Sound science for counting fish

Janet Coetzee explains the role of hydroacoustics in fishery surveys

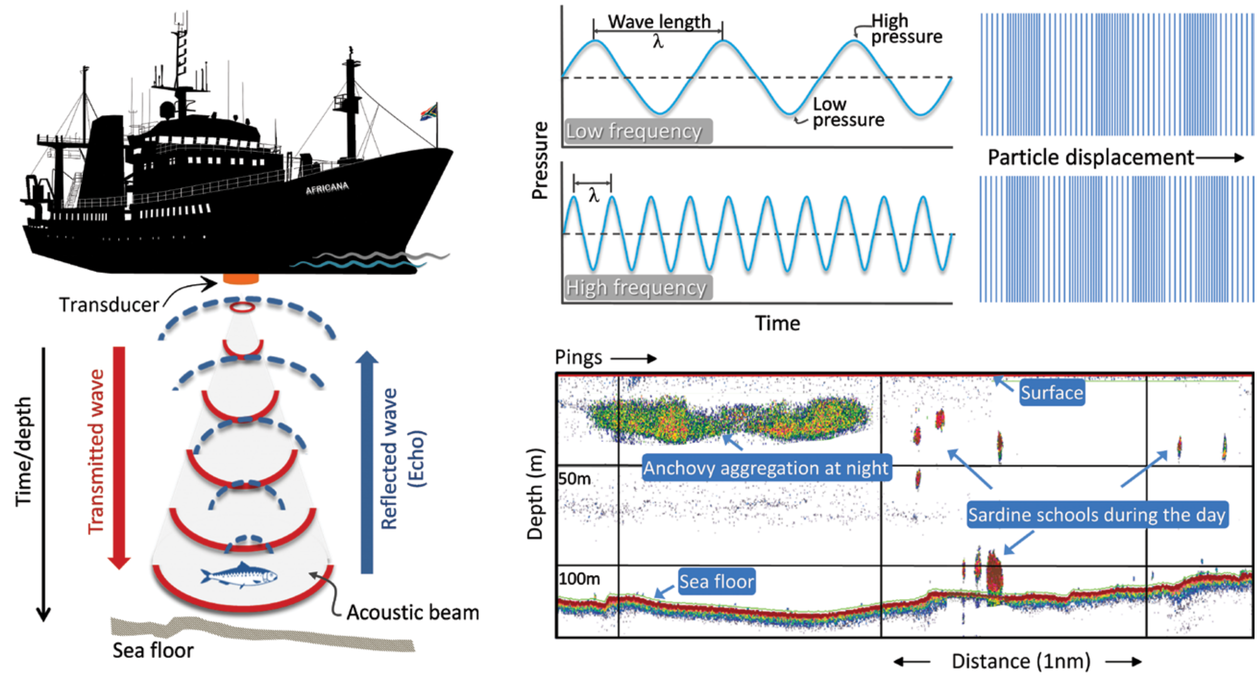
Imagine an area of almost 200 000 km^2 of ocean, stretching up to 150 nautical miles offshore (about 280 km) at its widest point and extending down to a depth of 200 m – now imagine counting the number of fish in that vast, mostly dark and inaccessible body of water. Impossible? No. Just listen….

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.

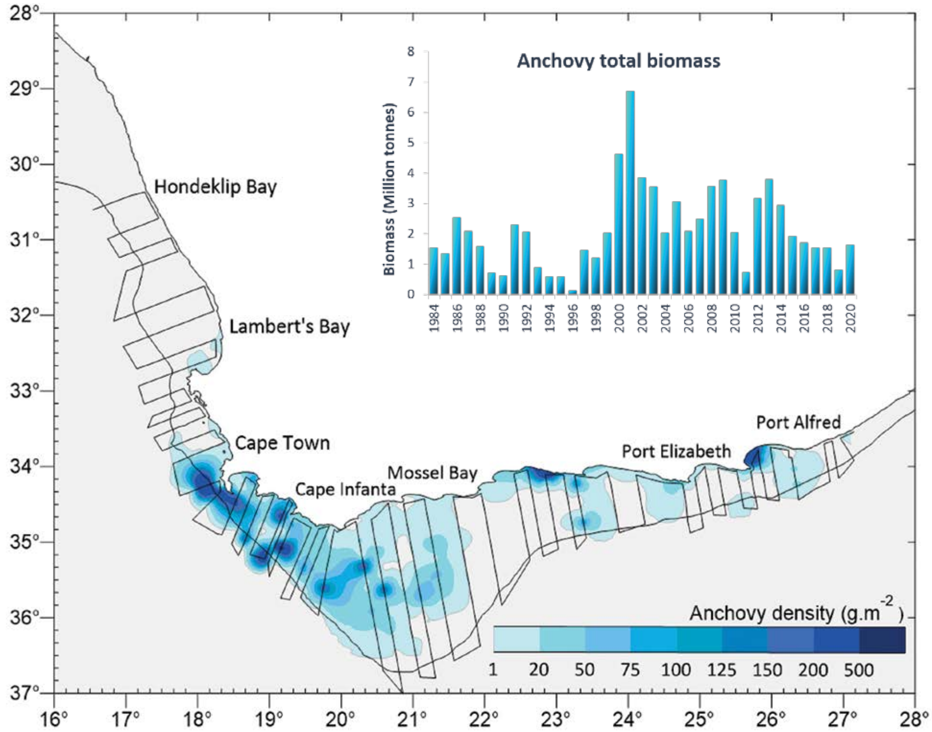
and low-frequency radio waves some tens of metres at best, sound waves can travel much further and faster in water. The speed of sound in seawater is approximately 1 500 m/s compared to 340 m/s in air, and sound waves at frequencies in the range of 10–200 kHz are able to travel hundreds of metres in 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

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.

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.

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.