Looking up: Life in tropical environments like the Amazon rainforests can also be experienced through VR. (Photo: Valdemir Cunha/Greenpeace.)

that accommodates smartphones to provide the full immersive experience. The first VR film on the Greenpeace app is based on material filmed by a Rainbow Warrior crew in the Arctic, complete with close-up encounters with polar bears. It is meant to raise awareness of the organisation’s work to protect the area’s natural environment that is now under particular threat as the disappearing sea ice offers new opportunities for shipping and resource extraction (Curr. Biol. (2012) 22, R547–R550). “Through the Greenpeace Virtual Explorer app we want our supporters to experience amazing places like the Amazon and Arctic, to see first-hand exactly what it is we’re campaigning to protect — and how important it is we succeed,” the organisation said on its website.

In a follow-up film project to be distributed via the app, director Chris Milk is telling the story of the resistance against the Munduruku hydroelectric dam project in the Tapajós basin in Brazil (Curr. Biol. (2016) 26, R779–R782) from the perspective of the Munduruku people, who are in danger of losing the land they depend on for their livelihoods.

Other indigenous populations are also opening their homes for virtual visitors, including yak herders in Central Asia and Maasai in Africa. Thus, many people can share experiences that they could not access in person without endangering their very existence. Similar arguments hold for archaeological sites such as Lascaux, which was seriously damaged by the millions of visitors that came before it had to be closed. Based on this experience, the more recently discovered Chauvet cave in the Ardèche gorge, southern France, was recreated as a real-world replica, possibly the last hurrah for a kind of representation that is bound to be made redundant by the rapidly improving virtual experiences.

Elsewhere, virtual travellers can also explore the deep sea and climb Mount Everest, swim with sharks or dolphins, dive under the sea ice or hang out with lions. Cameras carried by drones (Curr. Biol. (2014) 24, R629–R632) or mounted to wild animals are now widely used in ecology and conservation (Curr. Biol. (2015) 25, R585–R588). In combination with VR technology, these devices could also enable users to fly with migrating birds or immerse themselves into insect states.

The opportunities for education and raising awareness are endless. We just have to bear in mind that we are aiming to use the virtual world to save the natural one — not to replace it, lest we really do end up living in The Matrix.

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Q & A

Daniel Pauly

Daniel Pauly is University Killam Professor at the University of British Columbia and the principal investigator of the Sea Around Us (http://www.seaaroundus.org). He was born in Paris, raised in Switzerland, studied at Kiel University in Germany and earned a Master’s degree based on fieldwork in Ghana, a doctorate inspired by his fieldwork in Indonesia and an ‘Habilitation’ based on work conducted in the Philippines and elsewhere. His contributions to fisheries science and marine conservation include FishBase, the online encyclopedia of fishes, the documentation of marine ecological processes such as ‘fishing down marine food webs’, and concepts such as ‘shifting baselines’, which have earned him numerous awards worldwide.

You grew up in a land-locked country, why did you study marine sciences?

My reasons were practical: I wanted to study an applied discipline so that I could work and contribute to a — yet unidentified — developing country, to which I would eventually emigrate. To a biracial person — that’s me! — Europe, in the 1970s, was as unwelcoming as it is now, and I wanted to get out. I began studying agronomy at Kiel University in Germany, because agriculture is important in developing countries, but after one semester of daily confrontations with old Nazis — they were still around in 1969 — I found refuge in the Institute of Marine Sciences. Strangely enough, my weird emigration plan worked eventually and I did spend a large part of my adult life working in tropical developing countries, in Asia, Africa and Latin America.

What did you contribute to these countries? At the risk of sounding grandiose, I think that I was able to contribute to the empowerment of fisheries scientists in many tropical developing countries. I did this mainly by adapting the approaches and software devised for studying fisheries in cold-water countries, where exploited fish species are few and where the age of individual fish can be readily estimated, for use in the tropics, where a multitude of species are exploited whose age and thus growth could not be estimated.
I was lucky in that I began this work just as programmable calculators, and later, personal computers became widely available. In the 1980s and 1990s, I taught these new approaches and the use of the software implementing them at numerous courses for government and other fisheries scientists, many sponsored by the Food and Agriculture Organization of the United Nations (FAO) in Africa, Asia, Europe, Oceania and Latin America. Many of these methods are still used, which is very gratifying.

