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 O_2 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

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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

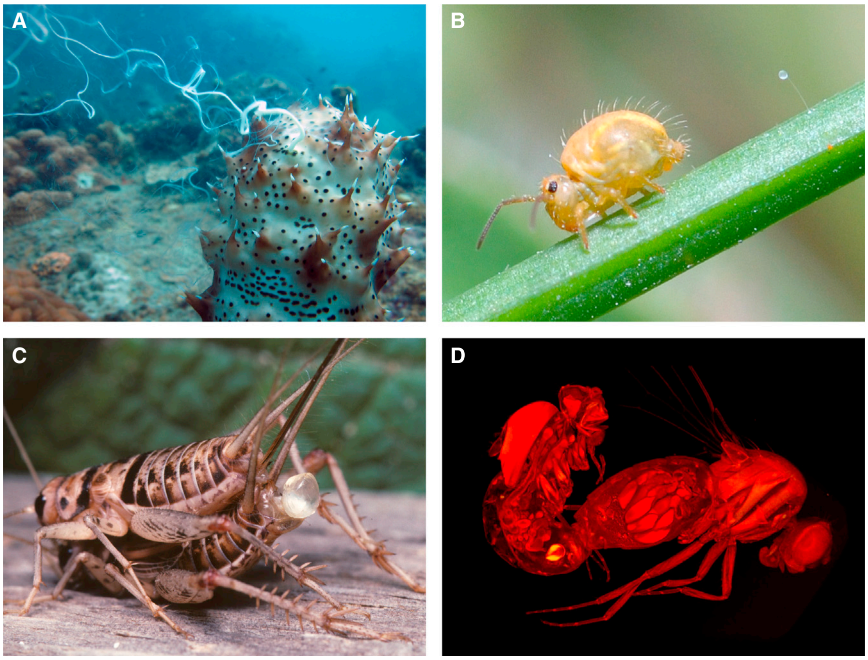

Figure 1. Ways of delivering seminal fluid and sperm.
(A) Release of sperm and seminal fluid by a broadcast spawner, the sea cucumber *Pearsonothuria graeffei.* Photo: ConserveMarine, Wikimedia Commons. (B) A clover springtail (*Sminthurus viridian*) alongside a stem-mounted spermatophore. Photo: Petter Bøckman, based on *Sminthurus viridis* (det F. Janssens).jpg by Drägüs, Wikimedia Commons. (C) Direct transfer of a spermatophore in the decorated cricket *Gryllodes sigillatus.* Photo: David H. Funk. (D) A longitudinal micro-CT section showing ejaculate transfer in the fruit fly *Drosophila melanogaster.* Image reproduced from Mattei, *et al.* (2015).

bias sperm use towards preferred males in response to seminal fluid traits, and evolve counter strategies to minimise any negative effects of seminal fluid receipt. This initiates a so-called 'arms race' between the sexes, further driving seminal-fluid evolution.

Do males ejaculate the same amount of seminal fluid every time? No. Repeated mating can leave males depleted of seminal fluid (and sperm); stress, food limitation, disease or senescence can have similar effects. Because of these constraints and the impaired fertility and competitiveness of deficient ejaculates, males are prudent with their allocation of sperm and seminal fluid. Both quantity and composition, based on factors such as the quality of their mates or the risk of competition from rival male sperm, exhibit significant plasticity. There is even evidence to suggest that males can 'exploit' the benefits of rival males' seminal fluid when copulating with recently mated females, allowing them to hold back on transferring precious components.

Is it of clinical importance? Low seminal-fluid exposure is associated with gestational disorders in humans, including preeclampsia and foetal growth restriction, suggesting some health benefits to its receipt. However, the inflammation-promoting properties of seminal fluid may also cause harm by facilitating cervical tumour formation and increasing susceptibility to HIV infection. Certain microbes present in seminal fluid have also been associated with impaired fertility and accessory gland disorders, such as prostatitis. Amazingly, it appears that seminal fluid can influence offspring development and mediate disease inheritance. Mechanisms that have been proposed to underlie this association include modification of the female reproductive environment by seminal fluid components, trafficking of phenotype-altering RNA payloads from accessory glands to sperm, and changes to the female reproductive-tract microbiome. These processes have led some researchers to implicate seminal fluid in driving telegony, where offspring inherit characteristics of their mother's previous partners.

What does the future hold? We're entering an exciting time for seminal fluid research: 'omics' tools are providing new ways to understand how diet, lifestyle, and age influence seminal fluid, and the consequences for the fertility of males, and the health of their mates and offspring. A deeper understanding of seminal fluid could contribute towards the design of pest-control techniques for insects, or enhance the efficiency of assisted-reproductive technologies in humans and animals of agricultural or conservation importance. Furthermore, dissecting the interactions between the female reproductive tract and seminal fluid provides an exceptional opportunity to investigate the delicate balance between sexual conflict and cooperation, with profound implications not just for evolutionary biology, but for clinicians too.

Where can I find out more?
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