Ungelöste Fragen und künftige Aufgaben der Meereskunde

Kann die Meeresforschung noch große Erkenntnisse erwarten, wenn sie weiter betrieben wird wie bisher?

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35 Jahre Deutsche Gesellschaft für Meeresforschung

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„Nichts macht Sinn in der Biologie außer im Lichte der Evolution“ Theodosius Dobzhansky

Womit machen wir Sinn? Mit welchen Sinnesorganen?

Mit den Augen?

Was steuert die Augen?

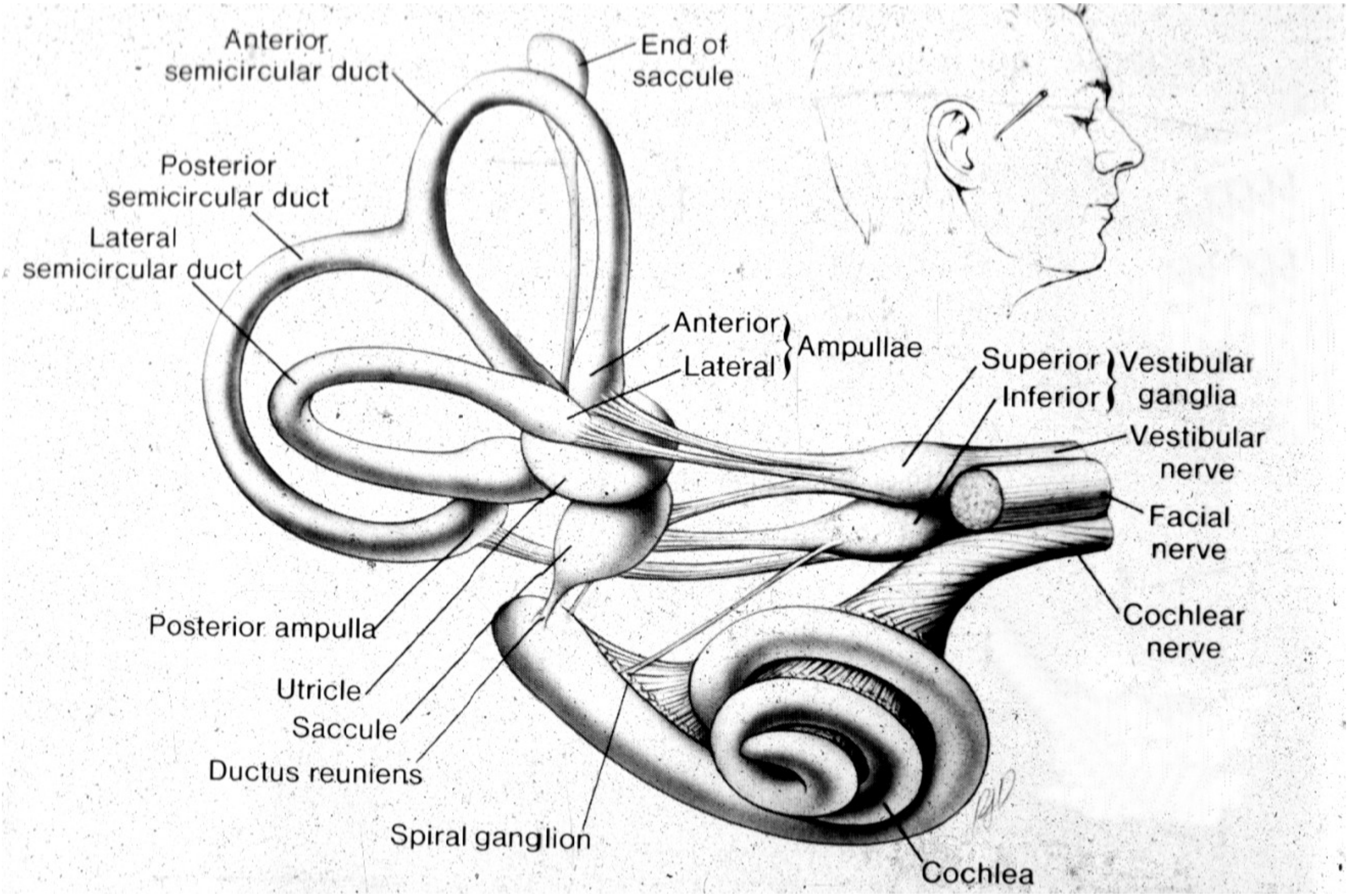
Das Vestibularsystem, das zugleich Gleichgewicht, Schwerkraft, Beschleunigung und Bewegung des Kopfes wahrnimmt.

Fingerbeispiel

Also, unsere Aufmerksamkeit, das Licht in dem wir Sinn machen, wird vom Vestibularsystem gelenkt.

Es ist auch die Grundlage unseres Wohlbefindens

Es tut gut, über den Einfluss des Vestibularorgans nachzudenken.


Anterior semicircular duct
End of saccule
Posterior semicircular duct
Lateral semicircular duct
Anterior
Lateral
Ampullae
Superior
Inferior
Vestibular ganglia
Vestibular nerve
Facial nerve
Cochlear nerve
Posterior ampulla
Utricle
Saccule
Ductus reuniens
Spiral ganglion
Cochlea

vestibular system, which contributes to balance in most mammals and to the sense of spatial orientation, is the sensory system that provides the leading contribution about movement and sense of balance. Together with the cochlea, a part of the auditory system, it constitutes the labyrinth of the inner ear in most mammals, situated in the vestibulum in the inner ear (Figure 1). As our movements consist of rotations and translations, the vestibular system comprises two components: the semicircular canal system, which indicate rotational movements; and the otoliths, which indicate linear accelerations. The vestibular system sends signals primarily to the neural structures that control our eye movements, and to the muscles that keep us upright. The projections to the former provide the anatomical basis of the vestibulo-ocular reflex, which is required for clear vision; and the projections to the muscles that control our posture are necessary to keep us upright.

Wikipedia

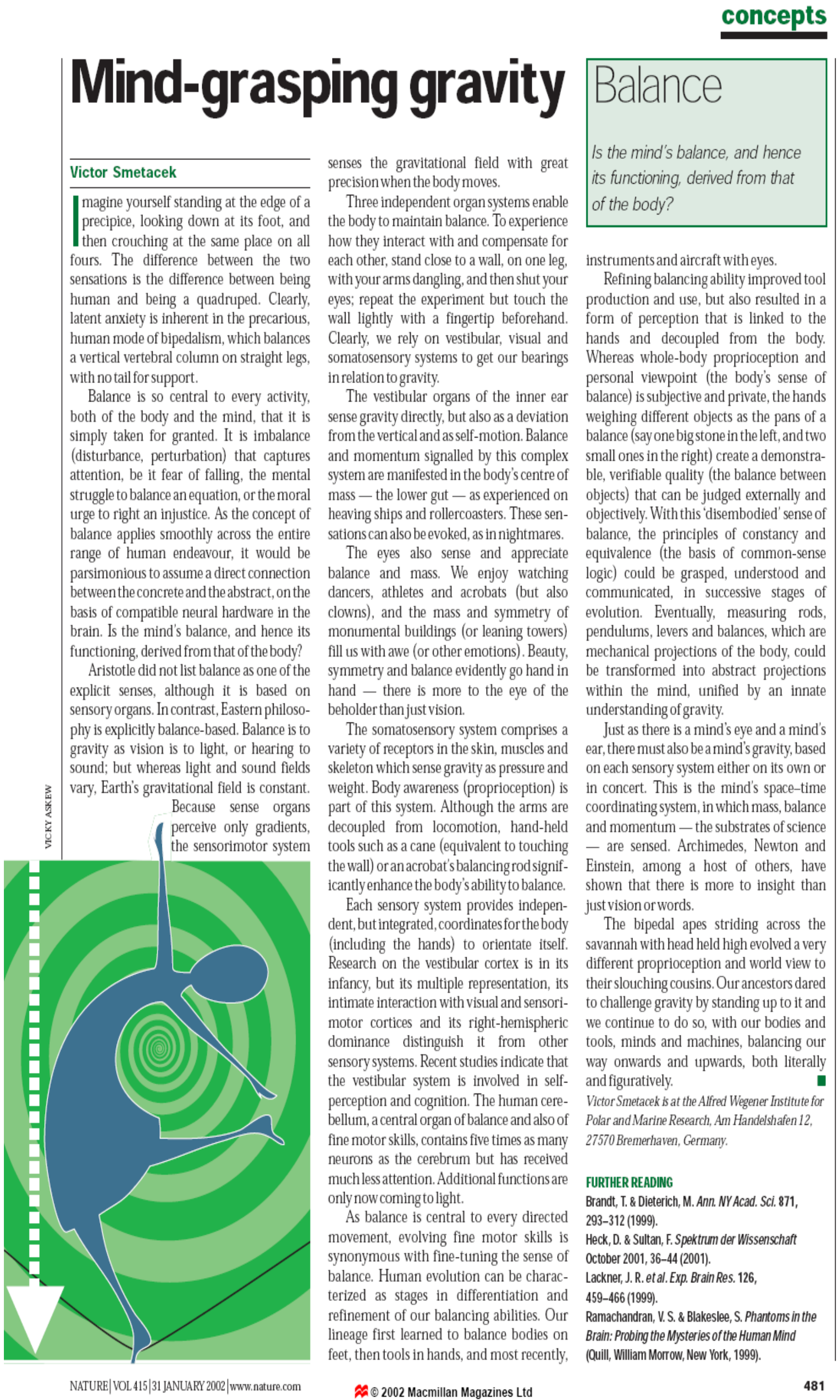
Is the mind‘s balance, and hence its functioning, derived from that of the body?

