Ocean soundscapes: how do fish hear?

To our human ears, the sounds of the ocean can be strange and disorientating. Fish, however, have ears that are adapted to life below the surface, and rely on the buzzes, clicks and whistles of the ocean soundscape to survive. At **La Trobe University** in Australia, **Dr Lucille Chapuis** is using groundbreaking and innovative techniques to study the hearing systems of fish and to understand how they are affected by human-made noise.

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Fields of research
Marine bioacoustics, neuroecology, animal behaviour

Research project
Studying the hearing systems of fish to understand how they are affected by human-made noise

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Talk like a ...

marine bioacoustician

Acoustic niche — the frequency range that a species has evolved to use, often unique within an ecosystem to avoid interference with other sounds

Anthropophony — sounds generated by humans and our technology

Bioacoustics — the study of how living organisms produce, transmit and respond to sound

Elasmobranchs — a group of fish, including sharks, rays and skates, that have skeletons made of cartilage instead of bone

Hydrophone — a microphone that is used underwater

Soundscape — the collection of sounds in an environment, including both natural and human-made sounds

As you stand waist-deep in the cold, salty surf, you listen to the sounds of the beach around you: children laughing and splashing in the waves, parents chatting on their deckchairs, seagulls squawking as they dive-bomb for chips. Plucking up the courage, you dive headfirst below the surface, and instantly the world becomes muted, muffled and quiet.

Your ears are designed to make sense of sound travelling through air, so, when you submerge them in water, they are of little use. If, however, you were a fish, your hearing system would have evolved to suit your underwater home. “Fish ears differ significantly from human ears in both structure and function, largely due to the contrasting physical properties of air and water,” says Dr Lucille Chapuis from La Trobe University. “Sound travels more efficiently in water, making it a vital source of information for aquatic species in marine environments, where visibility is often limited.”

Lucille is studying the hearing systems of elasmobranchs, a group of fish that includes sharks, skates and rays. “Elasmobranchs are particularly sensitive to low-frequency sounds, and use this sensitivity to detect environmental cues relevant to their survival, such as the sounds of their prey or predators,” explains Lucille. Unfortunately, the widespread introduction of human-made noise in marine environments – generated by activities such as shipping, seismic exploration and underwater construction – can interfere with elasmobranch hearing and put these fish at risk.

The impact of anthropophony

"Human-made noise, or anthropophony, has become a pervasive and increasingly disruptive force in marine ecosystems, fundamentally altering the underwater soundscape that many animals rely on," explains Lucille. "The result is often a disruption of normal behaviours such as mating, foraging and predator evasion." This is particularly true for elasmobranchs, as a lot of marine anthropophony, such as noise from ship engines, occupies the low-frequency range, masking important natural sounds that elasmobranchs rely on. "Experimental studies have shown that exposing elasmobranchs to artificial sounds can alter their swimming behaviour and increase stress indicators," says Lucille.

In order to fully understand the impact of anthropophony on elasmobranchs and other fish, we need a better understanding of fish hearing systems. "Elasmobranchs are ideal for studying fish hearing because they represent an early evolutionary branch of jawed vertebrates, meaning their auditory systems have had over 400 million years to diversify and adapt," explains Lucille. "They occupy nearly all marine environments, from shallow coastal nurseries to the deep sea, providing a wide ecological gradient to test hypotheses such as the eco-acoustical constraints hypothesis."

The eco-acoustical constraints hypothesis

Compared to other animal groups, fish have a remarkable diversity of inner ear structures. This diversity has puzzled scientists for years, but Lucille is hoping to solve the mystery. "One compelling explanation for this variation is the eco-acoustical constraints hypothesis which proposes that fish auditory systems have evolved in response to the specific acoustic properties of their environments," explains Lucille. "According to this hypothesis, fish inhabiting quiet environments, where background noise levels are low, may evolve enhanced auditory structures to increase sensitivity to faint or distant sounds. In contrast, species living in noisy habitats, such as turbulent coastal zones or reef environments, may not benefit from such specialisations because background noise would likely mask any subtle auditory cues."

The eco-acoustical constraints hypothesis predicts that fishes living in noisy environments would gain less advantage from evolving sophisticated hearing structures, and so are more likely to have simple auditory systems. "Historically, testing this hypothesis has been challenging due to the complex and modular nature of the fish inner ear and limited physiological data," says Lucille. However, recent technological advances are allowing researchers like Lucille to study this problem in depth for the first time.