Another line of work started when I realized that distributing bibliographies — then the standard approach for disseminating scientific information to researchers in developing countries, which often lacked effective national library systems — was about as useful as distributing cookbooks to alleviate a famine. The point was to distribute the information itself, which I did with colleagues, such as Rainer Froese and ‘Deng’ Palomares, by creating a database for all fish species of the world that contains the key biological traits (on growth, reproduction, food and feeding habits, distribution, etc.) extracted from thousands of scientific papers. The result was FishBase (www.fishbase.org) and later SeaLifeBase (www.sealifebase.org for marine animals other than fishes). These databases now enjoy about 50 million page views throughout the world in spite of the fact that Wikipedia and Google Scholar have encroached into an area that was previously occupied by us alone. Incidentally, as is the case for Wikipedia, we are experiencing difficulties in maintaining FishBase and SeaLifeBase as free information sources. In our age, maintaining a public good is difficult.

So, have you accomplished what you set out to do? Looking back, I am rather happy that I have been able to realize much of what I intended to do when I started my professional life. But, in truth, the gap between fisheries research and management, while now perhaps narrower than when I started, is still huge. We still massively overfish marine resources. This is frustrating, because we now know what should be done to put fisheries on a sustainable path. One of the things we do know is that establishing marine reserves is a sine qua non of marine conservation. Marine conservation is necessary for fisheries management because the industrial sector, left to its own devices, will capture the agencies that are supposed to regulate it, and then destroy the resources upon which it depends. I think, however, I have been effective in communicating this dynamic to a wide audience — though of course there are also flat-earthers in fisheries science — but again, it was easy, given the excesses of industrial fishing and its geographic expansion since the second world war. This expansion was largely driven by successive collapses in traditional fishing grounds, and hence the need for new fishing grounds. We are now even pumping krill around Antarctica to feed farmed salmon.

Why did you move to Canada? I came to Canada for a very down-to-Earth reason: the International Center for Living Aquatic Resources Management (ICLARM), which had enabled me to work in many countries from a base in the Philippines, suffered a governance crisis at the hand of inept leaders. When in 1994 it became clear that ICLARM would cease being the research powerhouse that it was, I accepted a position at the University of British Columbia’s newly founded Fisheries Centre (now: Institute for the Oceans and Fisheries), with the expectation that I would contribute to UBC’s international outreach. I did this by founding the Sea Around Us.

What is the Sea Around Us? Named after the book by Rachel Carson, one of my heroes (the other is Charles Darwin, to whom I devoted a book, ‘Darwin’s fishes’), the Sea Around Us is a research project I was able to launch in mid-1999 with the help of a generous grant from the Pew Charitable Trusts, and which is now funded by a variety of philanthropic foundations. Its mission, as for FishBase in the case of fishes, is to make key information on marine fisheries available to researchers globally (i.e., for all maritime countries, including the remotest small island states) so that empowered colleagues can perform their jobs better, providing fisheries management advice based on accurate data in a timely fashion. The single most important information about fisheries is their catch. Thus, we first undertook to make available through graphs and maps the catch statistics that member countries submit annually to the FAO, and which were available only in tabular format. However, a close examination of these graphs and maps revealed that these official catch data had issues that were not realized before, and we undertook a giant project to correct them, for all maritime countries, from the ground up. With the help of hundreds of colleagues throughout the world, notably many of the participants of various courses I had previously taught across five continents, this 12-year project is now completed (www.seaaroundus.org). However, the ‘reconstructed’ catch data that this project yielded are globally around 50% higher than official data and have sharply declined since 1996. These data will need to be updated regularly so that the various catch–derived indicators of the status of fisheries worldwide, and their impact on marine ecosystems, remain current.

It seems everything worked. What didn’t? There is one concept that I have had difficulty getting across: my explanation of why fish grow the way they do. They tend to grow during their entire lives, but their maximum size and the size at which they first mature are dependent on temperature and dissolved oxygen in a predictable fashion; they migrate such that they remain in the same temperature envelope, their food conversion efficiency declines with size, etc. In Indonesia, in the mid-1970s, I had identified the growth of fish as the key unknown in the management of tropical fish, and worked on this topic for my doctorate. The hypothesis I proposed has since been
corroborated multiple times. Simply put, fish grow as much as the surface of their gills allows, which explains, among other things, why tuna grow fast, but rockfish grow slowly. However, the idea never got much traction with colleagues. But then, global warming came along, with warmer waters doing to marine and freshwater fishes (and to aquatic invertebrates) all the things that are corollaries of the hypothesis that gill surface area is limiting growth and other processes in fish. Thus, temperature increases impact large fish more than small individuals of the same species, because they have a relatively smaller gill surface area per unit of body weight; they remain smaller — because the size at which O2 supply just meets tissue demand is reached at smaller size — and they mature at smaller sizes — because the metabolic level triggering maturation is reached at a lower threshold. Except for the above hypothesis, there is no single explanation for these patterns and several other related phenomena, and thus these ideas are gradually, and perhaps grudgingly, getting more attention than before. This would be nice if the context were not so awful, namely that we are describing the beginning of the unraveling of oceanic life.

