SOLVING A BIOMECHANICAL MYSTERY: HOW JELLYFISH SWIM AND FEED

IN THE PAST, BIOLOGISTS BELIEVED THAT ALL JELLYFISH PROPEL THEMSELVES FORWARD BY RAPIDLY SQUIRTING WATER OUT FROM THEIR PULSATING BELLS. HOWEVER, THIS THEORY DID NOT ENTIRELY MATCH UP WITH THEIR OBSERVATIONS. MARINE BIOLOGIST, **DR SEAN COLIN**, OF THE **ROGER WILLIAMS UNIVERSITY** IN THE US, USES A VARIETY OF TECHNIQUES TO SHOW THAT LARGER JELLYFISH USE COMPLETELY DIFFERENT MOTIONS TO SWIM AND FEED. HIS TEAM'S DISCOVERIES TELL US A LOT ABOUT THE LIVES OF THESE FASCINATING ANIMALS

TALK LIKE A MARINE BIOLOGIST

JELLYFISH – a group of primitive invertebrate animals from the phylum Cnidaria, which use pulsating, umbrella-shaped bells to move, and trailing tentacles armed with stinging cells to capture prey and evade predators

CTENOPHORE – similarly primitive gelatinous invertebrates, which use fused cilia (called ctenes) to move and to draw prey to where they can be sensed and captured

BIOMECHANICS – the study of the physical motions and structures used by living organisms

ECOLOGY – the study of the interactions of living organisms with each other and their surrounding habitat

PHYLUM – in biology, the level of classification that ranks above class and below kingdom

SCUBA DIVING – an acronym that stands for 'Self-Contained Underwater Breathing Apparatus', which many biologists use to study ocean ecosystems

JET PROPULSION – when an object rapidly ejects a fluid in one direction, propelling itself in the opposite direction

ROWING PROPULSION – an alternative propulsion mechanism discovered by Sean and his team, where pulsating bells manipulate pressure in the surrounding water

Among all of the creatures in our oceans, few are more ancient or mysterious than jellyfish and ctenophores. First appearing over 500 million years ago, ctenophores swim through water by waving tiny, hair-like protrusions on their cells, named 'cilia.' Jellyfish, also called 'jellies,' evolved at around the same time, but use completely different strategies to move around; in fact, they were the first animals to move using muscle-powered swimming. Incredibly, the muscle layer they use to swim is just one cell thick, making them extremely weak. Because of this, jellies needed to evolve highly efficient ways to propel themselves through water.

Today, all jellyfish do this by contracting their umbrella-shaped bells. In small jellies, this causes water to rapidly squirt out of the bell, generating enough force for them to dart around using jet propulsion. Previously, biologists thought that all jellyfish swam in this way. However, for animals with bells larger than 5 centimetres in diameter, the water volumes they hold become far too heavy for weak jellyfish muscles to expel them quickly. Dr Sean Colin at the Roger Williams University in Bristol, Rhode Island, US, was first faced with this biomechanical mystery early on in his career and he has studied it extensively ever since.

WHAT TECHNIQUES HAS SEAN'S TEAM USED TO STUDY JELLIES AND CTENOPHORES?

In their earliest studies, Sean and his colleagues used video recordings to study how jellies and ctenophores in captivity interacted with water and prey. Their aim was to study what types and how much food these animals tend to consume, as well as their wider roles in natural ecosystems. However, because oceans are such complex and intricate environments, the researchers could not be sure that even their most well-designed experiments were entirely realistic.

Since then, Sean's team has explored a variety of different ways to improve observations. These have included cutting-edge techniques in SCUBA diving, and the use of remotely-operated submarines in deeper water – both of which have allowed the researchers to accurately capture the behaviours of wild jellies and ctenophores. They have even worked with a team of engineers to design a robotic jellyfish. By tweaking the design of its bell to efficiently propel itself forwards, they could learn a lot about the real biomechanics used by real jellyfish.

DR SEAN COLIN

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FIELD OF RESEARCH

Marine Biology

RESEARCH PROJECT

Sean's research centres around the swimming and feeding habits of jellyfish and ctenophores.