Solving marine mysteries with technology

Lucille plans to combine innovative new tools such as 3D bioimaging, artificial intelligence (AI) and biomechanical modelling to test the eco-acoustical constraints hypothesis and explore the relationship between ear structure and function in elasmobranchs. For example, advanced, high-resolution 3D bioimaging techniques will allow her to reconstruct and compare the inner ear anatomy of different elasmobranch species living in different habitats. She will then use hydrophones to record the soundscapes of each species' habitat and use AI to identify each habitat's key acoustic features, before analysing whether these features can be used to predict the inner ear structure of the fishes living in each habitat.

"We will then develop the first biomechanical model of a fish inner ear," says Lucille. "This model will simulate how sound-induced forces cause displacement and stress within inner ear structures, allowing us to identify which anatomical elements are most functionally significant." The last step in Lucille's research project will involve raising shark embryos in tanks with different soundscapes to see if this affects the development of their inner ear structure. "This not only offers a novel test of the eco-acoustical constraints hypothesis in living animals, but also explores how flexible or vulnerable elasmobranch hearing systems are in the face of changing acoustic environments," says Lucille.

From research to conservation

"By illuminating how elasmobranchs hear and how their auditory systems are shaped by their habitats, this research provides a much-needed foundation for protecting these vulnerable species (and other fish) from the growing threat of underwater noise pollution," says Lucille. "With the right regulatory frameworks and adoption of quieter technologies, we can restore healthier ocean soundscapes and allow marine life to regain their acoustic niches. Ultimately, this project creates a robust scientific basis for understanding and managing the auditory ecology of elasmobranchs, a critical step toward ensuring their resilience in a rapidly changing world."

About *marine bioacoustics*

"Marine bioacoustics is an incredibly exciting field because it allows us to explore one of the least understood sensory worlds: sound in the ocean," says Lucille. "This field is still relatively young, and there is a tremendous amount yet to discover." Every research project has the potential to uncover something previously unknown about underwater sound and marine animals, and how they interact with each other and their environments.

"Marine bioacoustics can have real-world impacts by informing conservation strategies, shaping environmental policy and helping to protect vulnerable marine life from the rapidly increasing threat of noise pollution," continues Lucille. "There's something deeply fulfilling about contributing knowledge that can guide efforts to preserve the health and diversity of the oceans. In a field where much remains a mystery, even small insights can make big waves."

To study this unique environment, marine bioacousticians collaborate with experts from a wide range of disciplines, including physics, ecology, biology, engineering and data science. "Collaboration is not just helpful, but absolutely essential to advancing the field," says Lucille. "These partnerships allow us to tackle questions that no single discipline could answer alone."

Fieldwork can be central to a career in marine bioacoustics. "Fieldwork often means living and working closely with colleagues around the clock, sometimes for weeks at a time," says Lucille. "These intense shared experiences have forged some of my closest friendships. The bonds formed in the field, through challenging days, shared discoveries and lots of laughter, are absolutely invaluable."

"Science is a team effort, and the friendships and collaborations you build along the way are just as valuable as the discoveries," continues Lucille. "I've been fortunate to work with incredibly supportive mentors and collaborators who believed in my ideas and gave me space to grow."

Pathway from school to *marine bioacoustics*

Build a strong foundation in biology, maths, physics and computing at school to support understanding of areas such as animal behaviour, ecosystems, acoustics, coding and data handling.

At college and university, courses such as marine biology, zoology, ecology, acoustic engineering, physics, computer science and environmental science can all lead to a career in marine bioacoustics.

Lucille says, "Hands-on experience is key: volunteering with marine labs and getting involved in student projects at aquariums or universities, field courses at marine research stations, internships in acoustic monitoring, or even citizen science projects that involve underwater sound recordings can be valuable."

"Practising communication skills is just as important as mastering technical ones," says Lucille. "Outreach and communication are absolutely vital to raise awareness about how human-made noise can affect marine life."

