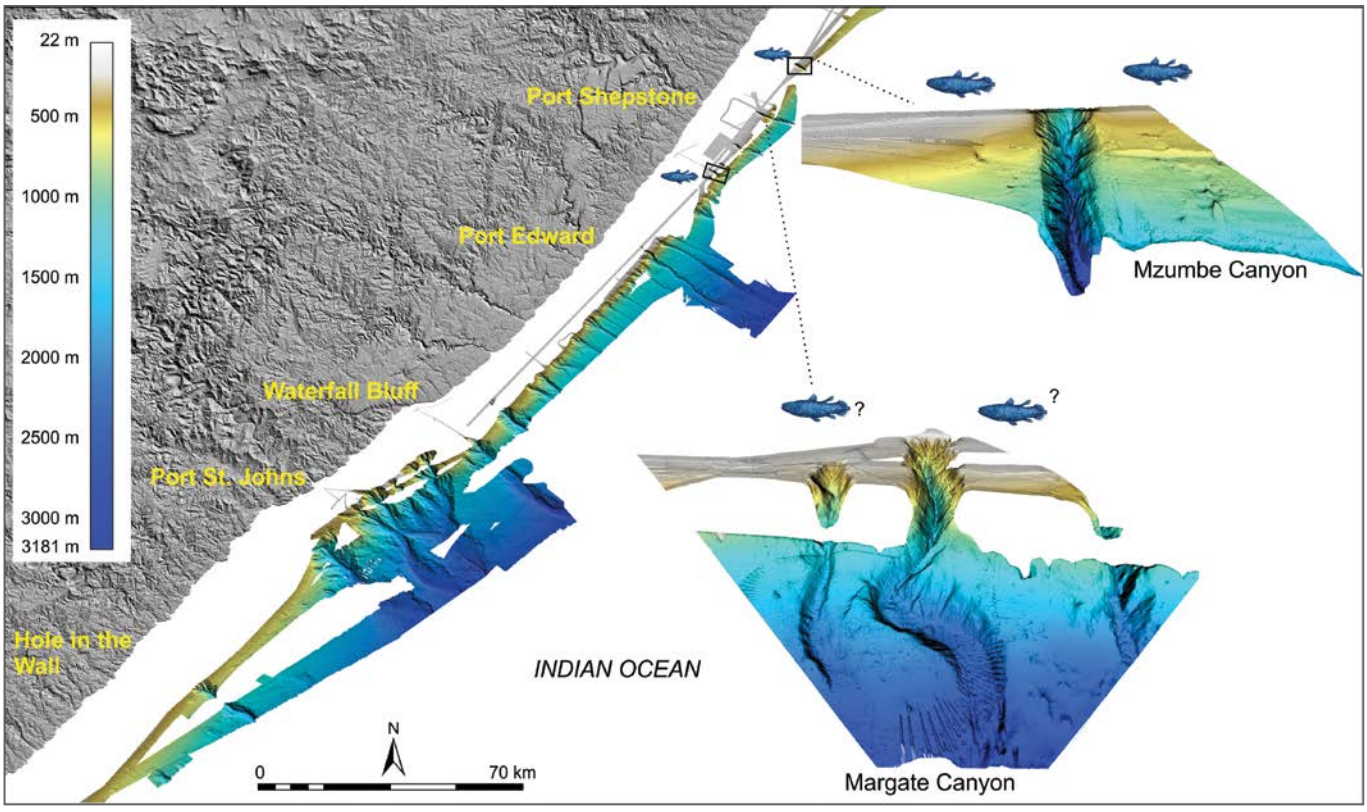
Acoustic backscatter

As sound pulses are reflected back to the transducer, they are returned with varying intensities based on the physical properties of the seafloor. The return of the sound pulse in the direction from where it originated is referred to as acoustic backscatter. Changes in backscatter allow for a qualitative assessment of the seafloor properties, such as hardness and roughness – harder seafloor will produce a higher backscatter intensity (with characteristic backscatter signatures), allowing for an interpretation of the seafloor composition. Grain sizes and shapes of sediment may also affect the degree of backscatter received, so it is possible to create maps of the seabed showing various sediment types. Subsequently, physical inspection using grab samplers, dredges, corers or even tethered or remotely operated cameras allow interpretations to be confirmed.

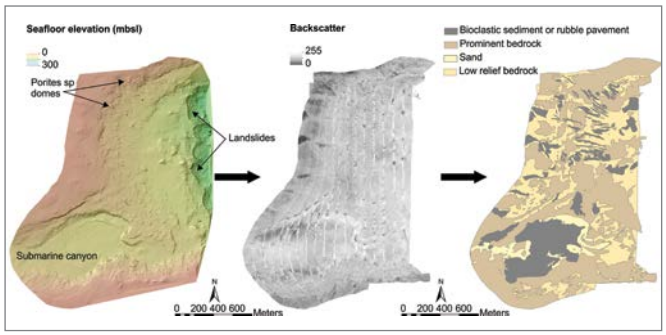
Acoustic backscatter has become an increasingly important tool in our quest to delineate marine habitats. Benthic (bottom-dwelling) and even pelagic (open-ocean) fish and other organisms have habitat preferences with regards to substrate types. Identifying substrates using this remote-sensing technique is thus helpful for habitat mapping and plays a key role in marine spatial planning for fisheries and conservation areas. Today, powerful computing packages coupled with machine learning techniques can auto-classify and help predict where particular habitats may occur, allowing for quicker and more spatially inclusive decisions to be made for ocean resource management.

Seismic surveying

Not only are people interested in what lies on the seabed, but also what lies below. Using the same principles as echosounding, seismic reflection surveying utilises sound pulses to get an impression of the seabed, while also gaining an understanding of the underlying strata. In this case, sound is emitted at a lower frequency and does not just bounce off the seafloor, but penetrates into the underlying strata, where it is reflected back from subsequent layers of different physical properties. The lower the frequency, the deeper the sound waves can



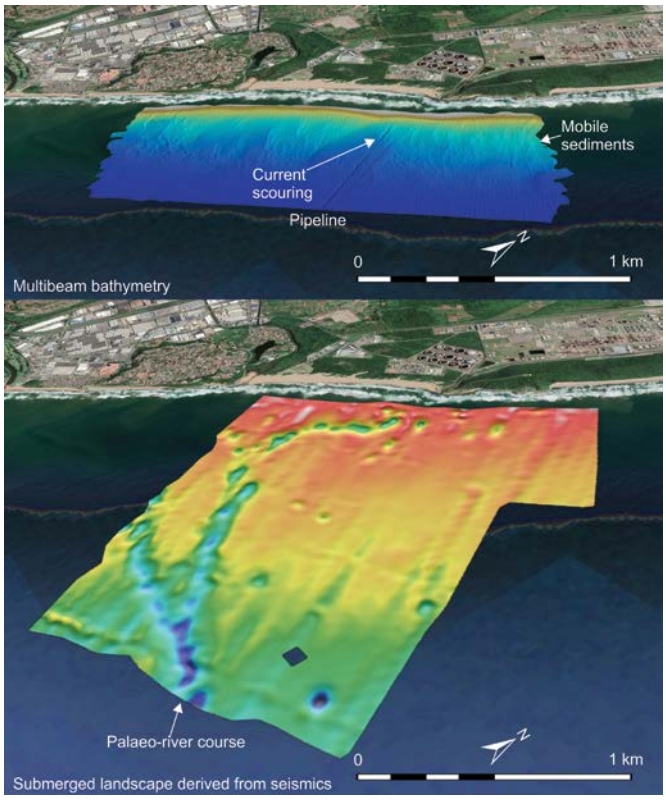
Multibeam bathymetry along South Africa's east coast revealed a multitude of deeply incised submarine canyons, many of which extend into waters less than 100 m deep. Some are known to be home to coelacanth, the 'living fossil' fish.



Multibeam data collected from the head of a submarine canyon (left) and co-acquired backscatter data (middle). The combined use of these datasets can produce an interpretative seafloor composition map (right). High levels of backscatter (white) signify harder substrates, with lower backscatter (black) indicating absorption of the sound pulse by the seafloor. Bioclastic sediment (shells), bedrock and sand can be delineated accordingly.

penetrate. Conversely, higher-frequency sound waves penetrate shallowly, but allow for a great deal more resolution between layers. Increased resolution means that successive layers with smaller spacings between them can be differentiated.

Sound is either emitted by a transducer similar to a depth echosounder, or from systems towed behind the vessel, where the sound source and listening devices are separated. In these cases, the return signal is detected by one or more hydrophones, and the sound pulses are of lower frequency, generated by either the explosive release of compressed air into the water column, or by creating a seismic pulse from an electrically operated diaphragm, which claps together to generate the sound.



Multibeam bathymetry of the seabed off the Durban coastline (top). Mobile sediments are transported over a pipeline where scouring occurs. Seismic data are used to reveal the underlying bedrock morphology (bottom). By stripping off the overlying sediment, the paleo-landscape entrenched into the bedrock can be examined. Here it shows a meandering river system, formed 18 000 years ago when sea levels were ~ 120 m below present and the shoreline was located ~ 20 km seaward of today.

Seismic surveying is synonymous with oil and gas prospecting in marine basins, but it has become an increasingly important tool in understanding the evolution of the seafloor over time – it essentially looks back in Earth's history with every layer it uncovers. High-resolution and high-frequency seismic surveying is now a staple in habitat mapping, helping to uncover buried river courses and areas with different degrees of sediment accumulation. Together with multibeam bathymetry, high-resolution seismic surveys are a key tool for the identification of cold-water coral accumulations. Seismic surveying is also heavily utilised in the siting of pipelines and telecommunication cables, where knowledge of the depth to bedrock is essential.

Densely spaced seismic surveys can also help to reveal older landscapes that are now buried by sediment. The overlying sediment cover can be stripped away using geophysical computing software and a picture of the underlying horizons generated. This has particular importance to marine geoarchaeological studies investigating areas used by humans when sea levels were lower. Similarly, this technique has aided in the search for diamonds in the ocean, because they accumulate along irregular bedrock surfaces that are easily revealed in high-resolution seismic surveys.

Looking to the future

Geological mapping of the seabed gives a window into the evolution of a piece of seafloor, transporting the observer back in time and allowing them to relate the modern oceanographic, biological and anthropogenic processes that currently affect the area to its overall development. From a purely scientific perspective, the seafloor is one of the final frontiers of exploration. Mapping helps us to answer big scientific questions such as what the magnitude and rates of large-scale sea-level changes were over the last several million years, how these affected coastlines and coastal sedimentary systems, and how changing sea levels may affect coasts today. Likewise, the expansion of the global blue economy is underpinned by accurate seafloor maps that highlight possible resources, in addition to staking claims for coastal nations' Exclusive Economic Zones. More investment by the South African government into academia, student training and research is needed to harness the potential of seafloor mapping, and put our marine geological programmes on a par with those of other developing nations.

Professor Andrew Green is chair of marine geology and sedimentology and heads the Marine Geology Research Unit at the University of KwaZulu-Natal. His research within the DSI/NRF-funded African Coelacanth Ecosystem Programme (ACEP) helped support the expansion of South Africa's Marine Protected Area (MPA) network in 2019.