FUNDER

National Science Foundation

Through these different techniques, Sean's team has now made several ground-breaking discoveries about the differences in biomechanics between large and small jellies.

WHAT HAVE THE RESEARCHERS DISCOVERED ABOUT JELLIES' SWIMMING HABITS?

The shapes of jellyfish bells can vary widely, depending on their sizes. Small jellies have more elongated, torpedo-shaped 'prolate' bells, which help them to jet quickly and efficiently through water. In contrast, larger jellies have flatter, plate-shaped 'oblate' bells. As Sean's team has discovered, these animals have evolved a completely different way of moving around than their smaller cousins.

An oblate jellyfish will start this motion by slowly contracting its bell. This causes the highly flexible circular margin at the bottom of the bell to suddenly bend and flair out, like the skirt of a twirling dancer. This means that the margin acts like a flappy oar: pushing water away from the outer edge of the bell, creating a large region of negative pressure in front of the jellyfish. Finally, the bell will move to compensate for this pressure deficit, and the entire jellyfish is propelled forwards.

Sean and his colleagues have now dubbed this behaviour 'rowing propulsion.' As well as clearly observing the process in wild jellies, they have also shown it to work in a robotic jellyfish – which could only move forwards when a flexible, circular flap was added to its margin. The speed it provides may be slow, but since the motion requires such little muscle power, the researchers have shown it to be one of the most efficient swimming mechanisms in the animal kingdom.

WHAT DOES THIS TELL US ABOUT THE DIFFERENCES IN FEEDING HABITS BETWEEN CTENOPHORES, AND LARGE AND SMALL JELLIES?

Sean's work has revealed that jellies use jetting and rowing for completely different processes. For smaller animals with prolate bells, an effective hunting strategy is to sit still inside a nutritious water current, with their stinging tentacles extended. When a predator comes along, or if the current becomes depleted of food options, the jellyfish can then rapidly dart away and reposition itself, allowing it to maximise the time spent feeding. This behaviour has had a big impact on the evolution of their tentacles: with the size and type of their prey depending on the spacing between their tentacles, and the number and type of stinging cells they contain.

In contrast, oblate-shaped rowing jellies are moving constantly. They use their own swimming motions to generate nutritious water currents, which they pull and circulate through their tentacles. This means that the capture surfaces have a significant impact on how these jellies interact with the surrounding water. In Semaeostomes (an order including Lion's Mane and Sea Nettle jellyfish), long, frilly arms are used to capture large plankton and fish larvae. On the other hand, the order Rhizostomes, which include Cannonball and Barrel jellyfish, do not have tentacles at all. Instead, they use oral feeding disks featuring large clusters of cilia, allowing them to filter for far smaller prey.

Ctenophores may have evolved at around the same time as jellyfish, but they use completely different strategies to capture prey. By waving the fused cilia on their bodies, they move water slowly past their sensory structures. This allows them to scan the surrounding water and divert any nutrients towards their tentacles.

WHERE COULD THIS RESEARCH LEAD IN THE FUTURE?

Sean and his colleagues will now continue to study the biomechanics of jellyfish and ctenophores. They will focus on areas including how their shapes relate to their swimming and feeding habits; their roles in ocean ecosystems; and how SCUBA techniques can be used to better study natural environments.

Many areas of research could benefit from these discoveries. Since oblate jellyfish usually have far larger guts than their smaller cousins, they can consume far larger amounts of prey at a time. A better knowledge of their feeding habits could help biologists to better assess their impacts on fragile marine ecosystems, particularly when species are introduced to new areas. Elsewhere, jellyfish and ctenophores could have a lot to teach us about how swimming and flying first evolved in other, more complex animals, and how they manipulate the fluid surrounding them to move.

ABOUT MARINE BIOLOGY

As with other strands of environmental science, what motivates those who work in the field of marine biology is a passion for the natural world and the mysteries it holds, a desire to uncover its secrets and an unflinching commitment to protect it. As Sean's research shows, years of meticulous research provide invaluable insights into the oceans, their ecosystems and the fascinating creatures who inhabit them. Perhaps most importantly, marine biologists – and other environmental scientists – are at the front line of effort to solve the many problems now facing the natural world.