Is there an innate sense of justice?

How did it develop and where are its neural correlates?

Relationship between material and abstract worlds.

From balancing bodies to balancing equations.



Mind-grasping gravity

Balance

Is the mind's balance, and hence its functioning, derived from that of the body?

Victor Smetacek

Imagine yourself standing at the edge of a precipice, looking down at its foot, and then crouching at the same place on all fours. The difference between the two sensations is the difference between being human and being a quadruped. Clearly, latent anxiety is inherent in the precarious, human mode of bipedalism, which balances a vertical vertebral column on straight legs, with no tail for support.

Balance is so central to every activity, both of the body and the mind, that it is simply taken for granted. It is imbalance (disturbance, perturbation) that captures attention, be it fear of falling, the mental struggle to balance an equation, or the moral urge to right an injustice. As the concept of balance applies smoothly across the entire range of human endeavour, it would be parsimonious to assume a direct connection between the concrete and the abstract, on the basis of compatible neural hardware in the brain. Is the mind's balance, and hence its functioning, derived from that of the body?

Aristotle did not list balance as one of the explicit senses, although it is based on sensory organs. In contrast, Eastern philosophy is explicitly balance-based. Balance is to gravity as vision is to light, or hearing to sound; but whereas light and sound fields vary, Earth's gravitational field is constant. Because sense organs perceive only gradients, the sensorimotor system senses the gravitational field with great precision when the body moves.

VICKY ASKEW

Three independent organ systems enable the body to maintain balance. To experience how they interact with and compensate for each other, stand close to a wall, on one leg, with your arms dangling, and then shut your eyes; repeat the experiment but touch the wall lightly with a fingertip beforehand. Clearly, we rely on vestibular, visual and somatosensory systems to get our bearings in relation to gravity.

The vestibular organs of the inner ear sense gravity directly, but also as a deviation from the vertical and as self-motion. Balance and momentum signalled by this complex system are manifested in the body's centre of mass — the lower gut — as experienced on heaving ships and rollercoasters. These sensations can also be evoked, as in nightmares.

The eyes also sense and appreciate balance and mass. We enjoy watching dancers, athletes and acrobats (but also clowns), and the mass and symmetry of monumental buildings (or leaning towers) fill us with awe (or other emotions). Beauty, symmetry and balance evidently go hand in hand — there is more to the eye of the beholder than just vision.

The somatosensory system comprises a variety of receptors in the skin, muscles and skeleton which sense gravity as pressure and weight. Body awareness (proprioception) is part of this system. Although the arms are decoupled from locomotion, hand-held tools such as a cane (equivalent to touching the wall) or an acrobat's balancing rod significantly enhance the body's ability to balance.

Each sensory system provides independent, but integrated, coordinates for the body (including the hands) to orientate itself. Research on the vestibular cortex is in its infancy, but its multiple representation, its intimate interaction with visual and sensorimotor cortices and its right-hemispheric dominance distinguish it from other sensory systems. Recent studies indicate that the vestibular system is involved in self-perception and cognition. The human cerebellum, a central organ of balance and also of fine motor skills, contains five times as many neurons as the cerebrum but has received much less attention. Additional functions are only now coming to light.

As balance is central to every directed movement, evolving fine motor skills is synonymous with fine-tuning the sense of balance. Human evolution can be characterized as stages in differentiation and refinement of our balancing abilities. Our lineage first learned to balance bodies on feet, then tools in hands, and most recently, instruments and aircraft with eyes.

Refining balancing ability improved tool production and use, but also resulted in a form of perception that is linked to the hands and decoupled from the body. Whereas whole-body proprioception and personal viewpoint (the body's sense of balance) is subjective and private, the hands weighing different objects as the pans of a balance (say one big stone in the left, and two small ones in the right) create a demonstrable, verifiable quality (the balance between objects) that can be judged externally and objectively. With this 'disembodied' sense of balance, the principles of constancy and equivalence (the basis of common-sense logic) could be grasped, understood and communicated, in successive stages of evolution. Eventually, measuring rods, pendulums, levers and balances, which are mechanical projections of the body, could be transformed into abstract projections within the mind, unified by an innate understanding of gravity.

Just as there is a mind's eye and a mind's ear, there must also be a mind's gravity, based on each sensory system either on its own or in concert. This is the mind's space–time coordinating system, in which mass, balance and momentum — the substrates of science — are sensed. Archimedes, Newton and Einstein, among a host of others, have shown that there is more to insight than just vision or words.

The bipedal apes striding across the savannah with head held high evolved a very different proprioception and world view to their slouching cousins. Our ancestors dared to challenge gravity by standing up to it and we continue to do so, with our bodies and tools, minds and machines, balancing our way onwards and upwards, both literally and figuratively. ■