The data shown in the figures were kindly funded or released by the following people or organisations: the Bundesministerium für Bildung und Forschung, the EAF-Nansen Programme, Hatch, Namdeb Diamond Corporation, the European Union H2020 programme, the University of KwaZulu-Natal and Dr. P.J. Ramsay of MIND Technology, Inc.

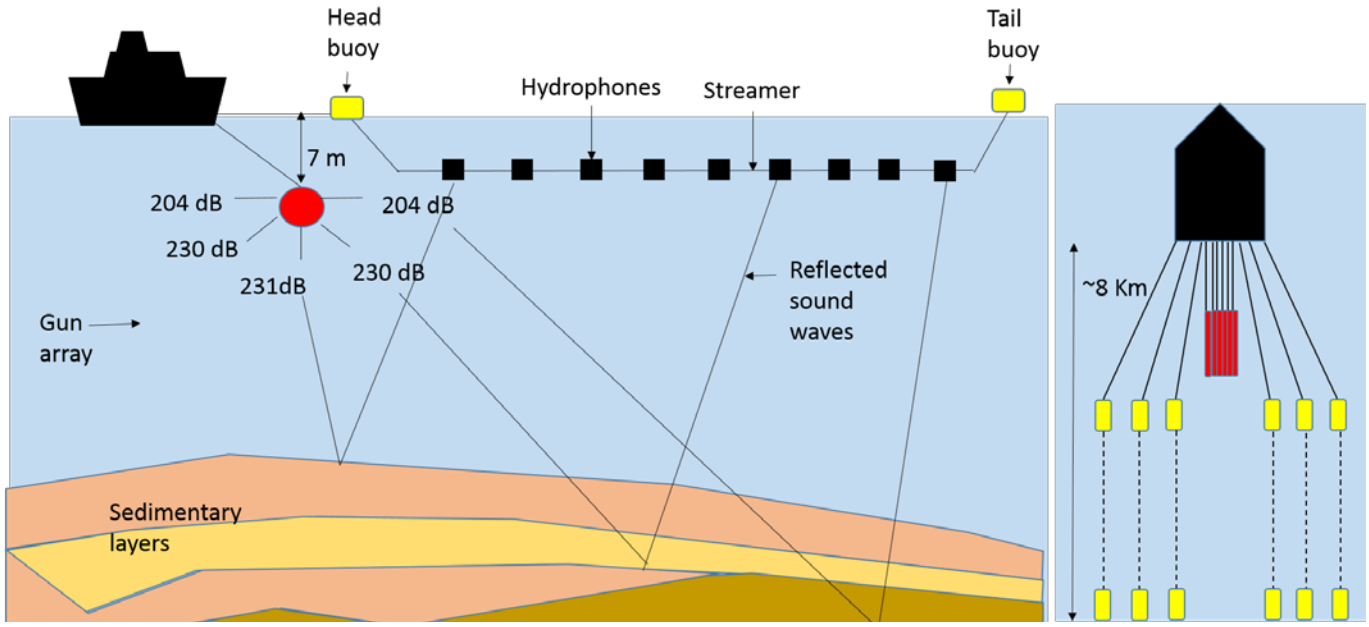
Ocean noise at FULL BLAST

Jean Purdon explains how seismic surveys could impact marine life

For a long time I worked on ships that survey the ocean floor, looking for oil and gas. My job was to ensure that marine animals, especially whales, dolphins, seals, turtles and diving seabirds, were not hurt by the loud, sudden sounds produced during the process.

These so-called 'seismic surveys' use large compressors to power airguns, which release blasts of air, creating bubbles that produce impulsive high-intensity, low-frequency sound waves as the bubbles expand and contract. The airguns generally consist of anywhere between three and six sub-arrays with 12 to 48 single airguns, all varying in volume size. They are towed behind the seismic survey vessel, at a depth of about 10 m. The vessel also tows as many as 20 cables that can be up to 10 km long. These cables, known as streamers, contain hydrophones that receive the sound signals reflected off layers in the seabed. The sound signals are processed and analysed to determine where reserves of oil and gas may be located.

Sound is a type of energy produced by vibrations in gases, liquids or solids. The vibrations create a sound wave as particles in the medium oscillate back and forth, transmitting the energy through a 'knock on'



A typical seismic survey layout of the vessel and equipment used, in side profile (left) and aerial view (right). Sound intensity levels in decibels are measured as dB re 1 µPa @ 1 m.

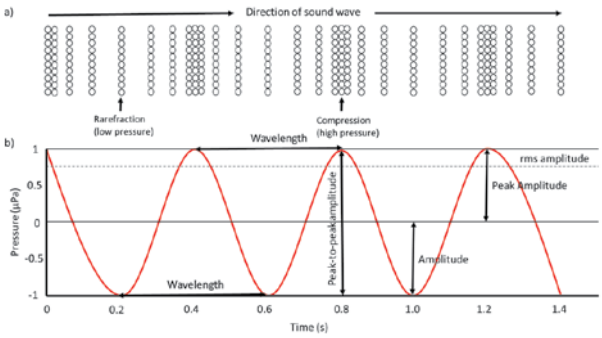


Diagram of a sound wave showing a) compression and rarefaction of particles and b) the amplitude and frequency.

effect. The particles move parallel to the direction of the wave, making sound waves longitudinal – as opposed to transverse – waves. Longitudinal waves are also known as compressional waves because they alternately compress and decompress particles, creating areas of high and low pressure. These pressure fluctuations are detected by the receiver, such as a hydrophone or a human ear.

The height of a sound pressure wave, known as the amplitude, corresponds with the highest pressure, and therefore its energy and loudness. The energy passing through a unit area per unit time is the sound intensity, measured in watts per square metre (W/m^2). Humans can hear over a very large sound range, but the way we perceive sound intensity does not follow a linear relationship. The relative loudness of sounds is therefore measured instead as a sound intensity level in decibels (dB). The decibel is a logarithmic unit that indicates the ratio of the physical intensity of a sound, relative to a reference value. In the case of sound pressure, the reference level for air is 20 μPa @ 1m (20 micropascals at a distance of one metre), but the reference level for water is 1 μPa @ 1m. The decibels measured a metre from the sound source is known as the source level, but the different reference levels mean that a source level of 150 dB measured in water is not the same as 150 dB measured in air.

Seismic surveys have been shown to produce source levels of up to 260 dB re 1 μPa @ 1 m. Because this is measured in water, a direct comparison with the level in air is difficult, but would be equivalent to about 200 dB – human eardrums typically burst at 160 dB. More typically, though, the air-equivalent sound is in the 140–180 dB range, which is still very loud, considering a rock concert produces sound measured at about 120 dB.

Seismic surveys also produce sound that is very low frequency, in the 10–100 Hz range. This low frequency enables seismic survey pulses to travel up to 4 000 km away from the source! A pulse can travel through the seabed sediment, re-emerging later in the water. As seismic survey sounds can travel so far and are so very loud, they have been shown to have significant implications for marine fauna that rely heavily on sound in the dark ocean environment.

Marine fauna use sound for many functions. For example, dolphins and toothed whales can acoustically 'visualise' their surroundings and locate food through echolocation, baleen whales communicate with each other through calls that travel long distances, while some fish and invertebrates use sound to attract mates and ward off predators. Given the importance of sound to these animals, we can begin to get a picture of how seismic surveys could affect them.

Seismic surveys can result in animals either losing their hearing completely (permanent threshold shift) or temporarily (temporary threshold shift). They have also been shown to cause the death of zooplankton, krill and some fish species. This in turn has an effect on ocean productivity, decreasing food supplies for many marine animals. Seismic surveys can also result in disorientation of deep-diving toothed whales, causing them to swim up to the surface very fast. Because of the pressure that these animals are subjected to deep in the ocean, nitrogen gas bubbles develop in their bloodstream if they rise to the surface too quickly – in the same way that human divers get

PGS

Seismic survey vessels tow airguns as well as the hydrophone-containing 'streamers' that may be up to 10 km long.

'the bends' – and this may result in whale deaths or mass strandings.

Seismic surveys produce loud shots every 10 seconds and can continue for months at a time, resulting in prolonged effects on marine life. Low-frequency seismic pulses cause large baleen whales to start avoiding the area and their communication may decrease or increase, signifying elevated stress levels. Stress could similarly affect foraging success and the ability to produce offspring in other animals. For example, African penguins are critically endangered, their population having declined by 70% in the last decade. In the Eastern Cape, they breed on Bird Island and St Croix Island in Algoa Bay, but a study showed that seismic surveys less than 100 km away caused the penguins to divert from their primary foraging areas. Some seismic surveys have occurred 25 km away from Bird Island, which is worrisome as this could severely affect their foraging ability and reproduction in the future, especially during the breeding season when the adults stay closer to the islands to care for their chicks.

Seismic surveys typically operate 24 hours per day in South African waters, and it is likely that the continual loud banging has a negative effect on the entire ecosystem, although this is very hard to measure and monitor. Companies conducting these surveys are legally obliged to obtain an environmental management plan (EMP) from an independent company that is registered to conduct EMPs, which provide guidelines on how best to reduce the environmental impact.

The EMP usually states that the survey vessel must have marine mammal observers (MMOs) on duty during the day and passive acoustic monitoring (PAM) operators on duty during the day and night. The MMOs keep a visual lookout for marine fauna using binoculars, while the PAM operators use a hydrophone connected to a computer to monitor whale and dolphin calls. The EMP also stipulates rules and regulations on how the airguns should be started to help protect marine fauna. The MMO and PAM operators check that the airguns start 'firing' slowly so that the noise causes any animals in the area to move away. In addition, the MMOs and PAM operators are required to monitor a mitigation zone, usually 500 m in diameter. If they see or hear any animals within this zone, they are required to advise the seismic survey company to stop the airguns until the animals have left the zone.

For many years I was an MMO and PAM operator, which led me to continue to research noise pollution in South Africa's oceans. However, I realise that oil and gas are essential in our everyday lives – to travel, to heat, to cool, to manufacture, even to brush our teeth with plastic toothbrushes. The oil and gas industry itself is huge, and many people's livelihoods depend on it. The renewable energy industry is developing rapidly, but wind and solar power is still not produced at a rate that is required for our planet of over seven billion people.

I found that the crews on seismic survey vessels are also concerned about and care for the welfare of marine life, and they do try to adhere to the suggestions and recommendations made by the MMOs and PAM operators. Personally, I felt that it is important for me to work closely with this industry to try and mesh the need for oil and gas with the need to conserve our ocean environment.

It is clear that more research needs to be conducted to fully understand the impacts of sound on marine organisms, so we can protect and safeguard South Africa's ocean life for future generations.

Jean Purdon is currently completing her PhD at the University of Pretoria, focusing on acoustic pollution in the marine environment.

Being a marine mammal observer on a seismic survey vessel provides opportunities to see ocean life such as the Atlantic spotted dolphin (top) and melon-headed whale (bottom).