WHAT IS REWARDING ABOUT STUDYING MARINE BIOLOGY?

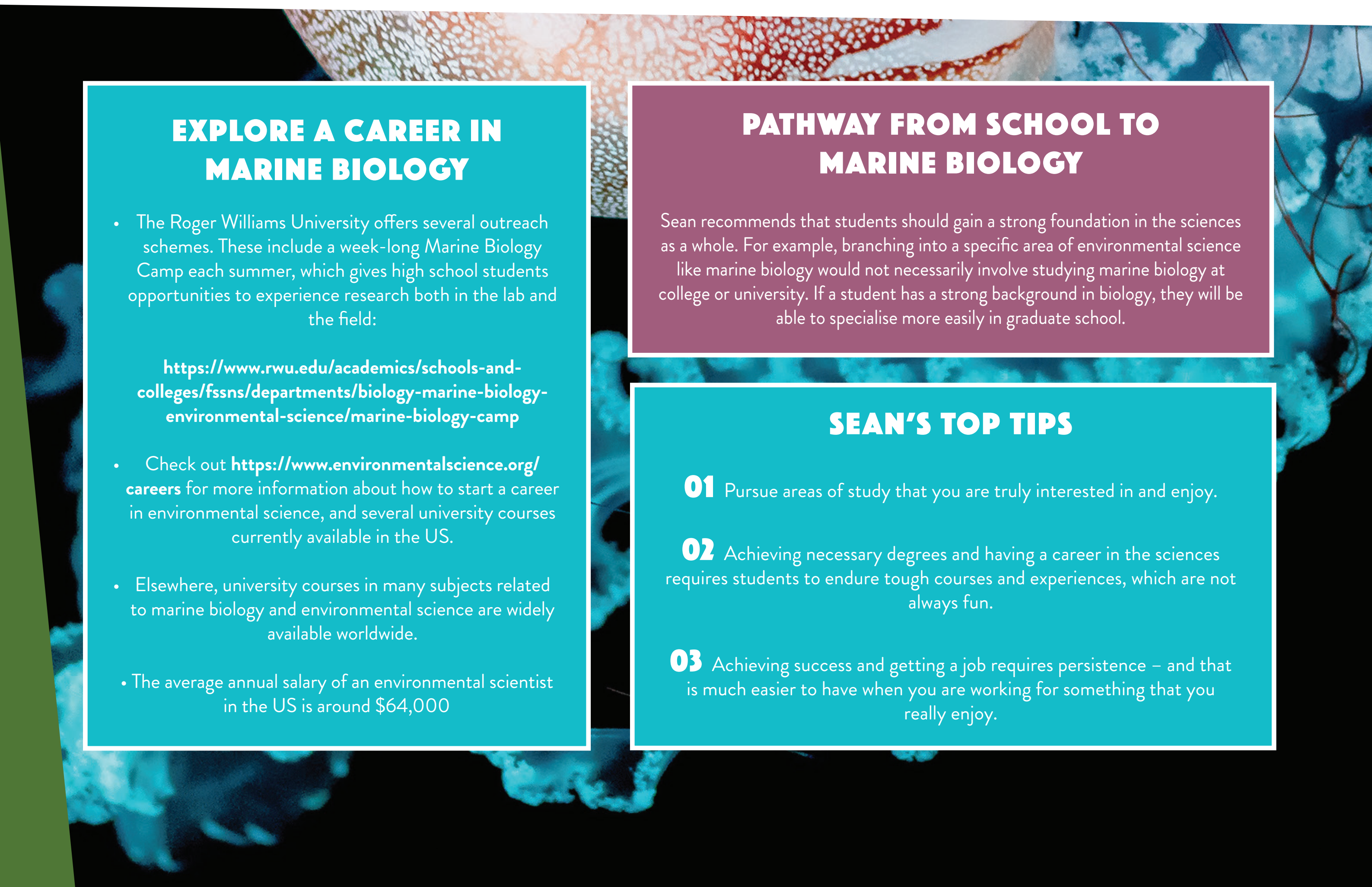
Marine biologists use a broad range of problem-solving skills to understand how organisms and ocean-based ecosystems function. Researchers then need to figure out how to collect and analyse data, and how to communicate their findings. If a scientist is truly passionate about their work, each of these steps can be fun and rewarding. A job like Sean's, for example, allows him to develop a diverse variety of skillsets, including teaching, SCUBA diving, videography, computer analysis, and writing.

