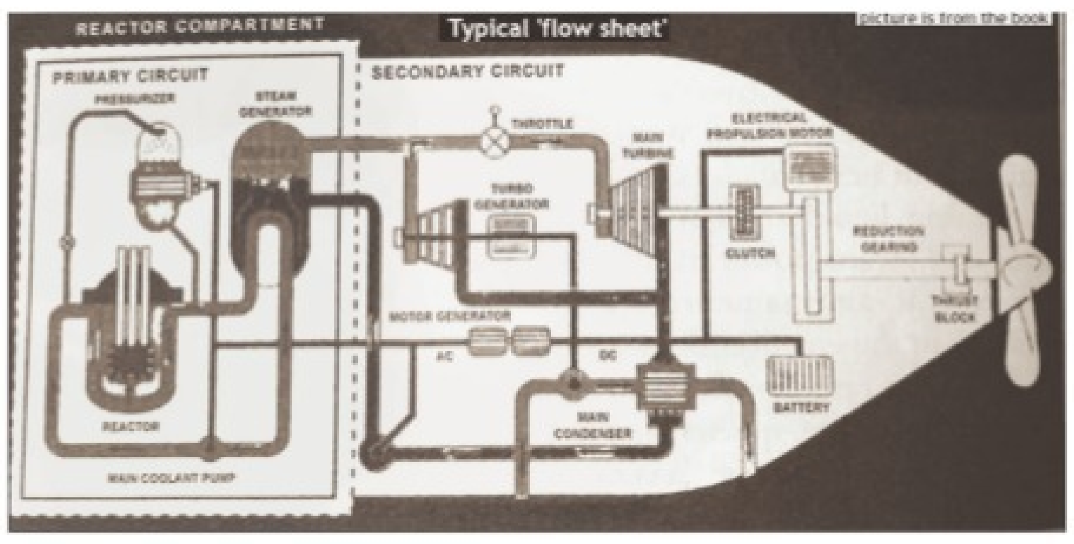
# India and the nuclear submarine

## A remarkable new book delves into the conquest of the oceans through independently-developed technology




AK Anand

S ANANTHANARAYANAN

In 2016, India became the first country outside the leading five — US, Russia, France, UK and China — to announce a nuclear-powered submarine.

In a book that is just on the stands, A K Anand, former director, Reactor Projects Group of India's Department of Atomic Energy, describes the story of how this achievement became possible. And along the way, he relates much history and politics of the growth of submarines, worldwide, since Jules Verne's imagination of the submersible *Nautilus* in the novel, *Twenty Thousand Leagues under the Sea*.

The submersible, in naval warfare, had the obvious advantage of being invisible. It was hence the dream of naval forces to be able to sneak undetected, up to enemy ships and destroy them by attack at their most vulnerable, in the hull. The difficulty, of course, was the technology and the propulsion, under water, without access to air that people and machines breathe.

The best answer was to drive the craft with electricity and batteries. As batteries had limited capacity and needed to be charged, the craft had to carry a diesel generator. And the craft had to come up to the surface for the diesel engine to run. Another way was to use a snorkel, like a diver uses, to take in air for the engine while the submarine stayed submerged. This had physical problems, of course, apart from water splashing into the snorkel pipe. And any method involved some exposure and detection, which would be followed by attack with depth charges.