JJ Harrison, CC BY SA 4.0

Seabirds and infrasound

Jeff Zeyl shares his research on low-frequency hearing in birds of the marine environment

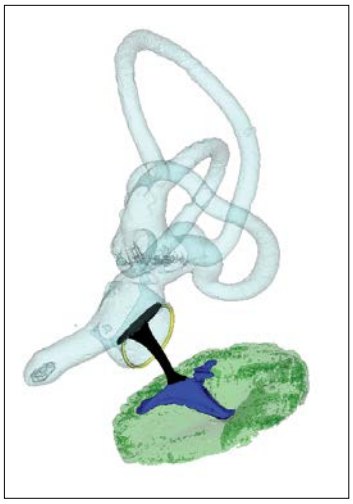
When one thinks of animals that may use infrasound, elephants and baleen whales might come to mind. These large animals communicate over long distances using acoustic signals that contain infrasonic frequencies. Besides these giants, infrasonic hearing has also been described in smaller mammals and birds that do not produce infrasonic vocalisations, such as mountain beaver, rock dove and chicken. Infrasonic hearing ability has been tested in relatively few animal species, which could mean that it is more widespread in animals than currently appreciated.

In birds, infrasonic vocalisation is quite rare. This is because relatively large volumes of air need to be displaced to produce infrasound, and most birds are too small to do this. However, there are a few exceptions. The cassowary – a large flightless bird – produces vocalisations that have some energy near 20 Hz, though the loudest components of their vocalisations are still higher frequency (not infrasonic). Male peafowls produce infrasound in their mating displays by shaking their large tail feathers, and peafowls are also able to hear infrasound. For birds such as rock dove or the chicken, which we know do not produce infrasonic vocalisations, infrasonic communication can't be the main function of infrasonic hearing. What might these birds be listening to at infrasonic frequencies?

Natural sources of infrasound include thunderstorms, surf, colliding ocean waves, and earthquakes. Some, such as thunder, are transient, while others, including surf, are more stable in space and time. Since low frequencies are much less absorbed than higher frequencies as they propagate through the air, infrasound can be detected at great distances from the source, in some cases hundreds to thousands of kilometres away. These unique features of infrasound, combined with our knowledge that some birds can detect sound in this frequency range, have led some scientists to the intriguing hypothesis that certain bird species use infrasonic cues from the geophysical environment to aid navigation. That ability might be useful for bird species that need to fly and navigate long distances as part of migration.

For my postdoctoral work at Stellenbosch University, I am working as part of an international team to investigate the possibility that seabirds use infrasound in navigation. This hypothesis confronts us with several unknowns. Can different seabird groups detect infrasound? If they can detect it, can they determine the direction of the sound? Can they distinguish between different infrasound sources? How might they change their behaviour when they hear different infrasound sources? One aspect of this project involves placing biologgers that record infrasound on albatrosses, which will help to better understand the birds' natural responses to infrasound. My contribution to the project focuses on elucidating the hearing mechanisms for detecting infrasound, and understanding the comparative auditory anatomy of seabirds.

It is not immediately obvious that birds could extract directional information from infrasound, allowing for orientation. To determine the direction of a sound, land animals typically use differences in sound level and time of arrival between the two ears. Depending on the angle of the sound source relative to the bird, the timing and amplitude information will differ slightly between each of the ears, allowing the brain to compare the two inputs and determine the direction. But for very low frequencies, the wavelengths are very long relative to the distance between the two ears, which means that the stimulus received by each ear might be so similar that it would be difficult for the brain to determine the source direction. Some alternative ideas have been proposed, such as detecting the sound direction by perceiving a shift in frequency caused by flying relative to a static sound source (this is known as the Doppler effect). Future work is needed to test these possibilities.



Jeff Zeyl

3D rendering of a bird ear from a microCT scan.

Little is known about the hearing abilities of seabirds, in general, so it was first necessary for us to review the evidence for their infrasonic hearing abilities and examine possible anatomical structures involved. The few birds in which infrasonic hearing abilities have been tested were not seabirds, but we know that the rock dove and some birds in the order Galliformes (chicken, guinea fowl and probably peafowl) are quite sensitive to infrasound, while other birds such as budgerigar and mallard duck are no more sensitive than humans at these frequencies. Seabird hearing is also likely to vary a lot in different taxonomic groups. For example, diving birds show a wide range of hearing sensitivity, with relatively poorer hearing in great cormorant, but relatively good sensitivity in the Atlantic puffin.

Bird hearing relies on a well-functioning tympanic middle ear, meaning the bird has an eardrum and ear ossicle(s) that transmit sound vibrations to the sensors in the inner ear. The tympanic middle ear is quite essential for detecting airborne sounds; without it, most of the sound energy would reflect off the body surface. For most birds, the tympanic middle ear vibrates maximally at 1–5 kHz, which corresponds to the frequencies at which their hearing is most sensitive. Below these frequencies of peak vibration, vibrations typically decline at a rate of approximately 6 dB/octave. In other words, the decline in vibration is directly proportional to the reduction of frequency.

Some bird species may have a middle ear that is particularly well-structured for low-frequency hearing sensitivity. This might be achieved by having larger cranial air cavities behind the eardrum and more flexible ligaments and cartilage in the middle ear, which would make the ear less stiff and more responsive at low frequencies. Large eardrums, which will have lower resonating frequencies, might also be an advantage for detecting infrasound. For example, we know the ostrich has very large eardrums that vibrate well at relatively low frequencies. Although we don't have any data on the ostrich's hearing abilities, we can expect that this species hears low frequencies very well.

Given that the middle ear vibrations can decline to such low levels at infrasonic frequencies, other 'extratympanic' hearing pathways could also be at play. Extratympanic pathways are sound vibrations reaching the ear through body tissues other than the tympanic middle ear. We know that for animals lacking tympanic middle ears, such as salamanders, snakes and frogs, the auditory response at low frequencies does not rely on a functional tympanic middle ear. Vestibular organs, which are sensors involved in balance and detecting the movement of the head, might also get stimulated by airborne infrasound, as their activation in response to low-frequency airborne sound has been demonstrated in some animals, as well as in humans.

Conducting infrasonic hearing tests on a large number of seabirds is not technically feasible, so we have focused on drawing inferences about hearing through a comparative study of anatomy. We collected (with permission from authorities) a diversity of naturally deceased seabirds and non-seabirds from various researchers and conservation agencies. We then scanned the ear region of the head using microCT (micro-computed tomography), which gave us a 3D rendering of the internal structures. From the scans, we measure several hearing structures, focusing largely on the middle ear. By comparing species with known superior low-frequency hearing abilities with seabirds, we can draw some conclusions about seabirds' hearing abilities. We can also see how the ear structures change in relation to bird size, and whether birds from different habitats or families have distinct ear structures.

This large anatomical dataset has also allowed us the opportunity to test other hypotheses about hearing in seabirds. Specifically, we are studying hearing structures which might be important for underwater hearing, and how these might affect hearing in air. Some seabird groups – such as cormorants, penguins and auks – spend a significant amount of time foraging in water, which is a very different acoustic environment compared to air. Most significantly, water is much denser than air, so ambient hydrostatic pressure applied to the body (and ear) can be very high as birds dive to deeper water. As a result, modifications to ear structure to enhance underwater hearing or to protect the ear from the high hydrostatic pressures might affect the ear's performance in air.

Several unknowns remain about which birds might hear infrasound, how they may detect it, and what they may gain from using that information. By compiling our anatomical data, we hope we are putting key building blocks in place for some exciting discoveries in this area.

- For more information, see the review on infrasonic hearing in birds by Zeyl et al. 2020 (https://doi.org/10.1111/brv.12596) and the website of the seabirds and infrasound project (https://seabirdsound.org/).

Dr Jeff Zeyl completed his PhD on hearing in turtles and salamanders at Auburn University in Alabama, USA, in 2016 and joined Stellenbosch University as a postdoctoral fellow in January 2018.

NASA/JPL-Caltech

What meteorites can tell us about Mars

Hundreds of millions of years ago, something crashed into the planet Mars with enough force to eject pieces of Martian rock into space. Some of these pieces of rock made their way to Earth where they entered our atmosphere as meteors. A precious few landed on the surface of our planet as meteorites. Thanks to scientists like Geoffrey Howarth, a geologist based at the University of Cape Town (UCT), these Martian meteorites are now being studied to better understand the structure and geological history of the red planet. Here's what we know so far.

Howarth, who grew up on a farm in the Eastern Cape, first came across the field of igneous petrology (the study of how volcanic rocks form) as an undergraduate. Little did he know then that he would one day specialise in two very different types of igneous rocks: one that formed in the heart of our planet and others that came from the surface of a planet 137 million kilometres away.

"As a child I liked to collect rocks because I found them mysterious, but it was only later when I first began studying geology that I became fascinated with what rocks can tell us about the history of a planet through time. I still remember the first time I came across a Martian meteorite, holding a little piece of a different planet in my hand definitely made an impression."

Today, Howarth's research focuses on kimberlite, the type of rock in which most diamonds are found, and which forms deep in the Earth's crust, as well as meteorites from Mars.

Messengers from the mantle

To date, Howarth and a global team of geologists have studied 252 individual Martian meteorites from 11 distinct ejection sites on Mars. Some of these samples are on loan from NASA, while many more have been sourced more recently in North West Africa by local Bedouin experts and commercial meteorite hunters.

"Studying these meteorites gives us insights into the composition, differentiation and evolution of the Martian mantle. The meteorites also offer clues into secondary geological processes such as the role that water has played in the formation of these rocks," explains Howarth.

To understand the chemical composition of the meteorites, Howarth and his team use an electron probe to analyse very fine sections of the rock. The data collected so far shows that Mars has a heterogeneous mantle, meaning it is made up of a variety of different kinds of rocks.

"These various mantle sources have not mixed very much because unlike Earth, Mars does not have any plate tectonics. The recent discovery of new Martian meteorites has revealed a diversity of sources and magmatic history, and that the Martian interior is more varied than previously thought."

A recent paper published in *Journal of Geophysical Research: Planets*, by Howarth and other geologists from around the world, also explains that the study of these Martian meteorites supports the idea that early Martian history involved fast accretion and core formation compared to Earth. But Howarth cautions that the majority of Martian meteorites studied to date are quite young by geological time standards, and combined with the fact that many come from the same ejection sites on Mars, they cannot give us a complete understanding of Martian geology.

Libby Young

UCT geologist Dr Geoffrey Howarth.

Time capsules from outer space

"Most of the meteorites studied so far are younger than 600 million years old. Three quarters of the meteorites are shergottites (named for the first location where they were found in Sherghati in India), which are almost identical to the rock basalt we find here on Earth. The rest are mostly made up of Nakhlites, named for the Nakhla meteorite found in Egypt in 1911. These are also igneous (volcanic) rocks composed largely of augite and olivine crystals."

Over the last two decades the number of recovered Martian meteorites has almost doubled, which has allowed scientists to study suites of meteorites for the first time. But according to Howarth, this still represents a biased sample with many coming from unknown ejection sites on Mars' surface.

"To really be able to look back in time and understand how the surface and interior of Mars was formed, we need samples from Mars itself. Lucky for us, the Mars 2020 Perseverance rover is aiming to collect over 30 diverse surface samples from the Jezero Crater on Mars. These rock samples may be returned to Earth as soon as 2031."

University of New Mexico

The Martian meteorite officially named North West Africa (NWA) 7034, but nicknamed 'Black Beauty', was found in Morocco in 2011.