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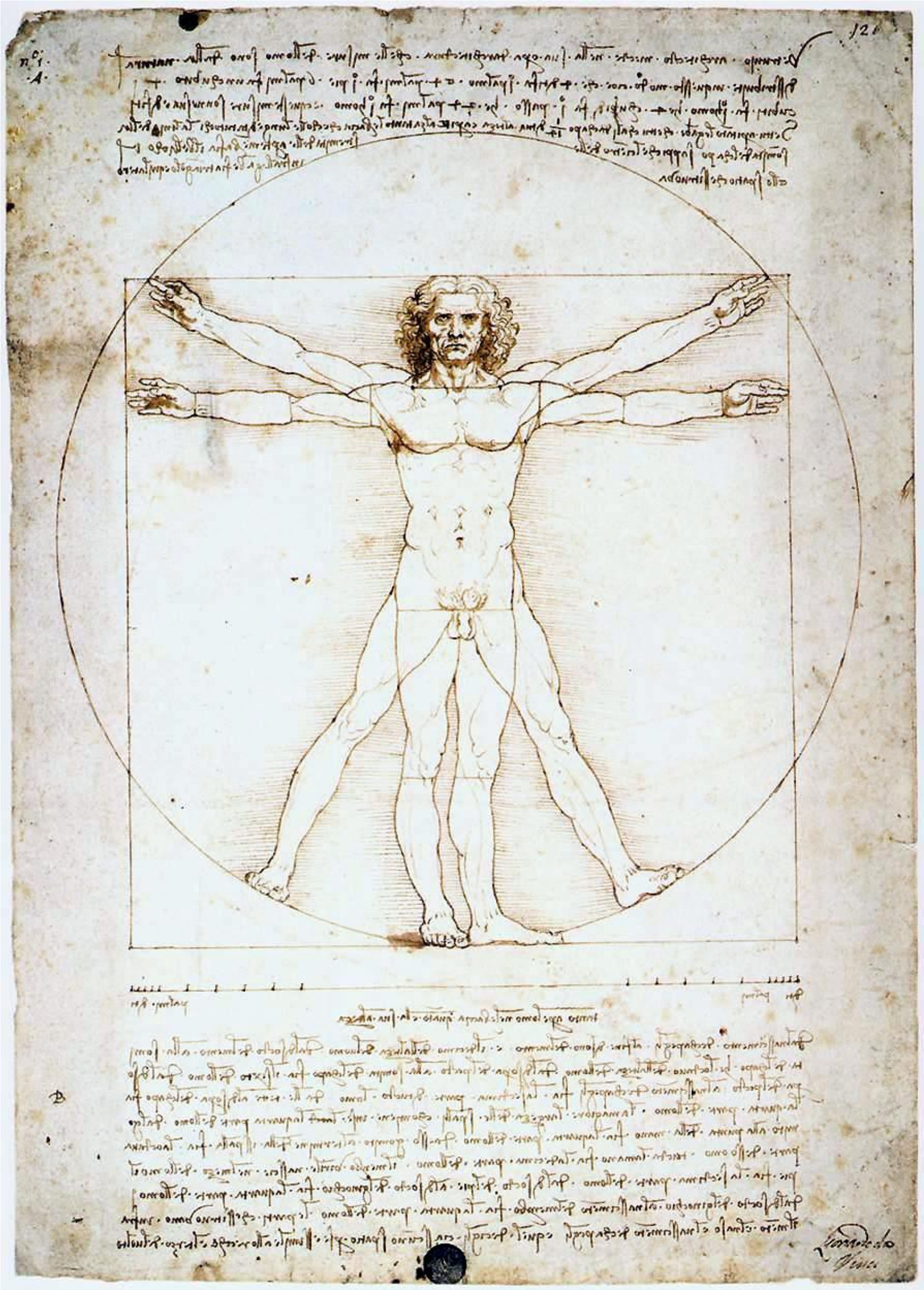
Proprioception: Körperwahrnehmung sowie Wahrnehmung von Objekten und Raum.

Im hohen Maße schon bei Protisten entwickelt

Oktopus Intelligenz beruht darauf



Proprioception: Is the sensory system that supports body posture and movement also the root of our understanding of physical laws?

The body and vestibular organs as our major sense organs.

Making sense

Proprioception: is the sensory system that supports body posture and movement also the root of our understanding of physical laws?

Victor Smetacek and Franz Mechsner

Aristotle argued that human beings have five senses at their disposal. Although various other sense organs have come to light since then, this antique dogma still constrains popular imagination. The term 'sixth sense' resonates with instinct and metaphysics, implying that although the five 'regular' senses represent reality adequately, there is something else lurking in the subconscious. The search for the sensory system with which the blind guide their movements revealed that the body's sense of posture and movement relies on different types of tiny receptors densely packed in the muscles and tendons. In 1906 Charles Sherrington coined the term proprioception (perception of one's own) for the sensory modality based on these receptors and called it our 'secret sixth sense'. But this concept of the body as a major sense organ has failed to arouse the interest it deserves.

Proprioception functions in much the same way as the conventional senses. Proprioceptors precisely measure physical properties, such as muscle length, tendon tension, joint angle or deep pressure. Signals from this sensory orchestra are sent by afferent nerves through the spinal cord to the somatosensory, motor and parietal cortices of the brain, where they continuously feed and update dynamic sensory-motor maps of the body. So proprioception provides information on the physics of the body, the momentary distribution and dynamics of masses, forces acting on the limbs and their highly nonlinear interactions. The maps derived from these complex calculations not only guide body movement, they also (together with touch) sense the size and shape of objects and measure the geometry of external space. Weight — one's own and that of objects — is measured independently by pressure sensors and muscular tension. So subjective body consciousness provided by myriad networking proprioceptors is the basis of objective knowledge of fundamental physical properties — space, time and weight — of external reality.

Our daily doings are coordinated and run by a trinity of independent sensory systems: proprioception, vision and the vestibular organs of the inner ear (which sense balance, momentum and guide the eyes). Their signals are so tightly integrated that it is impossible to unravel them through introspection, a view which seems to favour vision as the primary sense organ of the mind. But whereas in the congenitally blind other senses more or less compensate for the loss, a child born without proprioception would not know it had a body and would be physically and mentally retarded as a result.

Selective loss of proprioception in adults is rare. In the case of Ian Waterman, a rare disease caused degeneration of sensory nerves relaying information from the body to the brain from the neck down, but spared the motor nerves conveying signals in the other direction. He could see, but not feel, where his body was or whether it was moving or not. At the age of 19, he was left a helpless 'rag doll', who had to be fed, washed and dressed — attempts at movement elicited only uncontrolled jerks. However, his strong will and memory of his body enabled him to learn to gradually control and guide his movements with his eyes. But even after 30 years of intense practice, the simplest movement has not been automated, but requires concentrated visual attention so strenuous that he likens it to a daily marathon, and in the dark he still collapses like a rag doll. His case, and a few others, demonstrate that all purposeful movements, both conscious and unconscious, are controlled by proprioception.

The proprioceptive system is so efficient and reliable at granting us the freedom of movement we expect from our bodies that we unconsciously relegate it to a subconscious, background realm of reflexes below the sphere of the five 'primary' senses. This attitude is unjustified. Most of our movements are indeed automated and run, as in animals, by the more basic and evolutionarily older parts of the brain. But we easily forget, for good reason, the intense conscious attention required to learn complex skills, such as writing, skiing or driving. Learning a skill implies developing new patterns of movement by screening, coordinating and calibrating relevant information from the orchestra of signals supplied to the neocortex by the trinity of sensory systems. New neural programmes are computed, memorized by repetition and transferred to the more fundamental regions of the brain, from where they are run with less effort and relayed much faster than from the seat of conscious awareness. So mastering a skill amounts to automating it.

Human proprioceptive ability is far superior to that of animals, reflected in the range, variety and precision of our automated skills, and manifest in the tools we make and what we achieve with them. Just as tools are extensions of the body, so basic scientific instruments — the balance, pendulum and measuring rod — are extensions of body sense. Evolution of these instruments, together with optical ones, launched the scientific exploration of space and time domains outside those of the body experience. Interestingly, the models of external space based on mathematical language made sense before their confirmation by precise measurements. From where else could these models have come, if not from the neural correlates of internal models of the physical laws of motion which run our bodies automatically? So the rules and laws of science were in place, and obeyed blindly, before they were rediscovered in the external world. In short, the neural correlates of physics and mathematics did not evolve *de novo*, but are rooted in our 'subconscious' body sense. ■

Effortless grace? A body's fine-tuned actions belie inner complexities.