HOW IMPORTANT IS IT FOR MARINE BIOLOGISTS TO COLLABORATE WITH EACH OTHER?

Since every researcher has their own unique way of seeing the world, collaborating with others as part of a team is an essential part of being an environmental scientist. This can happen in many different ways: Sean, for example, has maintained a close collaboration with his research partner, Dr Jack Costello, since 1990. Together, they have carried out much of their research through close collaboration with small groups of undergraduate students. Working with others with different skillsets in this way enables scientists to complement each other's expertise. This increases their ability to answer questions, ultimately making their work more productive and enjoyable.

WHAT ARE THE KEY ISSUES FACING THE NEXT GENERATION OF MARINE BIOLOGISTS?

We all know that, due to climate change, Earth's ecosystems are now transforming rapidly – with every organism responding in a different way. This can have far-reaching consequences for natural environments, including our oceans, threatening many species with extinction and altering the natural systems which many people depend on to survive. In the future, environmental scientists will be at the forefront of efforts to understand these changes. It will be their challenge to understand and communicate the changes humans will need to make to ensure the future of Earth's ecosystems.



EXPLORE A CAREER IN MARINE BIOLOGY

- The Roger Williams University offers several outreach schemes. These include a week-long Marine Biology Camp each summer, which gives high school students opportunities to experience research both in the lab and the field:

  https://www.rwu.edu/academics/schools-and-colleges/fssns/departments/biology-marine-biology-environmental-science/marine-biology-camp

- Check out **https://www.environmentalscience.org/careers** for more information about how to start a career in environmental science, and several university courses currently available in the US.

- Elsewhere, university courses in many subjects related to marine biology and environmental science are widely available worldwide.

- The average annual salary of an environmental scientist in the US is around $64,000

