100 YEARS AGO

It is possible to believe that all the past is but the beginning of a beginning, and that all that is and has been is but the twilight of the dawn. It is possible to believe that all that the human mind has ever accomplished is but the dream before the awakening. We cannot see, there is no need for us to see, what this world will be like when the day has fully come. We are creatures of the twilight. But it is out of our race and lineage that minds will spring, that will reach back to us in our littleness to know us better than we know ourselves, and that will reach forward fearlessly to comprehend this future that defeats our eyes. All this world is heavy with the promise of greater things, and a day will come, one day in the unending succession of days, when beings, beings who are now latent in our thoughts and hidden in our loins, shall stand upon this earth as one stands upon a footstool, and shall laugh and reach out their hands amidst the stars. H. G. Wells

From *Nature* 6 February 1902.

50 YEARS AGO

Studies have been made of the probable 'handedness' of prehistoric man by investigating the various relics of his tools and weapons. It appears from the way they are carved that prehistoric man was predominantly right-handed. The choice of one hand, usually the right but occasionally the left, and not either hand indiscriminately, is characteristic of man. It would seem that ambidexterity is an animal rather than a human characteristic… although to be left-handed in a right-handed society has numerous disadvantages, in spite of attempts to stamp it out in Britain, Greece, the United States and France, approximately 4–6 per cent of the population are still left-handed. Why should this be? Left-handedness appears to be inherited; how is not known. In certain families there seems to be a high incidence of left-handedness. Some investigators have found that such families also have more than the usual number of twins, so that there might be some connexion between twinning and left-handedness. That more males than females are left-handed seems to be agreed by investigators and raises the interesting question of whether this is the original distribution, or whether it is the result of the pressure of society.

From *Nature* 9 February 1952.

popular tunes, some of which had been altered by inserting a wrong note. The subjects differed greatly in their ability to detect the altered melodies, and genetic model-fitting indicated a heritability of pitch discrimination of 70–80%.

Does this mean, then, that the basic building-blocks of our music-processing system are to a large part inherited? Hundreds of pages have been filled over the past 150 years with attempts to explain the appearance of music, starting with Charles Darwin[10], who believed that systems of calling in animals have a musical quality and evolved into speech. This view is echoed in a recent article by Gray *et al.*[11], which draws parallels between the songs of birds, whales and humans. Steven Pinker, the outspoken cognitive neuroscientist, on the other hand, notes that "of [all] mental faculties… music shows the clearest signs of not being [adaptive]"[12] and probably occurred as an epiphenomenon, as "auditory cheesecake".

The new data provided by Peretz *et al.*[4,5] establish congenital amusia as a specific developmental disorder. But to go further and help settle the debate, combined behavioural and genetic study of subjects with music-processing deficits will be needed to reveal more about the biological origins of our musical faculty. ■

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Microbiological oceanography

Hidden in a sea of microbes

David M. Karl

The photosynthetic activities of bacteria in the oceans are more diverse than previously thought. A full picture of the marine energy budget will require their separate contributions to be teased apart.

Green plants have been using oxygenic photosynthesis, in which oxygen is released, for more than 3 billion years. But there are two other non-oxygenic photosynthetic pathways, used not by green plants, but by certain bacteria. One pathway is known as anaerobic anoxygenic photosynthesis (AnAnP), because it can occur in the absence of oxygen; it pre-dates oxygenic photosynthesis, and is nowadays restricted to a few groups of bacteria that inhabit sunlit, oxygen-free habitats. The other pathway — aerobic anoxygenic photosynthesis (AAnP) — requires oxygen but does not generate it as a by-product; this pathway was discovered in marine bacteria only twenty years ago[1].

Most photosynthetic microorganisms in the open ocean were thought to be oxygenic, but there is growing evidence[2,3] that oxygen-consuming, light-harvesting AAnP bacteria could make up as much as 11% of the total marine community. On page 630 of this issue, Béjà *et al.*[4] identify new groups of AAnP bacteria in the sea, and show that these are much more diverse than expected.