R. SCHMIDT/AFP/GETTY IMAGES

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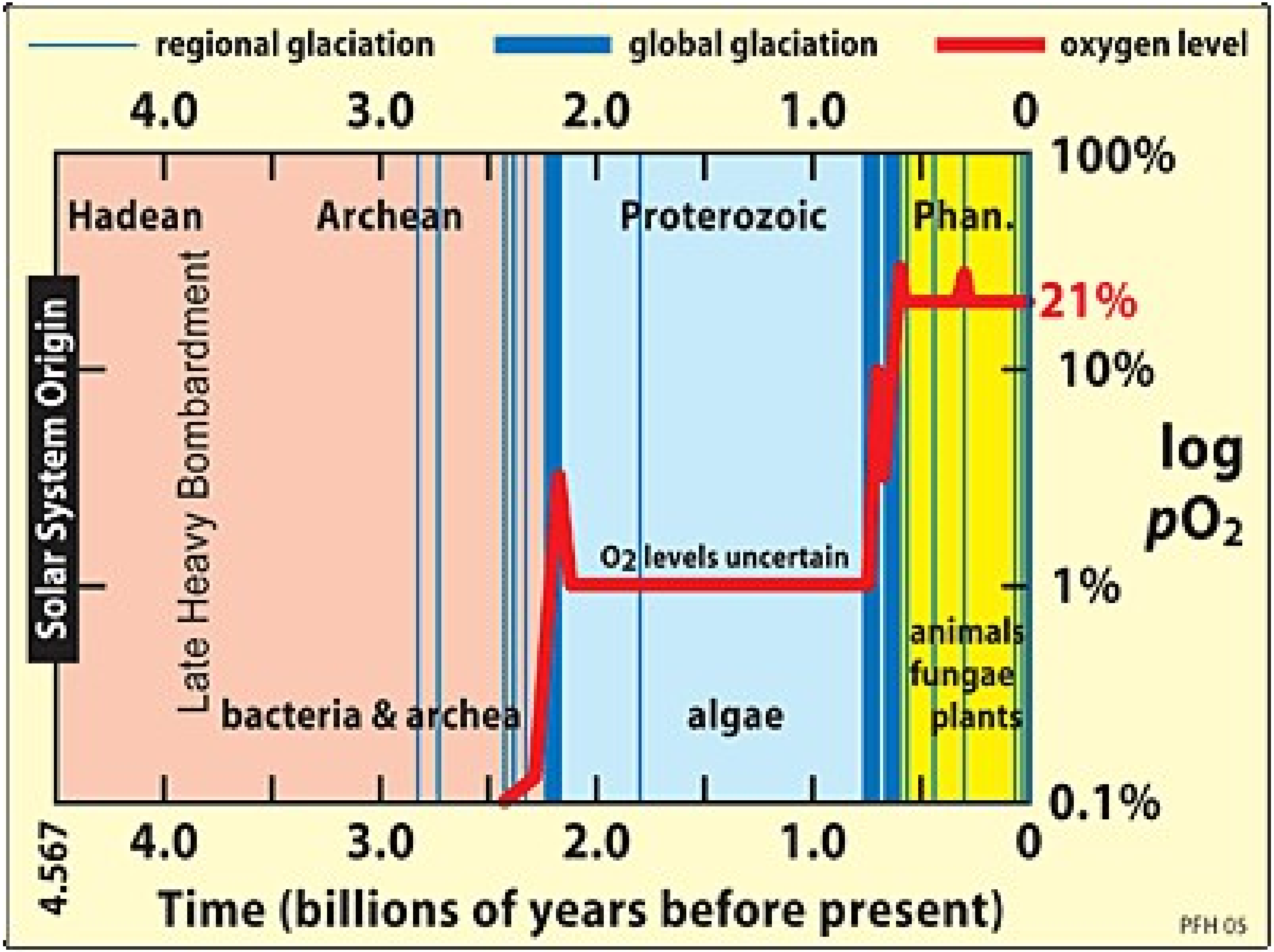


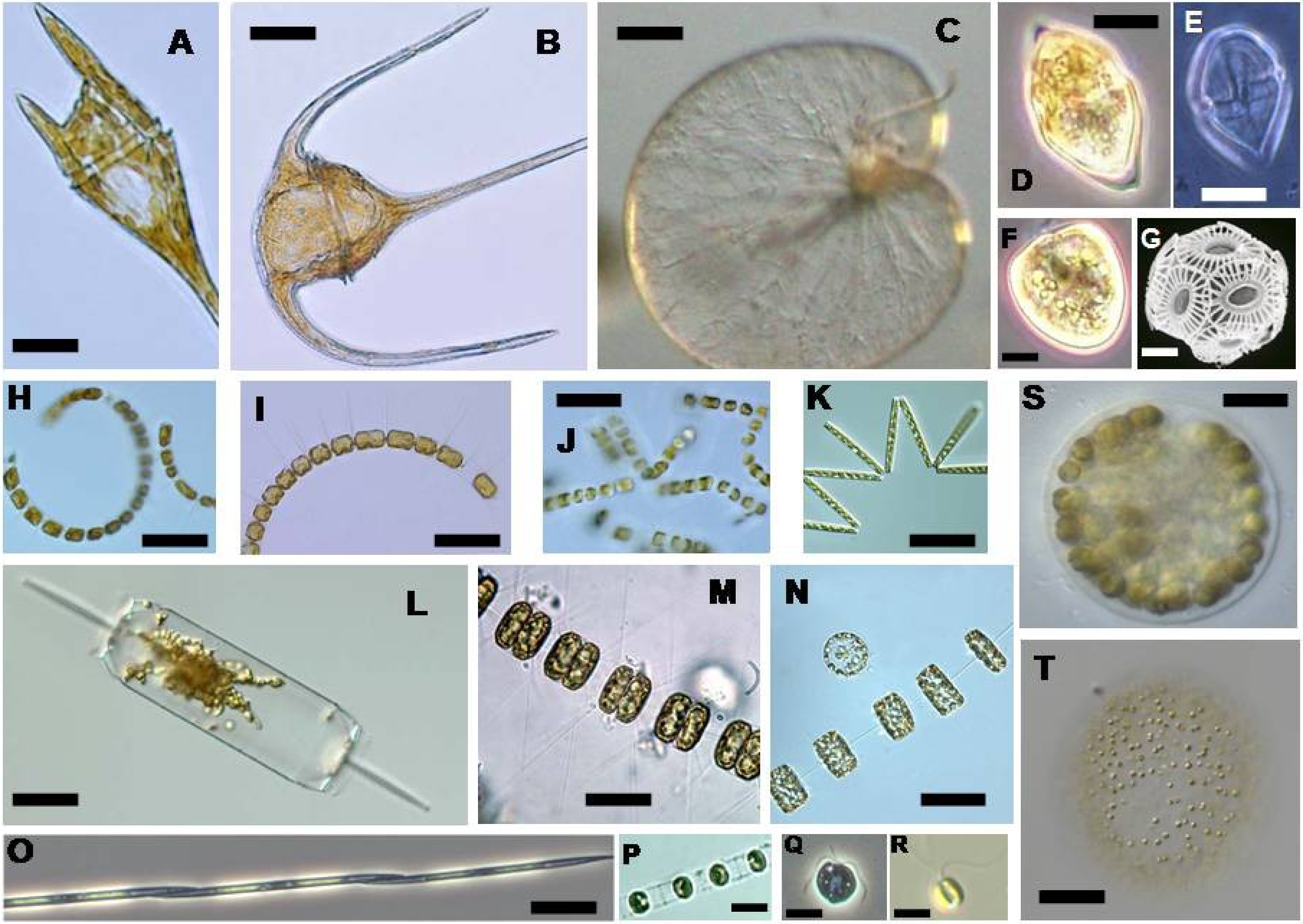
http://www.snowballearth.org/

The standard tree exemplified by *Gingko biloba* which is about 50 Mill. years old with recognisable relatives dating back to the Permian (270 Mill). Wind pollination, seed dispersal by large fruit. Few enemies, hence well protected. Trees survived Hiroshima bomb at 2 km distance.

Tree ferns (top left), cycads (top) and palm tree (left) showing convergent morphology driven by bottom-up constraints

Form and function make sense here: selection of optimal solutions, because we are terrestrial organisms and live in a strong gravity field

Does phytoplankton make sense?