These samples will allow scientists such as Howarth to analyse a greater variety of Martian rocks with known origins.

"Studying these rocks alongside the meteorites will help us to narrow our hypotheses of how the Martian interior and surface evolved," says Howarth.

Water on Mars

Howarth has a particular interest in the history of water on Mars and its role in atmospheric dynamics and volcanic activity. Previous missions to Mars have shown strong evidence for the past presence of water on its surface, as well as the current-day presence of ice at the polar caps and in the subsurface of the planet.

Howarth explains that by studying how and when minerals in Martian meteorites interacted with water, we can better understand the hydrologic history of Mars itself.

"While some of these minerals were formed from crystallised magma directly, others were formed through interaction with water occurring on the Martian surface or subsurface. So, we know that early on in the planet's history there must have been substantial water present. What we don't know is how much water cycling took place on Mars or how similar it might have been to our own planet."

Not over the moon yet

Howarth is hopeful that the discovery of new Martian meteorites here on Earth, or the return of samples from the next mission to Mars, will help to answer some of the many questions that remain about the planet's geology.

"Once we have access to older Martian rocks we can start to answer questions about the role of water in Martian magmatism (magma activity), such as how the magma ocean on Mars crystallised, how volcanic rocks came to be found at the surface of the planet, and how volcanic activity on Mars evolved over time."

But Martian meteorites are not the only bits of interstellar rock that Howarth is interested in.

"In the future I hope to apply such techniques to other meteorites, such as lunar meteorites from the moon. I think in many important ways Mars is really a jumping-off point. Although the current COVID-19 crisis has meant that I have had to put my plans for an outreach project on hold, I hope that I can soon share this work with students so that they too can get excited about its possibilities, just as I did the first time I held a little piece of Mars in my hand when I was a student."

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https://www.news.uct.ac.za/
Photo of Dr Howarth by Libby Young. Captions and additional images sourced by the Editor.

NASA/JPL-Caltech

ESA/DLR/FU-Berlin/NASA/JPL-Caltech

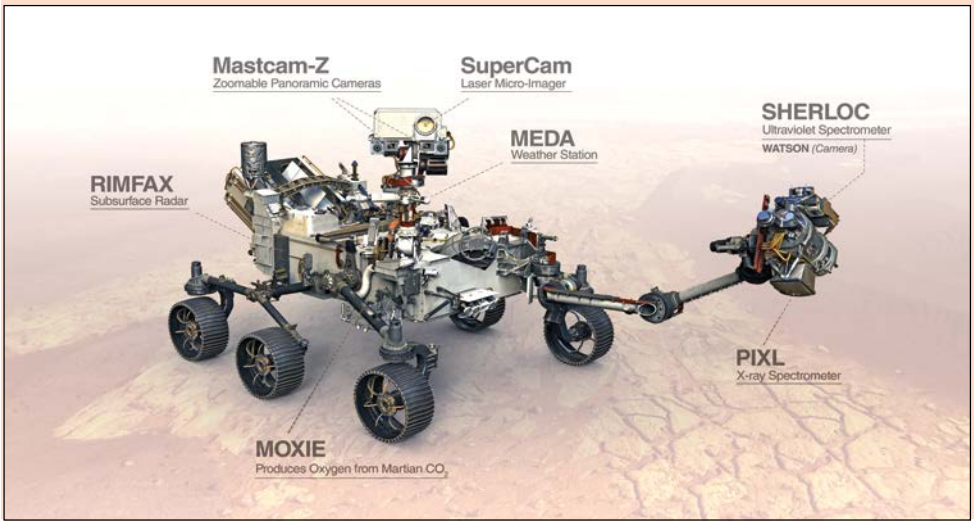
Watched by millions of people via live-streaming on television channels or online platforms, NASA's Perseverance rover landed on Mars on 18 February 2021, touching down on schedule in the Jezero Crater. Launched aboard a rocket that lifted off from Cape Canaveral Air Force Station in Florida, USA, on 30 July 2020, its mission is to search for signs of fossilised microbial life. Jezero is a 45 km-wide impact crater that is believed to have once been flooded with water, as it formed part of an ancient river delta.

Perseverance is the fifth rover that NASA has sent to Mars, and the largest to date, weighing in at 1 025 kg. It is also the first to carry a drill large enough to collect core samples of Martian rock and soil. These will be stored in sealed tubes for retrieval by a future mission, which would ferry them back to Earth for detailed analysis.

Perseverance also has a number of other instruments that collect geological data for immediate transmission to scientists on Earth. For example, SHERLOC – an acronym for Scanning Habitable Environments with Raman & Luminescence for Organics and Chemicals – is a Raman spectrometer that uses an ultraviolet (UV) laser to determine fine-scale mineralogy and detect organic compounds. By contrast, PIXL – the Planetary Instrument for X-ray Lithochemistry – is an X-ray fluorescence spectrometer that will permit more detailed analysis of chemical elements in surface materials than ever before. The Radar Imager for Mars' Subsurface Experiment (RIMFAX) is a ground-penetrating radar that will provide centimetre-scale resolution of the geologic structure of the subsurface.

Perseverance has a similar design to the Curiosity rover, which landed in the 154 km-wide Gale Crater in August 2012 and has since travelled more than 24 km. Curiosity's drill can only pulverise rock for analysis by its onboard instruments. Some 3 700 km separate the Gale and Jezero craters, so the two rovers will not be meeting up!

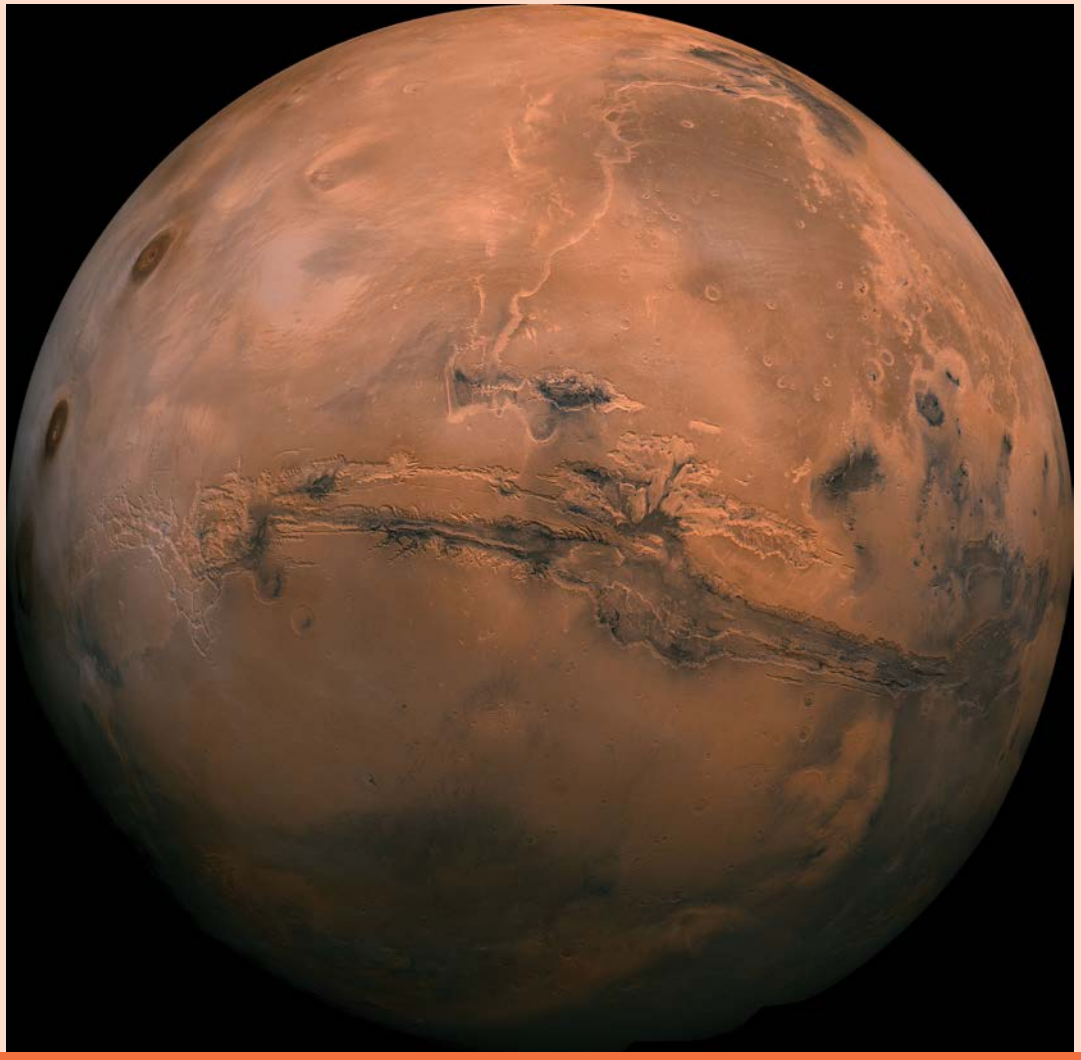
In January 2004, the twin Spirit and Opportunity rovers, which weighed just under 170 kg each, arrived on opposite sides of Mars. Their planned mission was only 90 days, but Spirit lasted until March 2010, having travelled more than 7.7 km. Opportunity sent its last communication during a severe dust storm in June 2018, by which time it had moved 45 km.



NASA/JPL-Caltech

The first Mars rover was the Sojourner, weighing just less than 10.5 kg, which landed in July 1997 as part of the Mars Pathfinder mission. It was operated through the Pathfinder base station, with which contact was lost in September 1997. During the intervening 85 Earth days, the Sojourner travelled just over 100 m.