All of these various photosynthetic bacteria harvest light energy using specialized pigments (the 'photo' part) and can convert CO_2 into organic carbon (the 'synthesis' part), albeit with differing efficiencies. This is why the oceans are thought to act as carbon sinks: marine bacteria and algae convert atmospheric CO_2 into organic matter, some of which then enters the food web, where it remains for variable time periods. In oxygenic photosynthesis, chlorophyll *a* is the primary pigment responsible for harvesting light energy, and water is the hydrogen donor for CO_2 reduction, so oxygen is generated as a by-product (Fig. 1). Much of the oxygen will be consumed by non-photosynthetic organisms during respiration, when they metabolize organic matter to generate energy and to synthesize cellular constituents.

Before the dawn of oxygenic photosynthesis, AnAnP bacteria used hydrogen sulphide or hydrogen gas, which were both abundant, as the hydrogen donors — this is why they do not produce O_2 (Fig. 1). These bacteria use bacteriochlorophyll *a* (Bchl*a*) as the pigment for harvesting light energy. AAnP bacteria, on the other hand, use oxygen to metabolize organic carbon, to synthesize Bchl*a* for example, but do so more efficiently when sunlight is available (Fig. 1). Like AnAnP bacteria, they do not use water as the hydrogen donor, so oxygen is not produced. These bacteria are being found in surprising amounts in the open sea[2,3], and could make us rethink our picture of carbon and energy flow in the oceans.

Béjà *et al.*[4] analyse genes encoding the photosystem and photosynthetic pigments from bacteria collected in the northern Pacific Ocean (both open sea and coastal sites), and report an "unsuspected diversity" among marine AAnP bacteria. A novel aspect of this study is the use of molecular techniques — specifically the polymerase chain reaction after reverse transcription of RNA — to identify active 'photosynthetic genes' in AAnP bacteria that have never been cultured in the laboratory, including several new β-proteobacterial species not previously found in the sea. These culture-independent bacteria discovered by genomic analysis are genetically, and perhaps physiologically, distinct from known AAnP cultures. In the past, the discrepancy between the number of bacteria that are easily cultured and the abundance of microorganisms found in ocean samples has been a source of frustration and uncertainty, so genomic studies of this sort are likely to become increasingly important in the future.

The discovery[4] of wide diversity among AAnP bacteria in the sea is important for several reasons. First, our understanding of the biogeochemistry (such as the carbon cycle) and the ecology (including the food web) of marine ecosystems is based on an oxygenic photosynthesis model typical of green plants. But local rates of photosynthesis in selected marine ecosystems may not always be linked to oxygen dynamics, and this may help to resolve a controversy about whether the open ocean is a net producer or a consumer of oxygen. If AAnP bacteria are important contributors to total marine production of organic matter, this would tip the apparent oxygen balance towards net consumption in their favoured habitats.

Second, Béjà and colleagues' work[4] follows closely on the heels of other reports of new marine microorganisms, including *Prochlorococcus marinus* (the dominant oxygenic photosynthetic organism in the open ocean[5]), planktonic *Archaea* in both surface[6] and subsurface[7] marine waters with yet unknown metabolic or ecological function, proteorhodopsin-containing bacteria[8] that may be able to metabolize light and organic matter simultaneously, and new unicellular nitrogen-fixing cyanobacteria[9] and small eukaryotes[10]. Collectively, these previously unknown marine microbes and unexpected metabolic diversity—now revealed by developments in molecular-based methods—are demanding a revision of our basic concepts of carbon and energy flow in the sea (Fig. 1). The potential ecological impact of these discoveries may be on a par with that of the original discovery of "little animals" (bacteria) in the sea by van Leeuwenhoek[11] more than three centuries ago.