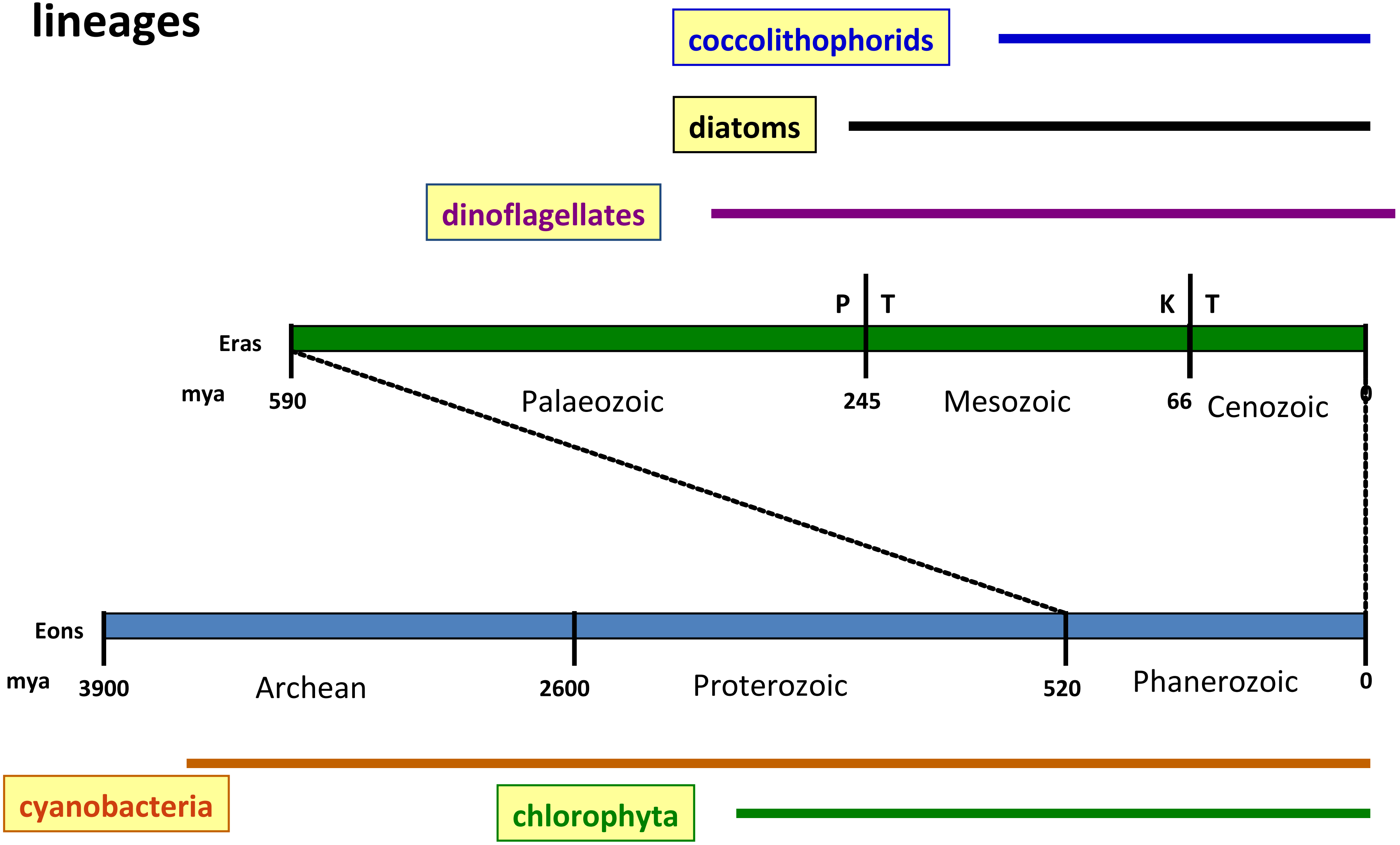


Was macht Sinn?

Landpflanzen, weil wir terrestrische Organismen sind: Kinder der Schwerkraft.

Aber Planktonorganismen sind für uns rätselhaft.

First appearance of phytoplankton lineages



Corethron pennatum

THREE SPECIES OF THE DIATOM GENUS *CORETHRON* CASTRACANE: STRUCTURE, DISTRIBUTION AND TAXONOMY

Diatom Research (1998), Volume 13 (1), 1–28

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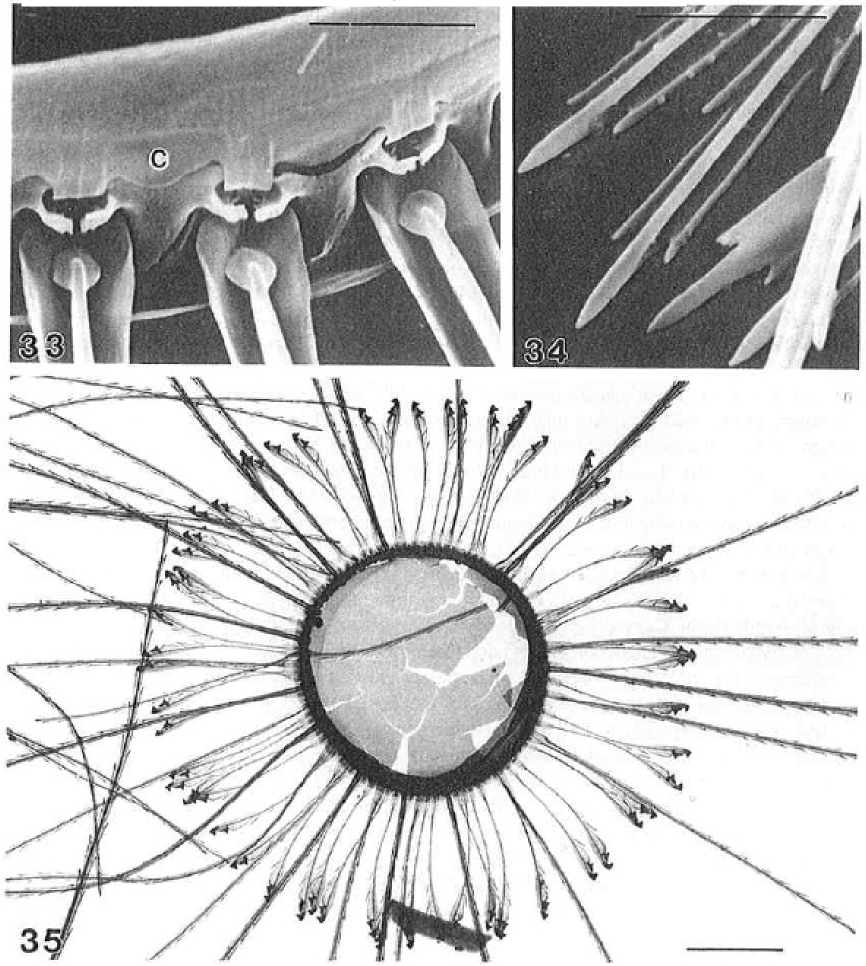
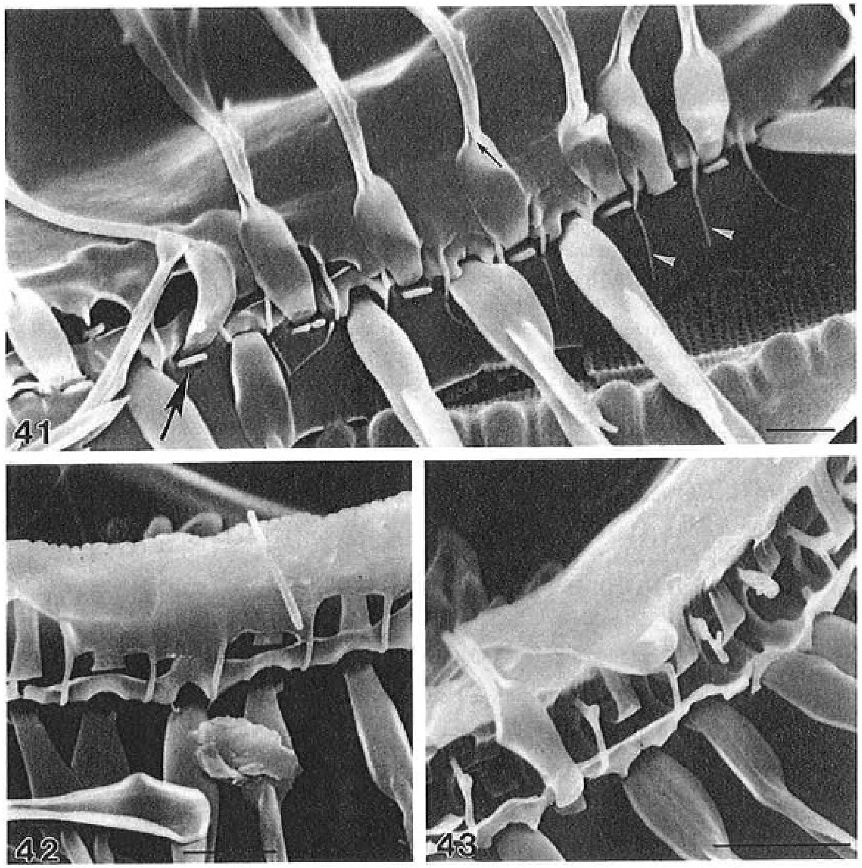
Claire Honeywill