- Find out more and follow Perseverance on an interactive map at https://mars.nasa.gov/mars2020/



NASA/JPL-Caltech

MARS FACTS AND FIGURES

- Mars is about half the size of Earth, having a radius of 3 390 km.
- It is the fourth planet from the Sun, at an average distance of about 228 million km.
- One day on Mars takes a little over 24 hours. Martian days are called sols – short for 'solar day'.
- Mars makes a complete orbit around the Sun (a year in Martian time) in 669.6 sols, equivalent to 687 Earth days.
- Mars is often called the red planet because iron minerals in the Martian soil oxidise, or rust, causing the surface and atmosphere to appear red.
- Mars was named by the ancient Romans for their god of war because its reddish colour was reminiscent of blood.
- Mars has two moons, Phobos and Deimos, named after the horses that pulled the chariot of the Greek god of war, Ares.
- Mars has a thin atmosphere made up mostly of carbon dioxide, argon, nitrogen and a small amount of oxygen and water vapour.
- The Martian atmosphere is too thin for liquid water to exist for long on the surface, but ice is found just under the surface in the polar regions, and salty brine seasonally flows down some hillsides and crater walls.
- The temperature on Mars can be as high as 20°C or as low as about −153°C.
- Strong winds sometimes create dust storms that cover much of the planet.
- The Olympus Mons, a volcano on Mars, is three times taller than Mount Everest.
- The Valles Marineris canyon is 4 800 km long, 320 km at its widest and 7 km at its deepest. That's about 10 times the size of USA's Grand Canyon.

https://solarsystem.nasa.gov/planets/mars/in-depth/

Tackling the **PSHB beetle**

Sue Matthews

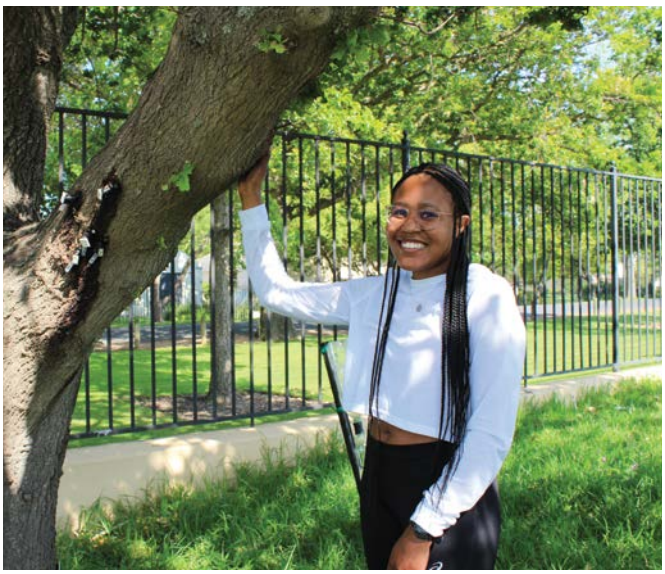
Student and historic estate managers join forces to save the trees

It's been more than three years since the polyphagous shot hole borer (PSHB) beetle was found to have infested the 100-year-old London plane trees in the KwaZulu-Natal National Botanical Garden in Pietermaritzburg. This was the first time the tiny beetle – native to South East Asia – was detected in South Africa, but it has since been recorded in all provinces except Limpopo.

In the Western Cape, the first report of the invasive alien's presence was in Somerset West in April 2019. Managers of the historic Vergelegen wine estate on the town's outskirts put measures in place to protect the farm's important tree collection, which includes five camphor trees planted by Cape Governor Willem Adriaan van der Stel soon after he established Vergelegen in 1700, as well as an English oak believed to be the oldest specimen in South Africa. The measures ranged from banning the transport of firewood onto the estate, to installing monitoring traps and repellent on the farm border.

Nevertheless, in February 2020 the PSHB beetle was discovered to have breached these defences and taken up residence in some of Vergelegen's trees. The estate, owned by Anglo American Farms since 1987, has been the site of numerous research projects conducted by staff and students from various universities, so the natural next step was to facilitate a study on this unwelcome intruder.

Heather Nependa from the Department of Conservation Ecology and Entomology at Stellenbosch University is undertaking research on the pest for her PhD, and has installed two types of traps on the estate to collect the beetle. One type uses chemical lures inside plastic bottles on steel stakes, intended to divert the beetles away from the trees, while the other is a 3D-printed trap secured over holes made by the beetles on trees. All traps are inspected every two weeks and their contents are delivered to the university for identification.



Judy Bryant

Heather Nependa

Stellenbosch University doctoral student Heather Nependa with 3D-printed traps over holes made by the beetle on an English oak within the Vergelegen Estate.

Judy Bryant

Heather Nependa checks a bottle trap with Vergelegen's risk and commercial manager, Leslie Naidoo. Fitted with a chemical lure, 50 of these traps have been staked out on the estate to divert PSHB beetles away from trees.

This monitoring programme is just one tool used by Nependa to meet the aims and objectives of her research, which are to:

- Learn more about the life history of the beetle, how it spreads, and the symptoms of damage on different tree species
- Improve understanding of the PSHB–fungus–tree relationship
- Test the effectiveness of lures and repellents
- Test potential pesticides (both insecticides and fungicides) and review their side effects and appropriateness
- Collect and analyse data in the field for a PSHB management plan geared to South African conditions.

Assisted by two honours students, Nependa has already produced an inventory of over a thousand Vergelegen trees. The data, including measurements of the diameter of each tree and its reproductive state, has been submitted to the USA-based website www.itreetools.org, which has free software for assessing and managing forests and community trees.

Next, temperature loggers will be placed at each of the monitoring sites to determine how climatic conditions affect beetle dispersal. This data will also be important for lab experiments on beetle and fungus biology and physiology. The fungus will be grown in the lab, and experiments conducted with nutrients and plant volatiles (the metabolites that plants release into the air) to determine the criteria required for successful fungus establishment. All of this information will be useful in modelling the PSHB's impact and potential distribution within the Somerset West area.

Issued by Judy Bryant of Meropa for Vergelegen Estate.

The polyphagous shot hole borer beetle, *Euwallacea fornicatus*, is known to have attacked more than 100 different tree species in South Africa, introducing its symbiotic fungi that cause weakening, branch die-back and ultimately the death of many trees. Worst affected are those species in which the beetle can breed, and to date more than a third of the tree species affected countrywide have been identified as such 'reproductive host trees'.

The adult female beetle, which is only about 2 mm long, bores into the tree, creating a tunnel through the wood. During this process, fungal spores carried in specialised structures near her mouthparts are deposited in the tunnels. The fungus subsequently grows on the tunnel walls and invades the tree's water-conducting tissue, the xylem. The female beetle lays her eggs in the tunnel, where the larvae feed on the fungi after hatching. They grow and develop, then pupate together in the tunnel. Once they emerge from the pupal stage as adults, the male and female beetles mate. The males, which cannot fly, remain in the tunnel or sometimes crawl out onto the tree bark. The females leave the tree through the entrance tunnel and fly off in search of a suitable host tree to lay their eggs.

The PSHB was already considered a serious pest in Israel and California by the time it was detected in South Africa in 2017. In an effort to curtail its spread, Minister of Forestry, Fisheries and the Environment, Barbara Creecy, published a call for comment in September 2020 on a proposed PSHB emergency intervention under the National Environmental Management: Biodiversity Act. The measures outlined would require owners or occupiers of land in certain areas to report the beetle's presence on tree species listed in the notice. In addition, people would be prohibited from bringing those tree species into protected areas, even as firewood. The sale of any PSHB-infested wood or other material would also be outlawed.

The Minister of Agriculture, Land Reform and Rural Development, Thoko Didiza, had likewise invited comment on draft control measures under the Agricultural Pests Act in July 2020. These would make it compulsory for people to report the beetle's occurrence – whether confirmed or suspected – on any land, especially where it has been recorded for the first time in a previously pest-free area.

- For more information, refer to the recent paper in *Quest*'s sister publication, the *South African Journal of Science*, by the researcher credited with discovering PSHB in South Africa, Dr Trudy Paap, and her co-authors.
  Paap T, Wingfield MJ, De Beer ZW, Roets F 2020. Lessons from a major pest invasion: The polyphagous shot hole borer in South Africa. *S Afr J Sci* 116 (11/12). https://doi.org/10.17159/sajs.2020/8757

Rachel Osborn, USDA APHIS PPQ, Bugwood.org

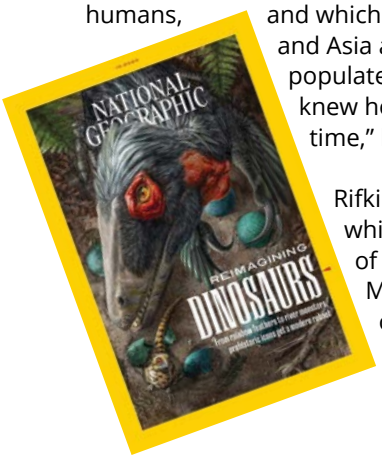
The polyphagous shot hole borer (PSHB) beetle

As a bioarchaeologist, Dr Riaan Rifkin studies ancient disease organisms at a molecular (DNA) level and works in the field of molecular archaeology. His research entails visiting excavation sites to search for DNA in sediments and human remains.

TRACING ANCIENT HUMAN DISEASES

Dr Riaan Rifkin, a research fellow at the University of Pretoria (UP), was honoured with a profile in *National Geographic* magazine for his work on tracing the DNA of ancient human diseases.

The National Geographic Society funds his research at the Centre for Microbial Ecology and Genomics (CMEG) at UP. Spending time in cave sites, searching for ancient DNA in sediments and human remains, is part of Rifkin's daily routine. He is looking for clues concerning the past prevalence of common and novel human diseases. He wants to find out "which diseases plagued ancient humans, and which of these were taken to Europe and Asia as our ancestors left Africa to populate these regions. Our ancestors knew how to overcome illnesses at that time," he says.



Dr Rifkin was profiled in the October 2020 edition of *National Geographic*.

Rifkin is a bioarchaeologist at CMEG, which is housed in the Department of Biochemistry, Genetics and Microbiology in the Faculty of Natural and Agricultural Sciences at UP. He holds a master's degree in prehistoric rock art from the Rock Art Research Institute at the University of the Witwatersrand, as well as a PhD from its Institute for Human Evolution. "My research focused on the use of red ochre – a soft clay-based earth pigment – by ancient southern Africans going back 100 000 years, and what this might tell us about the cognitive and social evolution of our species. While ancient humans likely used red ochre as a symbolic body cosmetic, our experiments have shown that this also proved to be a very good sunscreen, insect repellent, and animal-hide tanning ingredient."

Ancient humans using red ochre powder for these purposes were already very 'modern' at least 100 000 years ago, "before our species left Africa for Asia and Europe," he says.

Based on his work with the OvaHimba in Namibia, where women use red ochre daily, he developed an interest in the possible influence of diseases in our African ancestors. "The OvaHimba informed me that the red ochre mixture also prevented them from being bitten by mosquitoes. As mosquitoes are important disease vectors still today – including Zika virus, West Nile virus, Chikungunya virus, dengue, and malaria – I started to gather information concerning ancient African diseases, and how these would have influenced the evolution of our species in Africa."

As a bioarchaeologist, he studies ancient disease organisms at a molecular (DNA) level and works in the field of molecular archaeology. He says: "My research at UP focuses on discovering ancient DNA from southern African archaeological sites, including sediments and human remains. The remains span the period from circa 75 000 to 1 500 years ago. My primary aim is to generate a sub-Saharan African disease baseline database that precedes the departure of *Homo sapiens* from Africa after circa 75 000 years ago."

He recently secured funding for a five-year project through the Benjamin R Oppenheimer Trust, which awarded him a fellowship for his studies in molecular archaeology. The long-term objective of the fellowship is to contribute to alleviating the adverse influence of ancient re-emerging 'ancestral' diseases on contemporary humans.

But why study ancient diseases? And how can novel data about prehistoric pathogens benefit modern society? The impact of disease on prehistoric humans is illustrated by the fact that roughly two thirds of modern-day hunter-gatherers, such as the Kalahari San and the Tanzanian Hadza, succumb to disease before reaching 15 years of age. Despite the fact that many of the approximately 400 recognised human pathogens had a profound influence on human evolutionary history, many are still implicated in the deaths of millions of people annually.

"So, even in our modern day and age, we are not immune against pathogens. Epidemics caused by Zika virus, avian influenza and even the *Yersinia pestis* bacterium – the causative agent of the 'black death' plague – still pester modern human society. But recognising which disease-causing pathogens were brought from Africa to the rest of the world, after our ancestors left the continent some 65 000 years ago, is a challenging venture," says Rifkin.