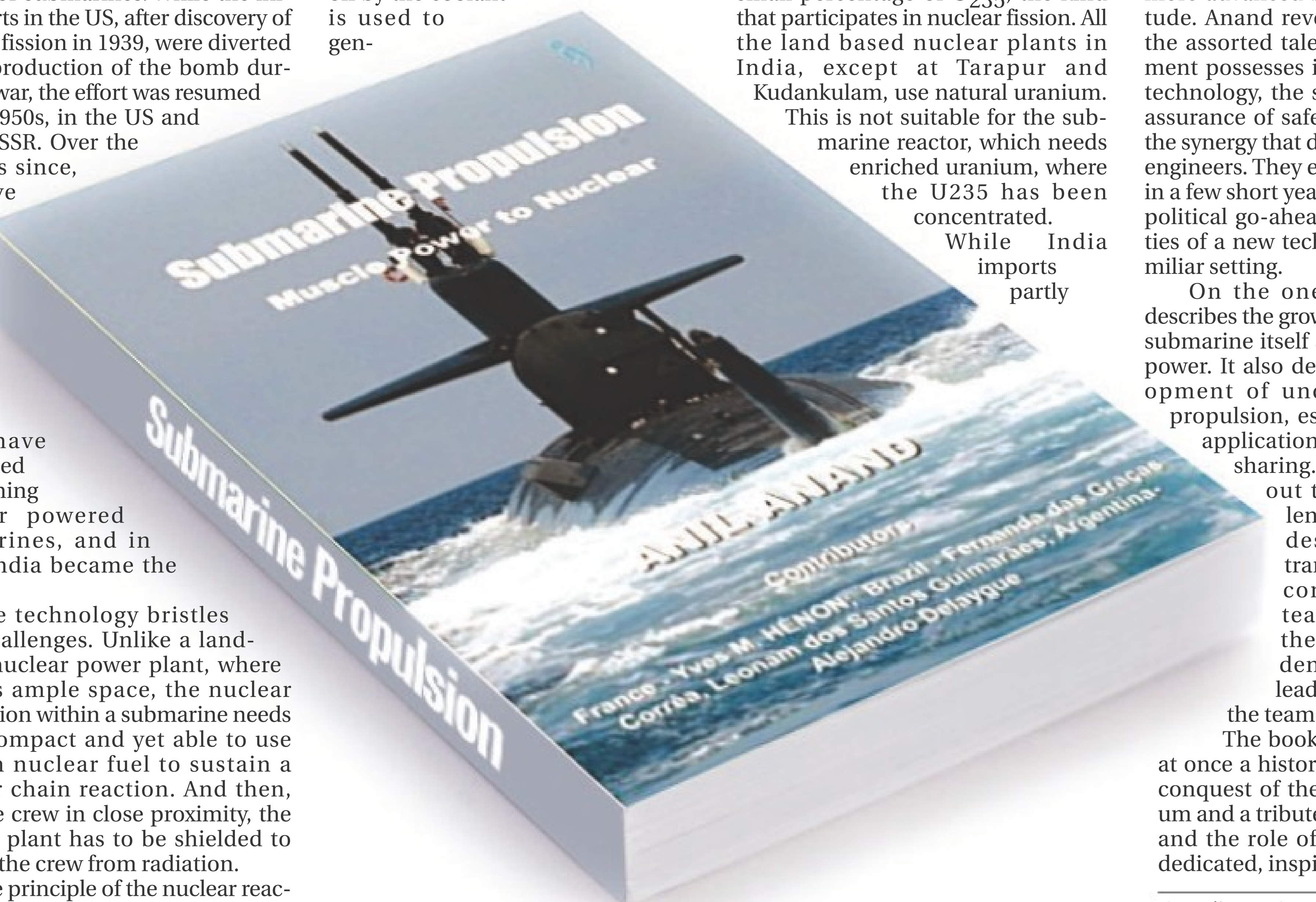
An improvement was the Air Independent Propulsion technology, first developed by the German, Hellmuth Walter, using hydrogen peroxide as the fuel that did not need air to burn. When $H_2O_2$ burns, it produces superheated steam, which can drive a turbine, and it gives off oxygen, which is useful for the crew. The method, however, had the danger of explosion, Anand explains in the book. Other technologies were the diesel or other engines with oxygen sources, like liquid oxygen, fuel cells or high capacity batteries. All of those, however, generally fell short of requirements and could not mature.

It was with the development of nuclear power that a picture of vast, pollution-free and air independent, electricity for cities and industry and to power sea-going vessels came into view. In the case of submarines, there was the possibility of staying submerged for months on end and being able to use power freely, to attain high speeds.

In the book, *Submarine Propulsions - Muscle Power to Nuclear*, Anand describes the build-up, starting from 16th century manual contraptions, to the design of nuclear power for submarines. While the initial efforts in the US, after discovery of nuclear fission in 1939, were diverted to the production of the bomb during the war, the effort was resumed in the 1950s, in the US and then, USSR. Over the decades since, only five countries have developed functioning nuclear powered submarines, and in 2016, India became the sixth.

The technology bristles with challenges. Unlike a land-based nuclear power plant, where there is ample space, the nuclear installation within a submarine needs to be compact and yet able to use enough nuclear fuel to sustain a nuclear chain reaction. And then, with the crew in close proximity, the nuclear plant has to be shielded to protect the crew from radiation.

The principle of the nuclear reactor is that when the nucleus of $U_{235}$ — a form of the uranium atom — is struck by a stray neutron, it splits into two more efficient parts and the packing energy that is saved is given off as heat. The break-up also creates a pair of neutrons, which can then set off other fission reactions, leading to a chain. Humongous heat is generated, to be drawn off by a coolant, and the process can be controlled by placing barriers between segments of uranium fuel. The heat drawn off by the coolant is used to generate steam, which drives a turbine, to generate electricity. The electricity then drives the propellers and the pumps that power the submarine.