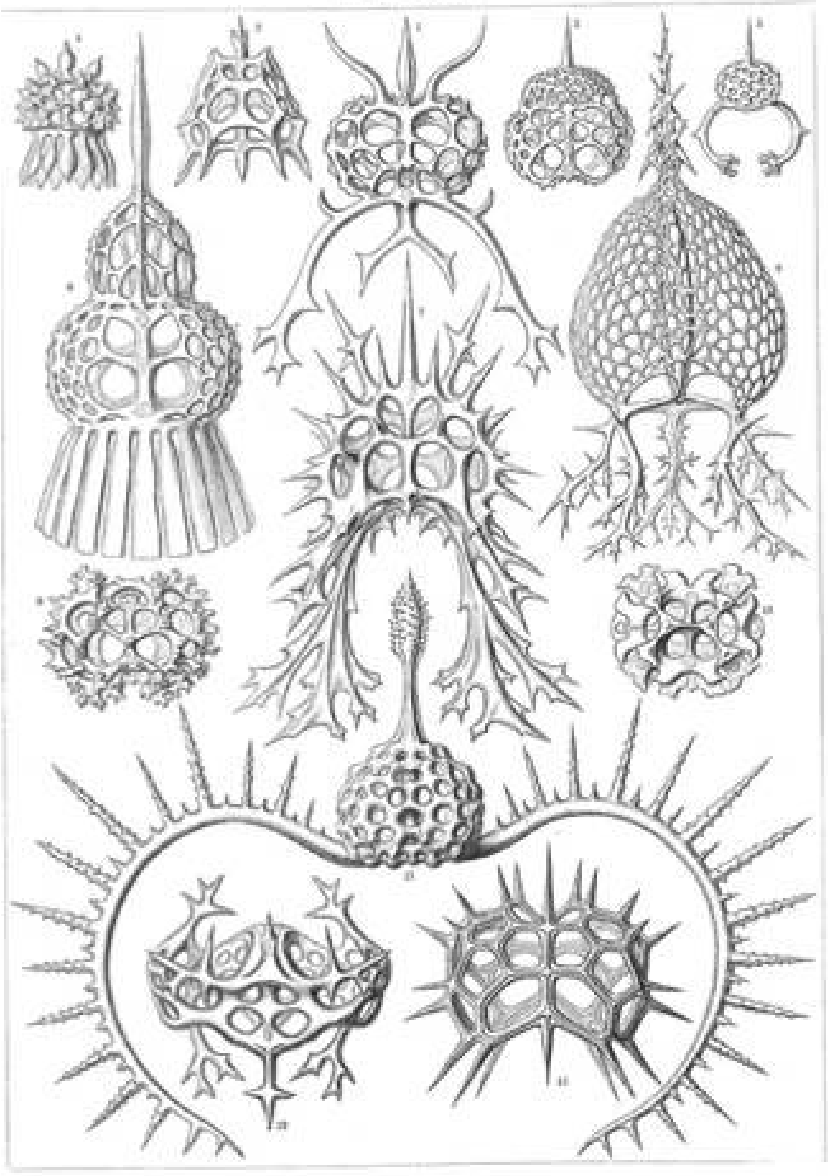
Figs 33–35. *C. hystrix*. **Fig. 33**. Bases of three long spines on type 1 valve, illustrating the clasping ledges and the curtain of material on the valve above (C). The base of the long spine differs from *C. pennatum* in the spoon-shaped base of the spine ridge. **Fig. 34**. Detail of tips of long spines. **Fig. 35**. TEM shows a near perfect complement of 59 hooked spines and 27 of the ca. 34 long spines. Scale bars = 1 µm (Figs 33, 34) or 10 µm (Fig. 35).



Figs 41–43. *C. hystrix*. **Fig. 41**. SEM of margin of type 2 valve, showing long spines below and hooked spines above. Also visible are the stops for the hooked spines (large arrow), a break in the curtain over the spine sockets (to the left), and the long, thin fingers of support for this curtain running down over the mantle (arrowheads). Note also the curling of the basal portion of the hooked spines to form the shaft (small arrow). **Fig. 42**. Detail of curtain, supports and spine bases. **Fig. 43**. Further detail with more of the curtain removed. Note the angle in the supports (like a wishbone). Scale bars = 1 µm.

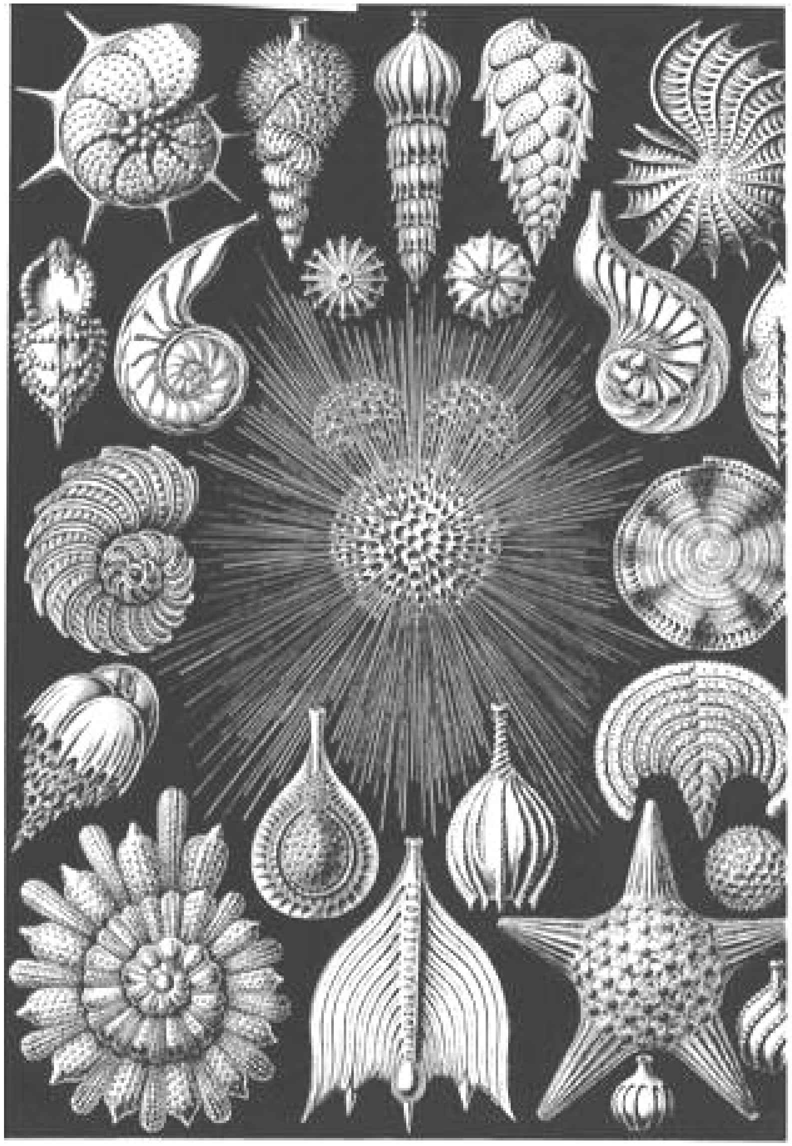
Ernst Haeckel, Kunstformen der Natur (1904)

Radiolaria shapes are baffling



Spyroidea. Nüßchenstrahlinge.