PATHWAY FROM SCHOOL TO MARINE BIOLOGY

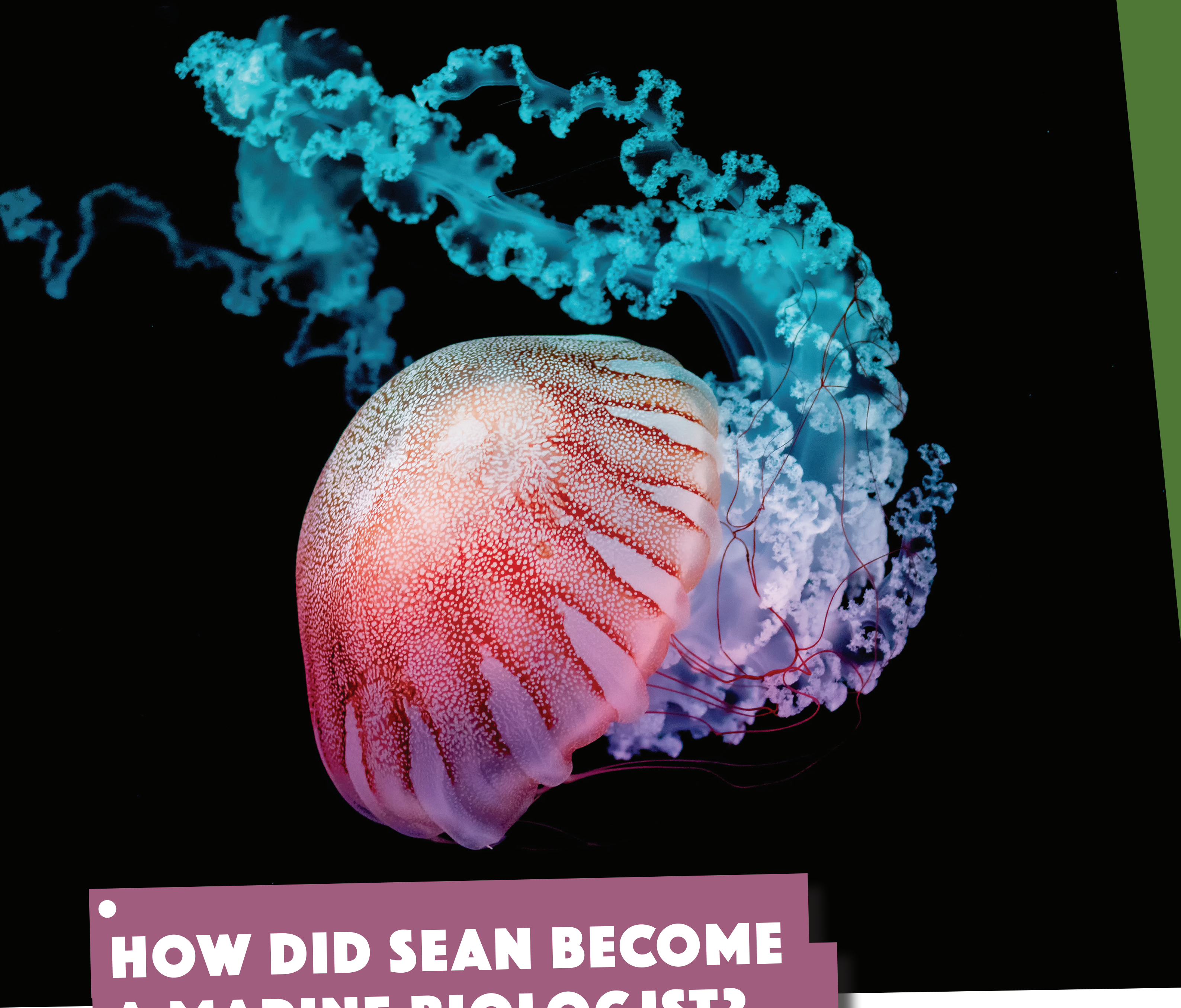
Sean recommends that students should gain a strong foundation in the sciences as a whole. For example, branching into a specific area of environmental science like marine biology would not necessarily involve studying marine biology at college or university. If a student has a strong background in biology, they will be able to specialise more easily in graduate school.

SEAN'S TOP TIPS

01 Pursue areas of study that you are truly interested in and enjoy.

02 Achieving necessary degrees and having a career in the sciences requires students to endure tough courses and experiences, which are not always fun.

03 Achieving success and getting a job requires persistence – and that is much easier to have when you are working for something that you really enjoy.



HOW DID SEAN BECOME A MARINE BIOLOGIST?

WHAT WERE YOUR INTERESTS AS A YOUNGSTER?

I enjoyed sports, being on the water and the outdoors. I always had a particular interest in animals and the water.

HAS THERE BEEN A BOOK THAT HAS MEANT A LOT TO YOU?

There are many books that have shaped my thoughts and inspired me, but one that stands out is *Air and Water: the Biology and Physics of Life's Media* by Mark Denny. It was the first book I read that helped me to understand how physics impacts animal movements and functions.

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

I was first inspired to become a scientist on a trip I made to the Bahamas as a child. On that trip, I snorkelled for a week straight through the coral reefs just off the beach where we were visiting. I think it was that trip that initiated my desire to become a marine scientist.

Since then, I have been repeatedly inspired by other scientists like Jack Costello, who I have collaborated with. Working with scientists who truly love doing science and discovering things about animals has been a continual inspiration throughout my career.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

I think being observant, persistent, creative, and having a strong intuition about how things work have all been important attributes that have contributed to my success. Observation is the basis of a lot of scientific discovery; persistence and creativity are needed to translate observations into quantitative and accepted scientific knowledge; and intuition helps to guide your thoughts and efforts.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

Persistence and creativity are critical to overcome challenges and obstacles. But collaborating with great scientists also helps a lot.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR, AND WHAT AMBITIONS DO YOU HAVE FOR THE FUTURE?

I am just proud and thankful that I have been able to have a career (and get paid!) being able to study the scientific questions that I find most fascinating. My main ambition is to do the best science I am capable of doing, so that I can continue to work on these questions for a long, long time.