So, as far as the future of the oceans is concerned, are you a pessimist or an optimist? Frankly, I hate to be asked that, because there never is time, at the end of public lectures or an interview, to explain that — in a very profound way — it doesn’t matter what a person feels about the future. I do what I have to do for ocean conservation, irrespective of whether or not the ocean will ‘die’ a hundred years from now. Every generation has its challenge. My parents’ generation had to deal with an attempt to abolish enlightenment values, and return to barbarism (the Nazis, again). This challenge had to be met, irrespective of whether a win was assured. Similarly, this generation — and yours, dear reader! — will have to confront the threats posed by global warming, species extinctions and our overpopulation. These must be confronted, if only to limit the damage. We have no choice, and the question is thus meaningless.

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Quick guide
Seminal fluid

Ben R. Hopkins, Irem Sepil, and Stuart Wigby

What is seminal fluid? Whether ejaculated directly into the female reproductive tract, deposited on the ground, or broadcast into the surrounding environment, sperm rarely travel alone (Figure 1). Instead, they are typically accompanied by a complex cocktail of functionally diverse substances that collectively constitute the seminal fluid.

What’s in it? In addition to water, seminal fluid may contain immune and glandular cells, salts, carbohydrates, organic acids, lipids, mucus, nucleic acids, vitamins, hormones, proteins, and microbes. Rather than forming a simple homogenous solution, seminal fluid is often structured: some components bind to sperm, some are soluble, while others are packaged into cargo-bearing vesicles, such as exosomes, that can fuse with sperm or interact with the female reproductive tract.

Where does it come from? The majority of seminal-fluid components are produced in specialised accessory glands, perhaps the best known being the prostate of male mammals. Between species, accessory glands are highly variable in number, size, and identity. For example, whereas the seminal fluid of dogs is composed of secretions from the prostate, ampullary glands and epididymis, bulls and humans further draw upon contributions from their bulbourethral glands and seminal vesicles. These glands can also display peculiar traits — the lifelong growth of the human prostate being the most familiar. The discovery that cells in the Drosophila melanogaster accessory glands grow with age hints at intriguing cross-taxa parallels in the biology of seminal fluid-producing glands.

What does it do? Seminal fluid supports the activities of sperm by providing energy and immune defence, along with contributions to their motility, transportation, capacitation, and fertilising ability. Once in contact with females, seminal fluid may stimulate ovulation, modulate immune activity, provide nutrition, alter reproductive-tract pH, and form mating plugs. Key functions of seminal fluid in insects include reducing female sexual receptivity and stimulating egg laying. In fruit flies, seminal proteins are further known to affect female pheromone profiles, reproductive-tract conformation, dietary preferences, and even increase aggression. Studies on fish also suggest that seminal fluid plays an important role in external fertilisers, where the concentration of ions can exert species-specific effects upon sperm traits, and secretions from the seminal vesicles may be involved in sexual olfactory signaling.

Does its make-up differ between species? Despite many shared functions, composition varies considerably between taxa. Human seminal fluid contains over 900 known proteins, compared to Drosophila melanogaster’s ~200. Furthermore, the ratio of sperm to seminal fluid varies, being more sperm-biased in bulls relative to stallion and boar. Many seminal proteins also evolve extremely rapidly, potentially facilitating reproductive isolation and the formation of new species.

So it evolves fast — why? Sexual selection and conflict are thought to represent potent evolutionary forces acting on seminal fluid. When mating males and females share evolutionary interests, selection should promote cooperation, perhaps favouring seminal fluids that provide an immune boost or nutrition to females. In turn, females may evolve preferences for males with the most beneficial seminal fluid. Conversely, when the evolutionary interests of the sexes differ — as might occur through conflict over paternity when females take multiple mates — selection may favour seminal fluids that harm females. ‘Toxic’ seminal fluid components might promote fertilisation success when competing with the sperm of rival males, but result in collateral damage to females. Far from being passive bystanders, females may cryptically

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