While design to contain these systems within the confines of the submarine is challenging, the nuclear reactor itself needs features that are not found in regular reactors. The submarine reactor also does not have the facility of using natural uranium as fuel. Natural uranium has only a small percentage of $U_{235}$, the kind that participates in nuclear fission. All the land based nuclear plants in India, except at Tarapur and Kudankulam, use natural uranium. This is not suitable for the submarine reactor, which needs enriched uranium, where the U235 has been concentrated.

While India imports partly enriched fuel for reactors which need it under special arrangements, India has developed her own facility for enrichment of uranium for the submarine application. "... Any new fuel geometry needs a lot of development work, so was it for PRP/Arihant," says Anand in a communication.

A conventional submarine would have only the battery and motor and a diesel generator. The nuclear sub needs the electric motor, a steam driven generator and then the nuclear reactor with its controls and circulation system. A conventional nuclear plant is spread over an acre of land but there is probably no place that is more cramped than inside a submarine.

Such technical constraints, along with the need for safety and to contain radiation, make the design and construction of a nuclear power-pack for the submarine a task that calls for sophisticated capability. The know-how, naturally, is not available off the shelf and needs to be developed by each country on its own.

India launched an audacious nuclear energy programme right after Independence. While India now has a robust nuclear industry, with a large number of indigenous reactors in action, the development of the nuclear submarine signifies very high technological attainment. Anand also describes the international resistance to share information and raw materials with India, especially since the country has not signed the Nuclear Non-proliferation Treaty (on the grounds that it was discriminatory). And again, after the underground test that India carried out at Pokaran.

Anand's book is a study and a first-hand account of what it takes for a team of essentially first-generation scientists and engineers of the Department of Atomic Energy, working with engineers of the Indian Navy, to discover and master a technology held close by countries that were more advanced by orders of magnitude. Anand reveals the working of the assorted talent that the department possesses in different areas of technology, the systems, method of assurance of safety and quality, and the synergy that developed with naval engineers. They enabled the mastery, in a few short years after they had the political go-ahead, of the complexities of a new technology in an unfamiliar setting.

On the one hand, the book describes the growth of the idea of the submarine itself and then of nuclear power. It also delves into the development of underwater nuclear propulsion, essentially a military application and hence not for sharing. And then it brings out the different challenges of the fuel, the design of systems, transfer of energy, the container, that the team faced and then the vision and confidence of the political leadership that allowed the team to give its best.

The book is a personal story, at once a historical narrative of the conquest of the underwater medium and a tribute to the organisation and the role of many individuals, dedicated, inspired and human.