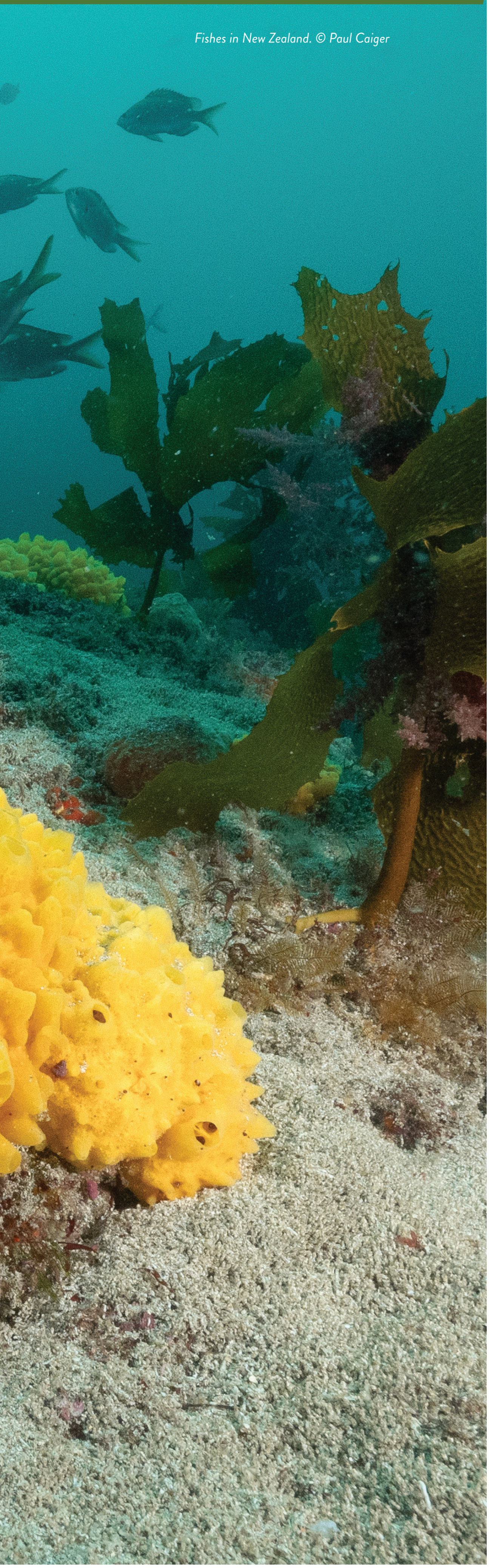
Lucille suggests following the tags #bioacoustics and #oceanacoustics on social media to discover scientists and research laboratories. You could even reach out with questions.

Explore careers in *marine bioacoustics*

Explore the websites of the International Bioacoustics Society (**ibac.info**), the Australian Acoustical Society (**acoustics.org.au**) and the Acoustical Society of America (**acousticalsociety.org**) to read about the latest research. You could even become a student member and attend events and conferences.

A career in marine bioacoustics could see you working as a teacher or researcher, as an engineer developing the next generation of sensors or software, or in non-profit roles, working to change marine policies or communicate with the public.

"A career in marine science is possible even if it seems difficult at the start," says Lucille. "I grew up in landlocked Switzerland, and now I study the sounds of the sea. If I can do it, so can anyone else!"



Fishes in New Zealand. © Paul Caiger

Meet *Lucille*

Growing up in landlocked Switzerland, I saw the ocean as a place of wonder and mystery, accessible only during holidays. It became a passion the moment I encountered marine animals firsthand. Having learned to dive in Switzerland's cold freshwater lakes, my initial dives in the sea were truly eye-opening experiences. I felt honoured to witness such vibrant ecosystems teeming with life. Sharks, in particular, captivated me with their magnificent presence.

What I love most about my job is the constant sense of discovery. Whether it's uncovering how a shark perceives sound, listening to the rhythms of coral reefs at night or developing new ways to study underwater soundscapes, each project brings a chance to learn something entirely new about the hidden lives of marine animals.

I deeply enjoy the interdisciplinary nature of my work. I collaborate with physicists, engineers, ecologists and neuroscientists from all over the world, pushing the boundaries of what's possible and making the science more robust and exciting. And then there's the fieldwork: being in the ocean, diving and recording sounds, reminds me why I started on this path.

My research has allowed me to live and work in multiple countries including Switzerland, Australia, the UK and New Zealand. Experiencing different cultures and ecosystems has enriched my personal and professional life in countless ways: it's a constant reminder of the diversity of both people and the natural world.

Persistence and a sense of humour have helped me weather the less glamorous side of research: equipment failures, hours of data analysis and long days at sea. These moments can be tough, but they also make the breakthroughs all the more rewarding.

To unwind from work, I run, often for long hours and over great distances. It's a space to clear my mind, reconnect with nature, reset both mentally and physically, and it reminds me of the strength that comes from pushing boundaries, whether on trails or in science.

Lucille's *top tips*

1. Follow your passion. Let your fascination with the ocean and sound guide you.
2. Stay curious, ask questions and read widely. Don't be afraid to explore tangents as they often lead to the most interesting discoveries.
3. Say yes to opportunities, even if they feel a bit scary! Travel, join a research cruise, go to conferences, talk to scientists. These experiences help you grow, and they often open doors to future collaborations or projects.
4. Be patient and persistent. Science doesn't always move quickly, and progress takes time. But if you stay motivated and passionate, the path can be incredibly rewarding.