This entails determining the evolutionary relationships between ancient African human populations and pathogenic and beneficial microbial species, and exploring the ways in which emerging 'ancestral' human diseases are expected to affect modern-day sub-Saharan African populations. The final step is producing policy guidelines for the integration of novel DNA information into epidemiological models about disease emergence and outbreak-response planning.

This involves integrating archaeology, molecular ecology and palaeo-epidemiology. While this innovative approach is promising for interpreting past human lifestyles, it also holds great potential for predicting the emergence of new diseases.

Article by Primarashni Gower republished from University of Pretoria News. https://www.up.ac.za/news/

Rita Willaert, CC BY-NC 2.0

A Himba woman shows a tourist how red ochre is made and applied.

CURRICULUM CORNER

LIFE SCIENCES: GRADE 11
Biodiversity: Microorganisms and diseases

LIFE SCIENCES: GRADE 12
DNA, the code of Life: Deoxyribonucleic acid
Genetics and Inheritance: Mitochondrial DNA

PHYSICAL SCIENCE: GRADE 11
Chemical systems: Lithosphere

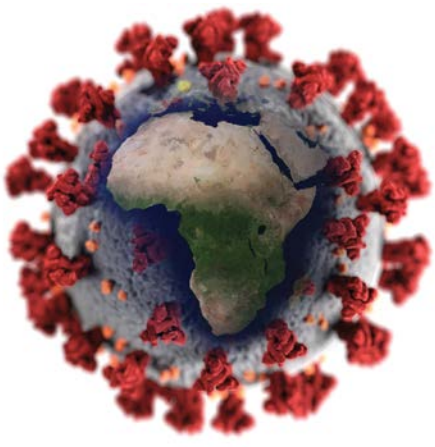
Government Communications Service

COVID-19 VACCINES

Edina Amponsah-Dacosta answers some frequently asked questions

'Coronavirus Disease 2019', or COVID-19, which is caused by the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), has become a major threat to public health since the initial outbreak in China in December 2019. By 20 February 2021, more than 110 million infections and 2.45 million deaths associated with COVID-19 had been reported worldwide, with more than 1.5 million infections and 48 940 deaths having occurred in South Africa.

To reduce the spread of SARS-CoV-2 and help end the pandemic, experts around the world have been working intently to develop safe and effective vaccines against COVID-19. Vaccines help our bodies to develop protection – known as immunity – by teaching the cells in our body to recognise and fight against viruses and other germs, in this way preventing us from becoming sick or from spreading diseases to others.



CDC & NASA

Do we have a vaccine against COVID-19?

By mid-February, a number of vaccines had been licensed and approved for prevention of COVID-19 – including the Pfizer-BioNTech, Moderna and Oxford/AstraZeneca COVID-19 vaccines – and other candidates were undergoing testing in clinical trials. In South Africa, one million doses of the Oxford/AstraZeneca COVID-19 vaccine (also known as COVISHIELD) were secured from the manufacturers based at the Serum Institute of India. However, shortly before the vaccination programme was due to begin, it was suspended because the vaccine was found to have limited effectiveness against mild to moderate COVID-19 caused by the SARS-CoV-2 variant identified in South Africa. Instead, the South African government began roll-out of Johnson & Johnson's single-dose Janssen vaccine to healthcare workers on 17 February. Although the clinical trial results had been released in early February, showing the vaccine was safe and effective, the licensing process was still under way. The South African Health Products Regulatory Authority (SAHPRA) approved the use of the vaccine for healthcare workers within an implementation study that would allow additional data to be collected, pending the full licensing.

Are there different types of vaccines against COVID-19?

There are four main types or categories of COVID-19 vaccines, some of which are in use now, while others are in clinical trials. These vaccine types are nucleic acid, protein

 **Nucleic acid vaccines**	 **Protein subunit vaccines**	 **Whole virus vaccines**	 **Vector vaccines**
These vaccines contain a portion of the genetic material – specifically the mRNA – of SARS-CoV-2. Within this mRNA is the 'recipe' for making a harmless protein (spike protein) that is unique to SARS-CoV-2. The COVID-19 mRNA vaccine is the first-ever approved vaccine to use this approach! Because mRNA is highly labile (unstable), these vaccines have to be stored at −80°C.	This type of COVID-19 vaccine contains purified pieces of the spike protein that is unique to SARS-CoV-2.	There are two approaches for whole virus vaccines. (1) Live attenuated vaccines make use of a weakened form of the SARS-CoV-2. (2) Inactivated vaccines make use of a killed form of SARS-CoV-2, where the genetic material has been destroyed using chemicals, heat or radiation.	A vector vaccine uses a harmless virus as a vehicle to deliver the viral genetic material – in this case the viral DNA – which contains the 'recipe' for the SARS-CoV-2 spike protein. DNA is not as fragile as RNA, so these vaccines are easier to store at 2–8°C.
Once introduced into our body, the mRNA in the vaccine is carried to our cells, where it instructs them on how to make the harmless spike protein. This protein triggers our cells to produce large quantities of antibodies against it. Our cells then develop immune memory, which makes them recognise and destroy the spike protein anytime it appears in our bodies.	Once vaccinated, the protein in the vaccine directly triggers our cells to produce large quantities of antibodies, and to recognise and destroy this spike protein the next time we are exposed to SARS-CoV-2.	Both live attenuated and inactivated COVID-19 vaccines can directly trigger our cells to produce antibodies. This response also triggers our immune memory cells to recognise and destroy the spike protein every time we are exposed to SARS-CoV-2, giving us immunity to COVID-19.	Scientists take the viral DNA and insert it into a harmless virus known as the adenovirus. This adenovirus vector is modified in a way that prevents it from causing any disease once inside our cells.
This means the next time we are exposed to SARS-CoV-2, which carries the spike protein on its surface, our triggered cells recognise the protein and destroy it, protecting us from developing COVID-19.	Vaccines developed using this approach have been around for a very long time, and include the hepatitis B and pertussis (whooping cough) vaccines.	Because the virus used in this type of vaccine has been weakened or killed, it cannot cause COVID-19 in healthy individuals. Examples of live attenuated vaccines are the measles, mumps, rubella, and chickenpox vaccines. Inactivated vaccines include the flu and polio vaccines.	When we receive the vaccine, the DNA is delivered to our cells where it is transcribed to mRNA. The mRNA is then translated into spike proteins which trigger our cells to produce large quantities of antibodies. Our immune cells are also triggered to recognise the spike protein and destroy it next time we encounter it.
Both the Pfizer-BioNTech and the Moderna COVID-19 vaccines are mRNA vaccines.	The Novavax candidate COVID-19 vaccine is an example of a protein subunit vaccine.	Examples of live attenuated and inactivated COVID-19 vaccines are the Sinopharm, Sinovac and Bharat Biotech COVID-19 vaccines.	The Oxford/AstraZeneca and Johnson & Johnson Janssen COVID-19 vaccines are types of viral vector vaccines.

US Secretary of Defence

South Africa has placed a large order for the Pfizer-BioNTech vaccine. Although originally required to be stored at ultra-low temperatures of −80°C to −60°C, the manufacturers showed in February that the vaccine is stable at −25°C to −15°C, allowing it to be stored in standard pharmaceutical freezers.

subunit, whole virus, and vector vaccines. The different vaccine types differ in whether they use the SARS-CoV-2 nucleic acid (or genetic material), the whole virus or just parts of the virus. All four of them are being developed with the same goal in mind: to give us immunity against COVID-19.

How do we know the COVID-19 vaccine will work?

The COVID-19 vaccines have been highly researched by experts through clinical trials around the world, and South Africa has participated in those for the Pfizer-BioNTech, Oxford/AstraZeneca, Novavax and the Johnson & Johnson COVID-19 vaccines. In these trials, some of the approved COVID-19 vaccines showed 94–95% efficacy in preventing symptomatic COVID-19 after the second doses. In the case of the Pfizer-BioNTech vaccine trial, for example, there were eight cases of COVID-19 among the more than 22 000 people who received the vaccine versus 162 cases among the other 22 000 people who received the placebo (8/162=5%). This implies that for every hundred people with COVID-19, only five would have got ill if they had received the vaccine. All vaccines are continuously evaluated and monitored, even after approval.

How do we know if it is safe?

It is important to note that none of these vaccines can give a person COVID-19 because they do not contain the actual infectious SARS-CoV-2 virus, but only harmless versions or parts of the virus. For a vaccine to be declared safe, it has to undergo and pass strict quality and standards tests set by internationally accredited regulatory bodies before final approval and licensure.

Who can receive the vaccine?

The approved COVID-19 vaccines have been licensed for use in individuals 16–18 years of age and older. As of mid-February, clinical trials to evaluate the safety and effectiveness of these vaccines in children with permission from their parents were still being conducted. The recommended dosage of most of the vaccines is two shots (scheduled up to 28 days apart) in the muscle of the upper arm. The first shot starts building immunity. After a few weeks, the second shot is needed to maximise the level of protection from the vaccine. Because there are limited doses of COVID-19 vaccines around the world, certain groups of people such as healthcare workers and the elderly, who are at higher risk of being infected and developing severe COVID-19, have been prioritised to receive the vaccine. With time, there should be enough vaccine doses available for everyone who wants to be vaccinated.

How many people should be vaccinated?

The South African government is aiming to vaccinate 67% (40 million people) of the population against COVID-19. It is anticipated that this strategy will help to achieve 'herd immunity', which is when most of the population is immune, thereby indirectly protecting the remainder of the population who are not immune for various reasons. The more people are vaccinated, the higher the chances of reducing the spread of the virus within our communities.

While the COVID-19 vaccine programme is rolled out, we must all continue to adhere to the recommended risk-reduction measures such as wearing cloth masks over our nose and mouth, practising physical distancing, and frequently washing and sanitising our hands. These measures have been proven to reduce the risk of contracting and spreading SARS-CoV-2, and together with vaccination will help control the devastating burden of COVID-19.

Dr Edina Amponsah-Dacosta is a postdoctoral research fellow at the Vaccines for Africa Initiative (VACFA) at the University of Cape Town (UCT). She obtained her PhD in medical virology from the Sefako Makgatho Health Sciences University in 2017, and then completed the Master of Public Health programme at UCT in 2019.

Njengoba uhlelo liokugomela Igciwane le COVID-19 seluqalile, kumele sonke siqhubeke nokulandela imigomo ebekiwe yokwehlisa ukutheleleka ngegciwane, efana nokufaka izimfonyo, sivale ikhala nomlomo,siqhelelane kanye nokugeza izandla ngokwevamile.

Translated by Zamantimande Kunene

Traditional healers discuss sustainable use of **medicinal plants**

Some 72% of South Africans still use medicinal plants on a regular basis, but this demand is placing pressure on remaining populations of such plant species, resulting in a significant decline in availability over the past three decades.

The South African National Biodiversity Institute (SANBI) is therefore developing a Biodiversity Management Plan for Species (BMP-S) for threatened medicinal plant species in Mpumalanga's Ehlanzeni District Municipality, which comprises the four local municipalities of Bushbuckridge, Mbombela, Thaba Chweu and Nkomazi.