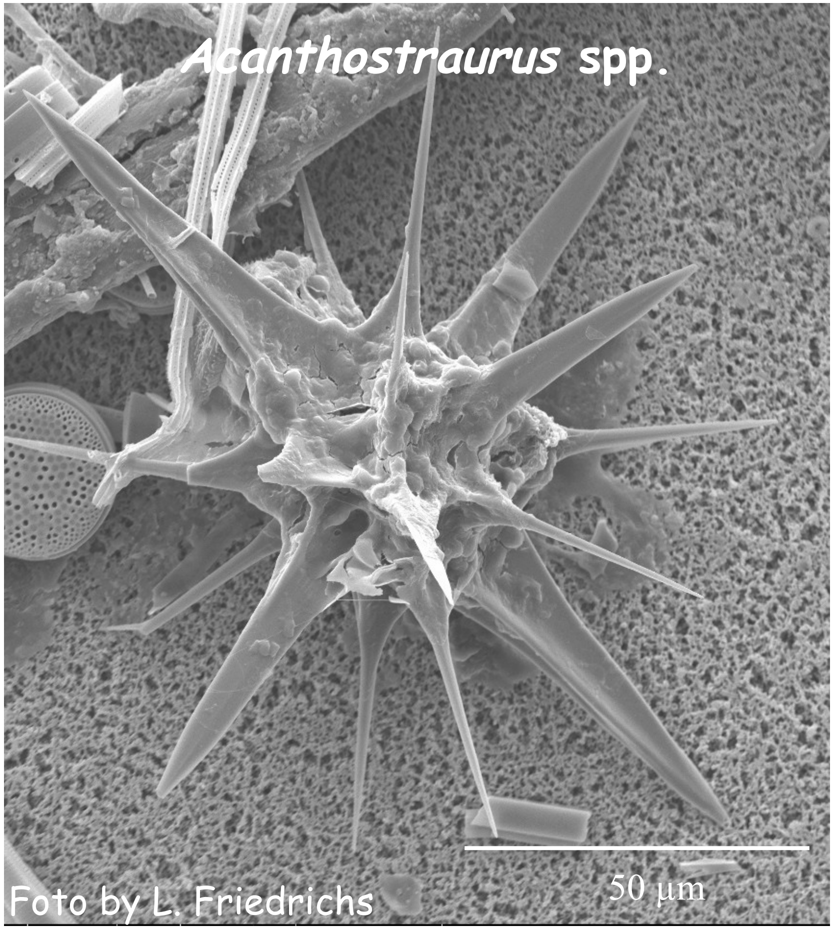
But what about Foraminifera?
What do they remind us of?



Thalamophora. Kammerlinge.

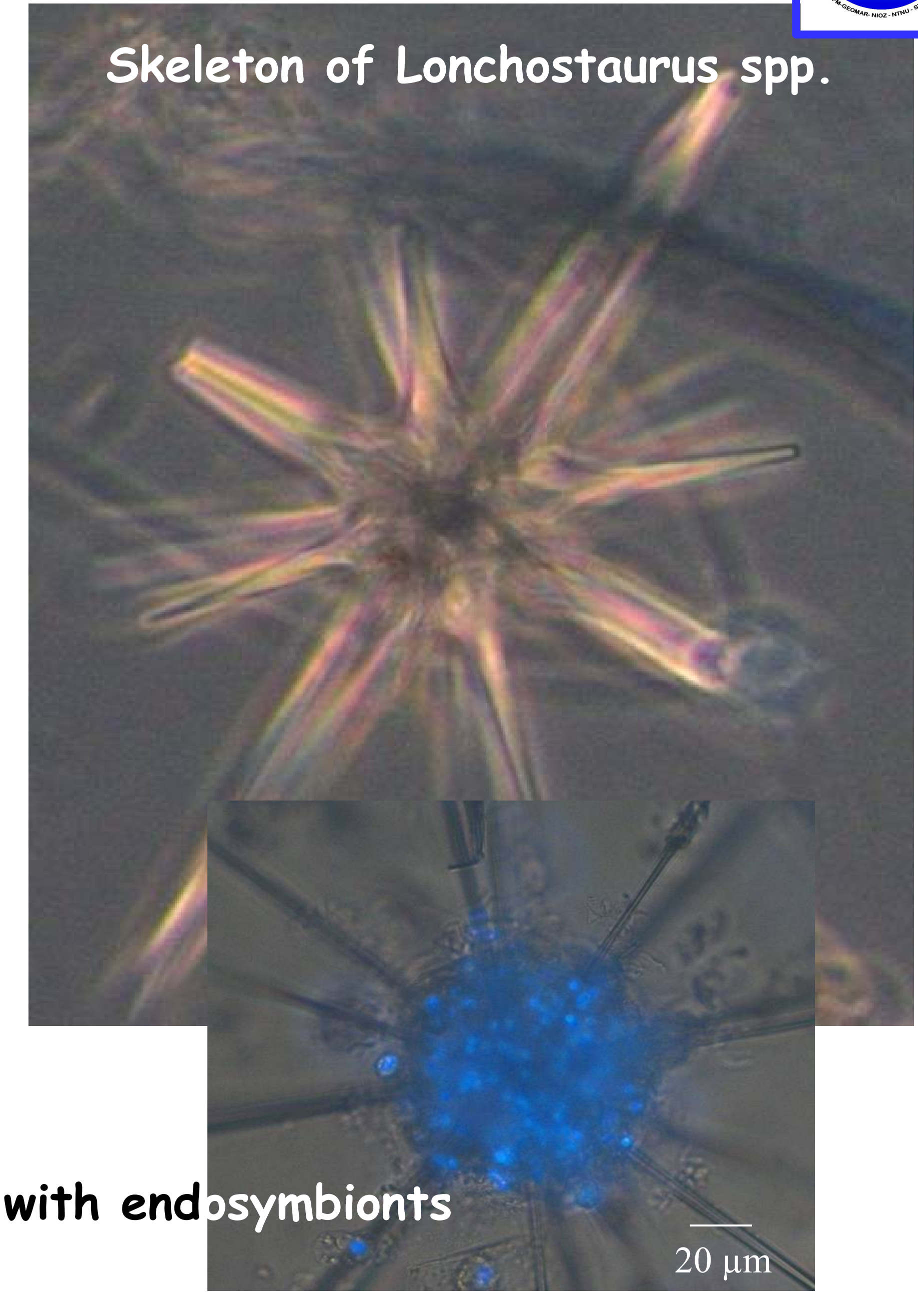
Kammerling (Foraminifera ca. 0.5 mm)

Large Protists: Acantharia



Acanthostraurus spp.