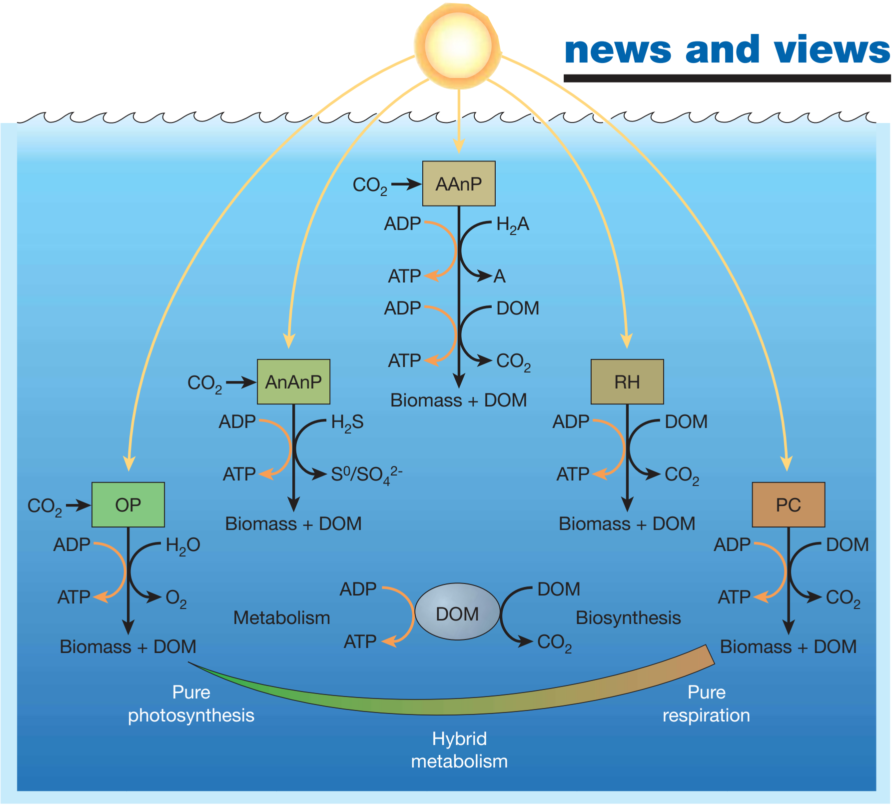

Figure 1 **A current view of the complex relationships between sunlight, biological energy production and dissolved organic matter (DOM) in the open sea. Recent discoveries of new marine bacteria[2–9] include all three modes of photosynthesis: oxygenic photosynthesis (OP), anaerobic anoxygenic photosynthesis (AnAnP) and aerobic anoxygenic photosynthesis (AAnP), as well as two other potentially important light-driven processes, rhodopsin-based (RH) and phytochrome-based (PC) interactions that involve both light and DOM. Together, these light-driven processes, as well as others not shown here, sustain and control the flow of external energy into the global ocean. Each metabolic pathway is also dependent on the availability of DOM, ranging from low dependence (true photosynthesis) to high dependence (light-stimulated DOM respiration). DOM has at least two key functions: metabolism (ATP formation) and biosynthesis. Pure OP may be the exception in low-nutrient oceans, whereas mixed light–DOM metabolic processes are more likely in the open sea. Ecologists have yet to establish a comprehensive metabolic budget for these complex marine systems.**

We must now determine the physiological, metabolic and ecological relevance of each new group of bacteria to the ocean ecosystem. Goericke[12] recently reported that the percentage of AAnP pigments found in bacteria increased as total pigment content decreased, so the pigment-poor open sea may be a dominant habitat for AAnP bacteria. That study downplayed the role of AAnP bacteria in total photosynthesis because of the low overall occurrence of Bchl*a*, but AAnP bacteria are known to contain much less pigment per unit biomass than oxygenic bacteria and algae because they have other metabolic options and so rely less on light energy[13]. It is possible, even likely, that the newly discovered AAnP bacteria can use light and organic matter simultaneously. However, without complete knowledge of their metabolism, a comprehensive energy budget for the marine ecosystem will remain missing from the global ecological puzzle.

Future studies must recognize and embrace the fact that a comprehensive understanding of the marine ecosystem is literally hidden in a sea of microbes. The diversity of microorganisms in the marine environment and the broad spectrum of their metabolic potential, including gene expression and regulation, are rapidly becoming as large as the sea itself. By most accounts, we can culture fewer than 10% (by number) of the microbial inhabitants of the sea, so existing ideas of marine ecology must be flexible and accommodating to change. Both the stakes and the level of excitement in microbiological oceanography are at an all-time high, and the field, in my view, is poised for even more significant discoveries in the near future. ■

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