This project is part of the broader Biodiversity and Land Use Project funded by the Global Environment Facility. The project is engaging with traditional healers and *muthi* gatherers to cooperatively develop Biodiversity Management Plans for six threatened medicinal plant species, to ensure conservation and sustainable use.

Selecting the species entailed identifying those for which the selling price was rising as they were becoming harder to find in the wild and in markets, and then prioritising these based on conservation status, population trends, distribution patterns, demand, ease of propagation and presence in protected areas.

Two of the six medicinal plants chosen are the endangered pepper bark tree *Warburgia salutaris* (Isibhaha; Xibaha; Monaka) and the critically endangered wild ginger *Siphonochilus aethiopicus* (Isiphephetho; Xirungulu; Isidungulu). The others are the bulb *Bowiea volubilis* (Ugibisisila; Moemo), a medicinal plant from the carrot family *Alepidea cordifolia* (Ikhathazo; Lešoko), the succulent *Haworthiopsis limifolia* (Umathithibala; Kgopa), and the elephant foot caudex plant *Dioscorea sylvatica* (Inyathelo-lwe-ndlovu; Kgato).

Engagement between conservation practitioners, traditional healers and *muthi* gatherers is vital to determine the management interventions required to conserve the existing medicinal plant species and ensure availability of medicinal material for future use. The team working on the BMP-S travelled from village to village in the four local municipalities to reach as many healers as possible. A total of 137 healers and three *muthi* gatherers were interviewed, and key representatives from each village were then invited to a workshop held at the Lowveld Botanical Gardens in Mbombela in November. Attendees had the opportunity to engage directly with law enforcement officials and conservation practitioners working both within the district and in national government.

It emerged that 90% of the healers travel long distances to collect medicinal plants, the majority of healers buy

SANBI

Traditional healers, conservation practitioners and law enforcement officials came together for a workshop at the Lowveld Botanical Gardens in Mbombela (formerly Nelspruit) in November.

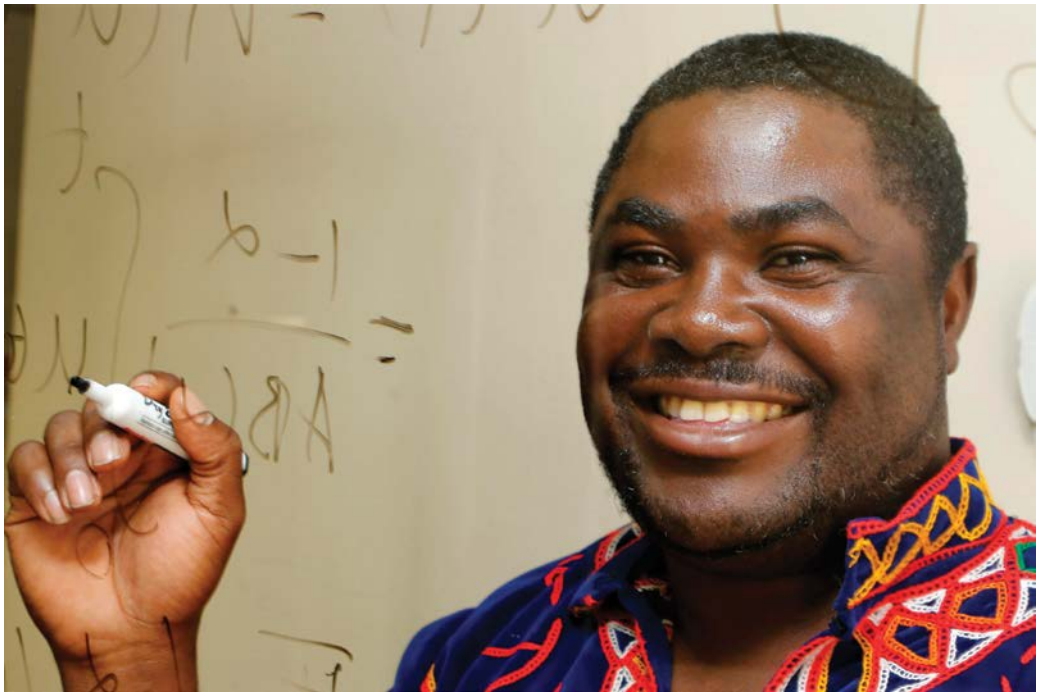
medicinal material from markets and pension payouts, and healers from three of the four municipalities cultivate medicinal plants. The healers identified cultivating as the key conservation intervention needed to conserve species, and indicated they would be willing to grow plants in their home gardens should they be provided with seedlings. Participants also mentioned that protected areas should cultivate those species that will be difficult for communities to cultivate because of habitat differences, water and land availability.

In addition, the need to simplify the permit process was identified as a management priority. Healers spoke about the victimisation they experienced when harvesting material without permits, but the relevance of having permits and how it benefits the sustainable use of species was explained. The workshop was beneficial to healers as they made direct contact with officials from whom permits could be obtained in future.

As part of the development of the management plan, the team is conducting extensive surveys of all six species in the wild, and has already discovered many populations not previously known. Many of these are in protected areas and on private land, so they can act as long-term genetic resource banks. The team also found areas of communal land where there are still good populations of medicinal plants. The communities that have tenure over these areas require support to ensure that overharvesting by gatherers from other parts of South Africa does not take place.

Issued by SANBI. The management plan will be finalised in 2021 and will be made available for comment. If you would like to know more about this work or would like to contribute to the management actions, please contact: Domitilla Raimondo at d.raimondo@sanbi.org.za

MATHS PROF MAKES HIS MARK



UFS

Prof. Abdon Atangana, a professor of applied mathematics at the University of the Free State (UFS), was given the first TWAS-Mohammad A. Hamdan Award by The World Academy of Sciences (TWAS) in December 2020. The new award is named after the esteemed mathematician who served as TWAS Vice President for the Arab Region until his death in February 2020. The award comes with a 'purse' of US$5 000, and will be given every two years for outstanding work in pure mathematics, applied mathematics, probability or statistics by a scientist working and living in the Africa or Arab regions.

Prof. Atangana is recognised for his contributions in the mathematical field of fractional derivatives. In an essay published by Clarivate on the Web of Science Blog in January 2018, he explains these for non-specialist readers.

"To a layman, most physical problems can be expressed in terms of mathematical formulations called differential equations; the differential equation's aim is to analyse, understand, and predict the future of a physical problem. One of the most used differential operators was that developed in the 17th century by Isaac Newton and Gottfried Leibniz, but this failed to model complex real-world problems. The concept of non-local operators called fractional derivatives and integrals was suggested by Bernhard Riemann and Joseph Liouville with the aim to capture more complex phenomena, but also failed to model many important real-world problems."

In 2016, Prof. Atangana proposed the Atangana-Baleanu fractional derivative to more accurately model complex real-world problems. His paper was subsequently named a New Hot Paper for Mathematics in the Clarivate Essential Science Indicators database, and in 2019 he was named a Clarivate Highly Cited Researcher – ranking in the top 1% of citations in the Web of Science – in the field of Mathematics. In 2020 he was included on the list again, but in the Cross-Field category recognising researchers who publish multiple highly cited papers in several different fields.

Prof. Atangana was awarded his PhD by the UFS Institute of Groundwater Studies for his thesis on the use of fractional derivatives to estimate uncertainties in modelling flow within a pollution-contaminated aquifer in the coastal city of Douala, Cameroon – his home country. He has since been employed at the Institute, but he uses his mathematical skills to solve problems in other fields of science, technology and engineering too. These include, for example, predicting the spread of various diseases, modelling flow in internal combustion engines, and detecting edges in advanced image processing.

Apart from being a prolific contributor of scientific papers, Prof. Atangana has written two books published by Elsevier, and has served on the editorial boards of more than 20 journals.

- Read Prof. Atangana's essay on the Web of Science Blog at https://clarivate.com/webofsciencegroup/article/fractional-derivative-modeling-real-world-problems/

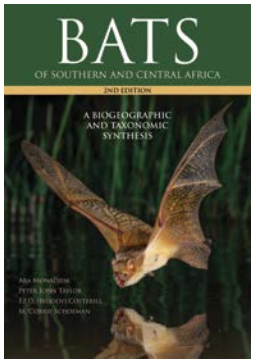
The World Academy of Sciences (TWAS) is based in Trieste, Italy, but was founded in 1983 by a distinguished group of scientists from the developing world, under the leadership of Abdus Salam, the Pakistani physicist and Nobel laureate. It was originally known as the Third World Academy of Sciences, as its goal is to advance science in developing countries. Today, TWAS is a programme unit within UNESCO – the United Nations Educational, Scientific and Cultural Organisation – and has more than 1 200 elected Fellows, 14 of whom are Nobel laureates.

Books

Batty about bats

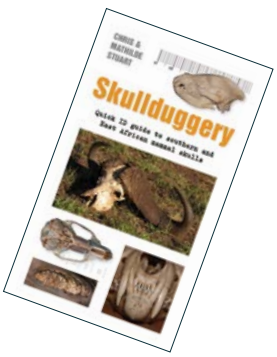
Two new books on bats have been published in South Africa recently, but they couldn't be more different in their format, approach and level of detail.

At one extreme is ***Bats of Southern and Central Africa***, published by Wits University Press. This is a revised edition of a book first published in 2010, and includes an additional eight newly described species to supplement the original 116 species accounts. It's a hefty tome of 640 pages, and the recommended retail price is a whopping R600.

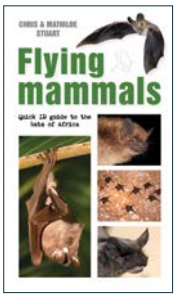


This hardcover book would clearly be a prized possession for bat specialists, but it would also appeal to other scientists and conservationists needing a comprehensive reference work on bats, as well as to serious amateur naturalists. Although not a 'coffee-table book', it does contain plenty of large, high-quality colour photographs, and the chapters on bat biology and ecology, biogeography and echolocation provide an easy-to-digest introductory overview before the species accounts, which make up the bulk of the content. These include descriptions, measurements and diagnostic characters as well as detailed information about the distribution, habitat, roosting habits, foraging ecology and reproduction of each species. The updated species distribution maps are based on 6 100 recorded localities, while new spectrograms can help identify bats in acoustic surveys.

The authors – Ara Monadjem, Peter John Taylor, Fenton (Woody) Cotterill and M. Corrie Schoeman – are all based in southern Africa. The first two are zoology professors from the University of eSwatini and University of Venda, respectively. Woody Cotterill is a research fellow with the National Geographic Okavango Wilderness Project, while Corrie Schoeman is an honorary associate professor at the University of KwaZulu-Natal.



At the other extreme of the publication scale is ***Flying Mammals*** by Chris and Mathilde Stuart. This is a very slim pocket guide in the 'Quick ID guide' series the authors have published under Penguin Random House South Africa's Struik Nature imprint. Although only 40 pages long, it is all that the average reader would need to identify a bat to family level, from the large fruit bats to the insectivorous horseshoe bats, leaf-nosed bats, slit-faced bats and others.



A short introduction provides information on bat evolution, flight, echolocation and reproduction, followed by useful photos of the skulls of 16 insectivorous and eight fruit-bat species. Then the bat families are covered in a few pages each, split into sections on description, diet and roosting, with a number of photos of different species. The closing pages touch on conservation and research, with a box on the impact that COVID-19 may have on these aspects, given that the disease likely originated in bats.