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# Functional units

## Most genes code for the amino acid sequences of polypeptide chains

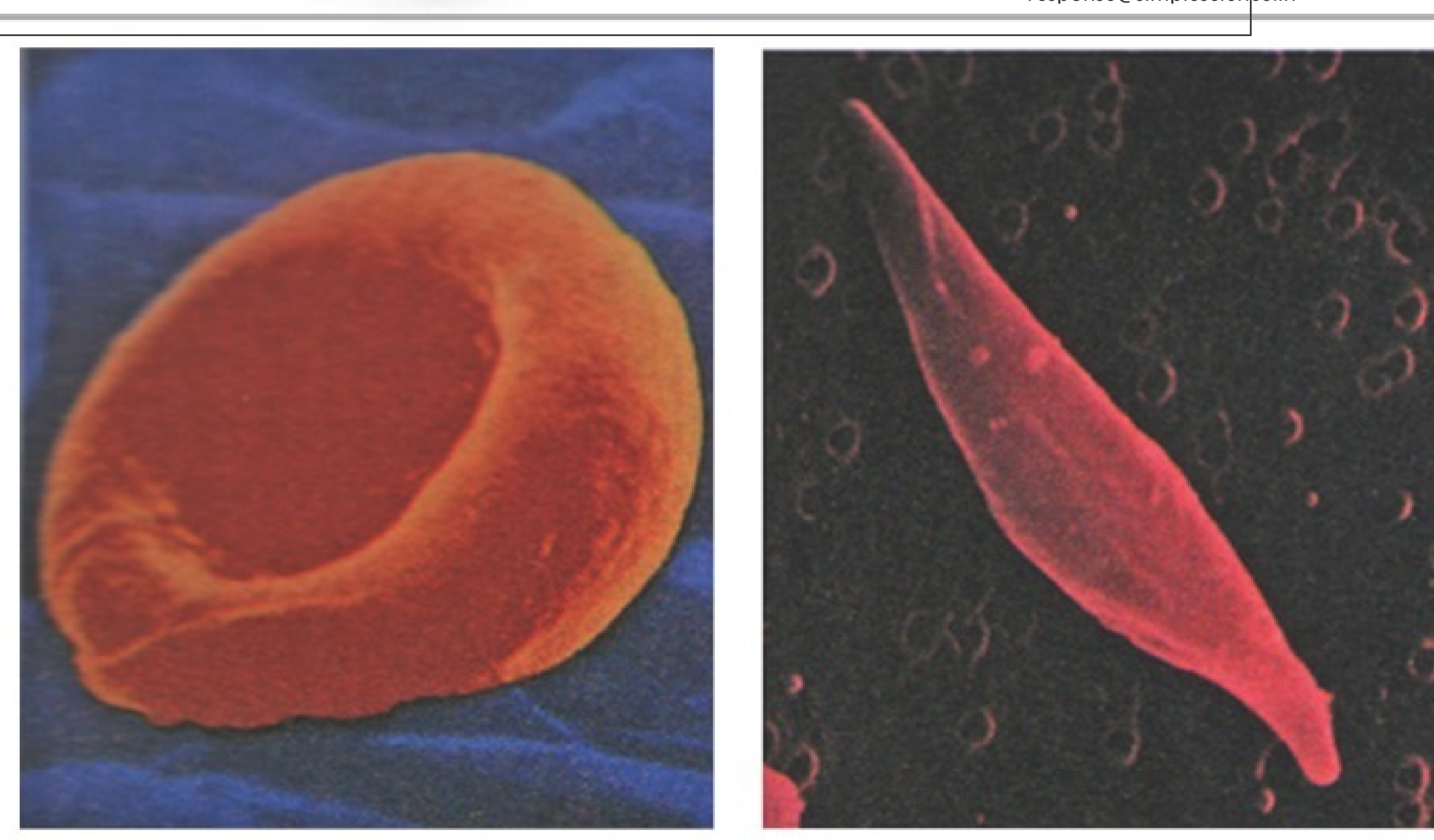
TAPAN KUMAR MAITRA

The theory that genes direct the production of enzyme molecules represented a major advance in our understanding of gene action, but it provided little insight into the question of how genes accomplish this task. The first clue to the underlying mechanism emerged a few years later in the laboratory of Linus Pauling, who was studying the inherited disease sickle-cell anaemia. The red blood cells of individuals suffering from sickle-cell anaemia exhibit an abnormal, "sickle" shape that causes the cells to become trapped and damaged when they pass through small blood vessels.

In trying to identify the reason for this behaviour, Pauling decided to analyse the properties of haemoglobin, the major protein of red blood cells. Because haemoglobin is a charged molecule, he used the technique of electrophoresis, which separates charged molecules from one another by placing them in an electric field. Pauling found that haemoglobin from sickle cells migrated at a different rate than normal haemoglobin, suggesting that the two proteins differ in electric charge. Since some amino acids have charged side chains, Pauling proposed that the difference between normal and sickle-cell haemoglobin lay in their amino acid compositions.

To test this hypothesis, it seemed necessary to know the entire amino acid sequence of haemoglobin. At the time of Pauling's discovery in the early 1950s, the largest protein to have been sequenced was less than one-tenth the size of haemoglobin, so determining the complete amino acid sequence of haemoglobin would have been a monumental undertaking.

Fortunately, an ingenious short-cut devised by Vernon Ingram made it possible to identify the amino acid abnormality in sickle-cell haemoglobin without determining the protein's complete amino acid sequence. Ingram used the protease trypsin to cleave haemoglobin into peptide fragments, which were then separated from each other. When Ingram examined the peptide patterns of normal and sickle-cell haemoglobin, he discovered that only one peptide differed between the two proteins. Analysis of the altered peptide revealed that a glutamic acid in normal haemoglobin had been replaced by a valine in sickle-cell haemoglobin. Since glutamic acid is negatively charged and valine is neutral, this substitution explains the difference in electrophoretic behaviour between normal and sickle-cell haemoglobin originally observed by Pauling. The discoveries by Pauling and Ingram necessitated several refinements in the one gene-one enzyme concept of Beadle and Tatum. First, the fact that haemoglobin is not an enzyme indicates that genes encode the amino acid sequences of proteins in general, not just enzymes. In addition, the discovery that different genes code for the a and j3 chains of haemoglobin reveals that each gene encodes the sequence of a polypeptide chain, not necessarily a complete protein. Thus, the original hypothesis was refined into the one gene-one polypeptide theory. According to this theory, the nucleotide sequence of a gene determines the sequence of amino acids in a polypeptide chain.