The authors are Struik Nature stalwarts, having written numerous field guides and pocket guides, mostly on mammals, for the publishers since the 1980s. The recommended retail price for this handy little book is R80.

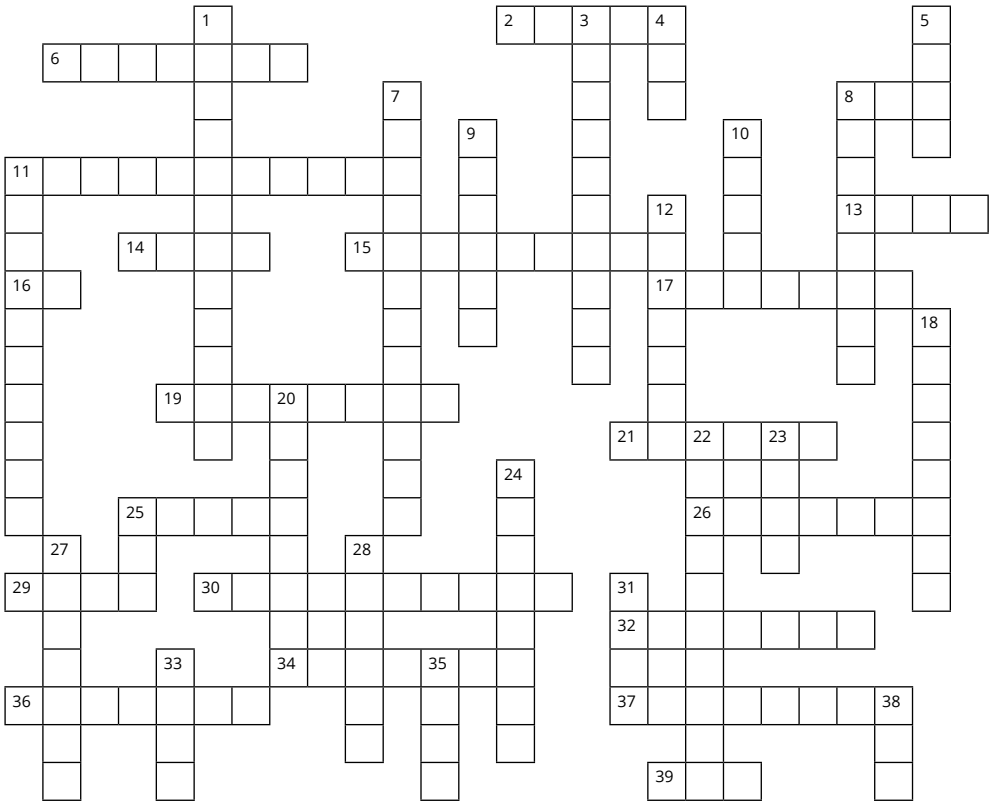
The Stuarts have also produced two other offerings in Struik Nature's Quick ID series recently. ***Avian architects*** is a guide to nests and eggs of southern African birds. A key to the main nest types on the inside front cover directs the reader to the correct section. These types include, for example, mud-pellet nests, woven nests, holes in earth banks and self-excavated tree holes, as well as nests on cliffs, on water, on tree branches and on the ground. Of course, in its 40 pages the book can only provide an introduction to the topic and describe some nests and eggs most likely to be seen, but it is fascinating to see the variety of nests, and also the characteristics that distinguish very similar-looking eggs.

Anyone who has ever come across a skull in the veld will appreciate how useful ***Skullduggery*** would be to have at hand. It's a guide to mammal skulls, from the largest such as elephants, rhinos and hippos to the smallest rats, mice and shrews. It also covers marine examples that might be found on the beach – some whale, dolphin and seal skulls. An introductory section explains mammal dentition and dental formulas, which are provided for most groups featured in the book.

Previous Quick ID guides by the authors focus on animal tracks (*On Track*), droppings (*Scatalog*) and behaviour (*Behaviour Briefs*).

Test your knowledge

All of the answers can be found in this issue of *Quest*



ACROSS

2 A clay-based earth pigment used by the Himba people
6 Sonar is short for sound navigation and ___
8 Often referred to as the code of life
11 Describes the reflected 'echo' of waves, particles or signals back towards the receiver
13 Acronym for advanced echosounders
14 The largest type of whale
15 A 'space rock' that lands on Earth
16 The symbol for the SI unit for frequency
17 A coastal fish species that matures in estuaries
19 A type of graph recording depth or underwater distance from an echosounder
21 A group of fish
25 A ___ net is used to catch bottom-dwelling fish
26 The unit for measuring sound intensity level
29 The pulsed sound signal sent by echosounder transducers
30 Sound with frequencies above the range of human hearing
32 Species name for humans
34 A type of geophysical survey that uses sound to investigate underground structures
36 A marine mammal that uses echolocation to find prey
37 The quacking calls of Antarctic minke whales
39 Mars is known as the ___ planet

DOWN

1 The study of sounds produced by and affecting animals
3 A dolphin species found only in the Benguela Current ecosystem
4 Acronym for an approach to fisheries that takes ecosystem impacts into account
5 South Africa declared 20 new ones in May 2019 to protect ocean ecosystems
7 The name of the rover that landed on Mars in February
8 The sound made by some fish using sonic muscles
9 Filter-feeding whales have this instead of teeth
10 A ___-seine net is used to catch sardines and anchovies
11 Refers to depth and seafloor topography
12 Describes fish living in surface waters, including sardines and swordfish
18 A deep-sea fish that is known to produce 'mating calls'
20 The 'ear bones' of fish
22 An underwater device to detect and record sound
23 Another name for a killer whale
24 A ___ trial is conducted to test the efficacy and safety of new vaccines and medicines
25 A device bearing a unique identification code inserted into a fish to track its movements
27 Refers to a type of computed tomography
28 Relating to or found in the sea
31 Acronym for an invasive borer beetle attacking trees in South Africa
33 Informal term for a vaccine or drug dose delivered by injection
35 The Pfizer-BioNTech and Moderna COVID-19 vaccines are this type
38 A Martian day

BRAINTEASERS

Sipho paid R210 for five presents. For A and B he paid a total of R60. For B and C he paid a total of R100. For C and D he paid a total of R70. For D and E he paid a total of R90. How much did Sipho pay for each present?

A goldfish costs R10.80. An angelfish costs R10.40. Nasreen paid exactly R200 for some fish. How many of each kind did she buy?

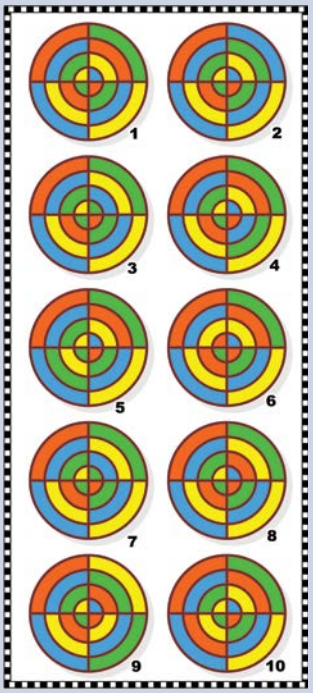
Answers to Brainteasers in Vol. 16 No. 4

Desmond won R540 000.

Rose put 12 coins on the table.

PICTURE PUZZLE

Find the two identical images.



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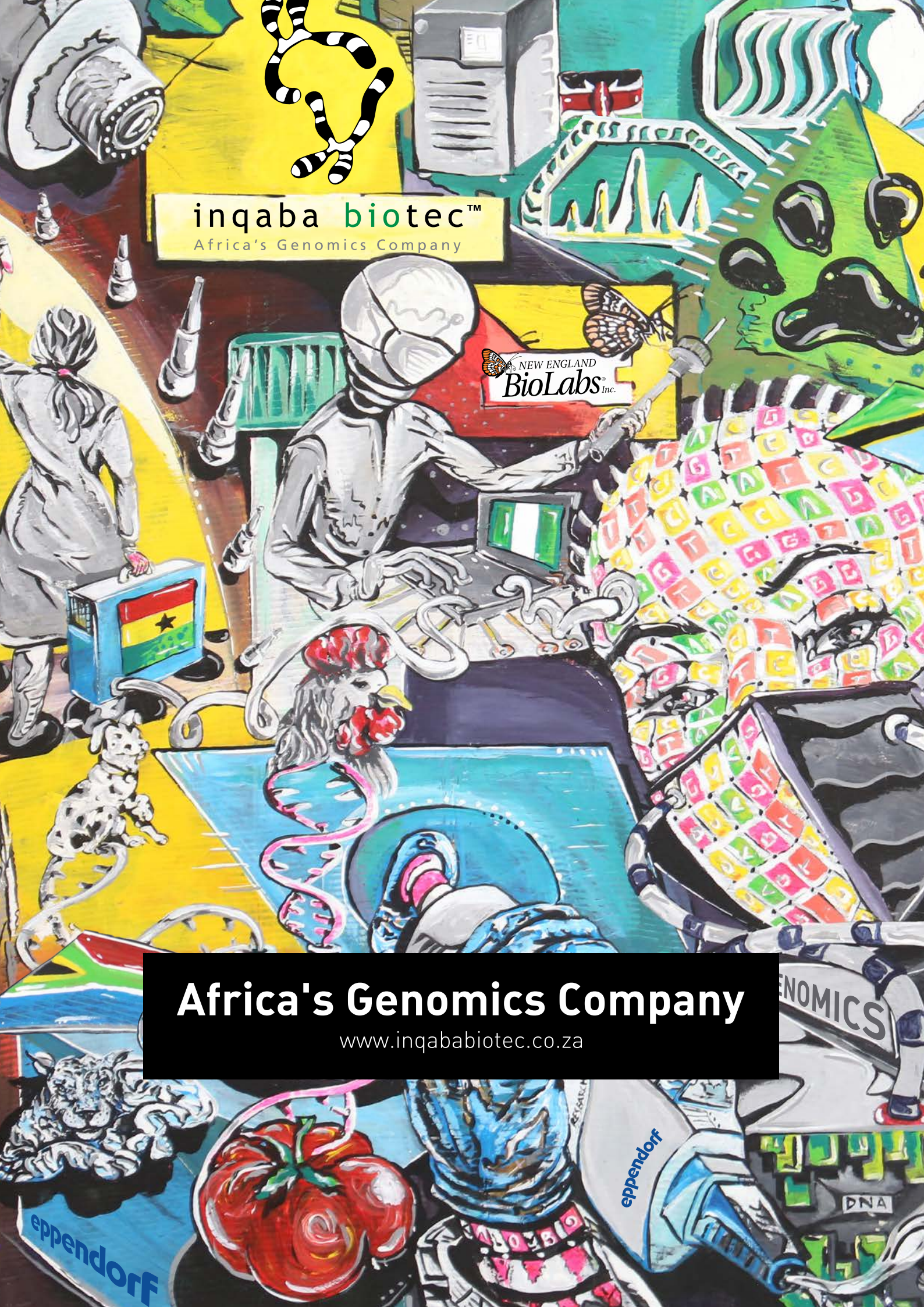
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