Normal and sickled red blood cells: The micrograph on the right reveals the abnormal shape of a sickled cell. This distorted shape, which is caused by a mutated form of haemoglobin, allows sickled cells to become trapped and damaged when passing through small blood vessels.

In the mid-1960s, this prediction was confirmed in the laboratory of Charles Yanofsky, where the locations of dozens of mutations in the bacterial gene coding for a subunit of the enzyme tryptophan synthase were determined. As predicted, the positions of the mutations within the gene correlated with the positions of the resulting amino acid substitutions in the tryptophan synthase polypeptide chain. Showing that a gene's base sequence specifies the amino acid sequence of a polypeptide chain represented a major milestone, but subsequent developments have revealed that gene function is often more complicated than this, especially in eukaryotes. Most eukaryotic genes contain non-coding sequences interspersed among the coding regions and therefore do not exhibit a complete linear correspondence with their polypeptide product. Moreover, the coding sequences contained within such genes can be read in various combinations to produce different mRNAs, each coding for a unique polypeptide chain. This phenomenon, called alternative RNA splicing, allows dozens or even hundreds of different polypeptides to be produced from a single gene.

There are several types of genes that do not produce polypeptide chains at all. These genes code for RNA molecules such as transfer RNAs, ribosomal RNAs, small nuclear RNAs, and microRNAs, each of which performs a unique cellular function.

Thus the one gene-one polypeptide view of gene function has become obsolete, replaced by a broader view in which genes are seen as functional units of DNA that code for the amino acid sequence in one or more polypeptide chains, or alternatively, for one of several types of RNA that perform functions other than specifying the amino acid sequence of polypeptide chains.

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PLUS POINTS

## Eavesdropping

Scientists have developed an algorithm to monitor the underwater chatter of dolphins with the help of machine learning.

Using autonomous underwater sensors, researchers working in the Gulf of Mexico spent two years making recordings of dolphin echolocation clicks. The result was a data set of 52 million click noises. To sort through this vast amount of information, the scientists employed an "unsupervised" algorithm that automatically classified the noises into categories.

Without being "taught" to recognise patterns that were already known, the algorithm was able to seek original patterns in the data and identify types of click. This enabled the scientists to determine specific patterns of clicks among the millions of clicks being recorded, and could help them to identify dolphin species in the wild.

"It's fun to think about how the machine learning algorithms used to suggest music or social media friends to people could be reinterpreted to help with ecological research challenges," said Kaitlin Frasier of Scripps Institution of Oceanography, the lead author of the study published in the journal *PLOS Computational Biology*. "Innovations in sensor technologies have opened the floodgates in terms of data about the natural world, and there is a lot of room for creativity right now in ecological data analysis," she said.

Monitoring dolphin populations at sea is challenging. Frasier and her colleagues think their techniques could be employed to sift through large quantities of data and keep track of dolphin populations in a non-disruptive way.

Dolphins are an incredibly diverse family of mammals, and different species use different types of click to echolocate. This research team's work so far was able to identify one click type associated with a particular dolphin species — Risso's dolphin — and they intend to conduct field work that will link other click types with other known species.

They also hope their research will allow them to monitor the impact of oil spills and climate change on the dolphin populations of the Gulf of Mexico.

The independent

## Changing characteristics

Scientists at the University of Sheffield have discovered that living creatures' responsiveness to changes in the environment can evolve and depends on the conditions they experienced in their past.

The study, published in *Nature Ecology and Evolution*, is the first to show that the ability of a living creature to change its characteristics in response to changes in its environment can itself evolve. Such flexibility in how organisms develop has fascinated scientists for generations. This flexibility has emerged as a crucial factor in the study of how animals and plants respond to natural and man-made changes to their environment, which include predators, disease and changes in temperature.

The University of Sheffield study, led by Dr Andrew Beckerman from Sheffield's department of animal and plant sciences, in collaboration with researchers from across Europe, investigated changes to the characteristics of water fleas.

Water fleas are an iconic example of how the flexibility of a living creature's ability to develop in response to changes in their environment can evolve. They can grow helmets or spikes on their necks in response to smells emitted by their predators, which signal a risk of mortality.

Water fleas can reproduce without sex, giving birth to genetically identical offspring, which allowed the researchers to look at how genetically identical individuals respond to different predators.

Furthermore, water fleas can smell their predators, and this smell triggers changes in development at very early ages that results in helmets and spikes forming on their heads, altered timing of size at which they reproduce and the number of offspring.