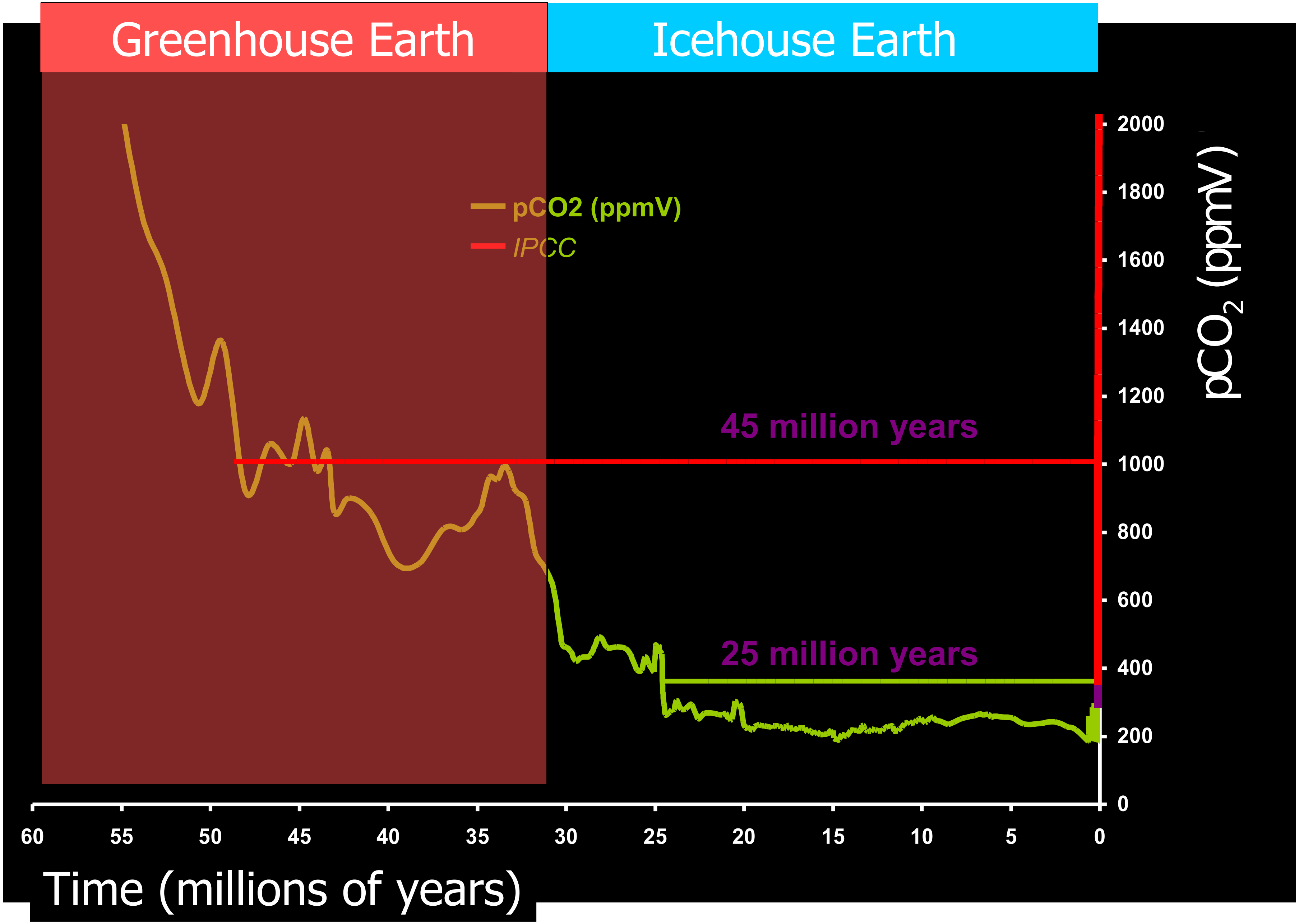
Foto by L. Friedrichs



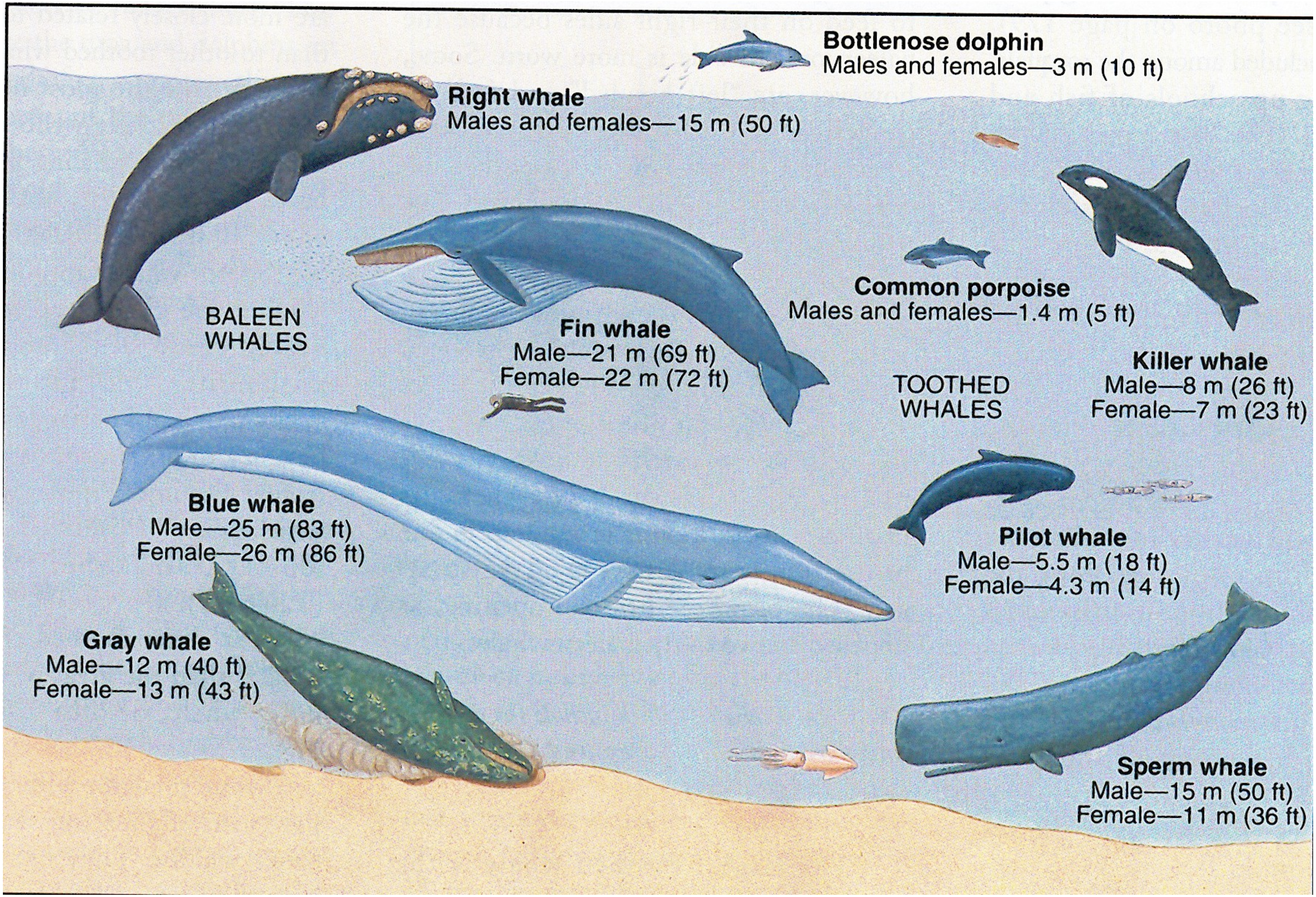
Skeleton of Lonchostaurus spp.

Stauracon spp. with endosymbionts

Courtesy: Henk Brinkhuis



Whales: baleen (11 species) and tooth (67 species) whales

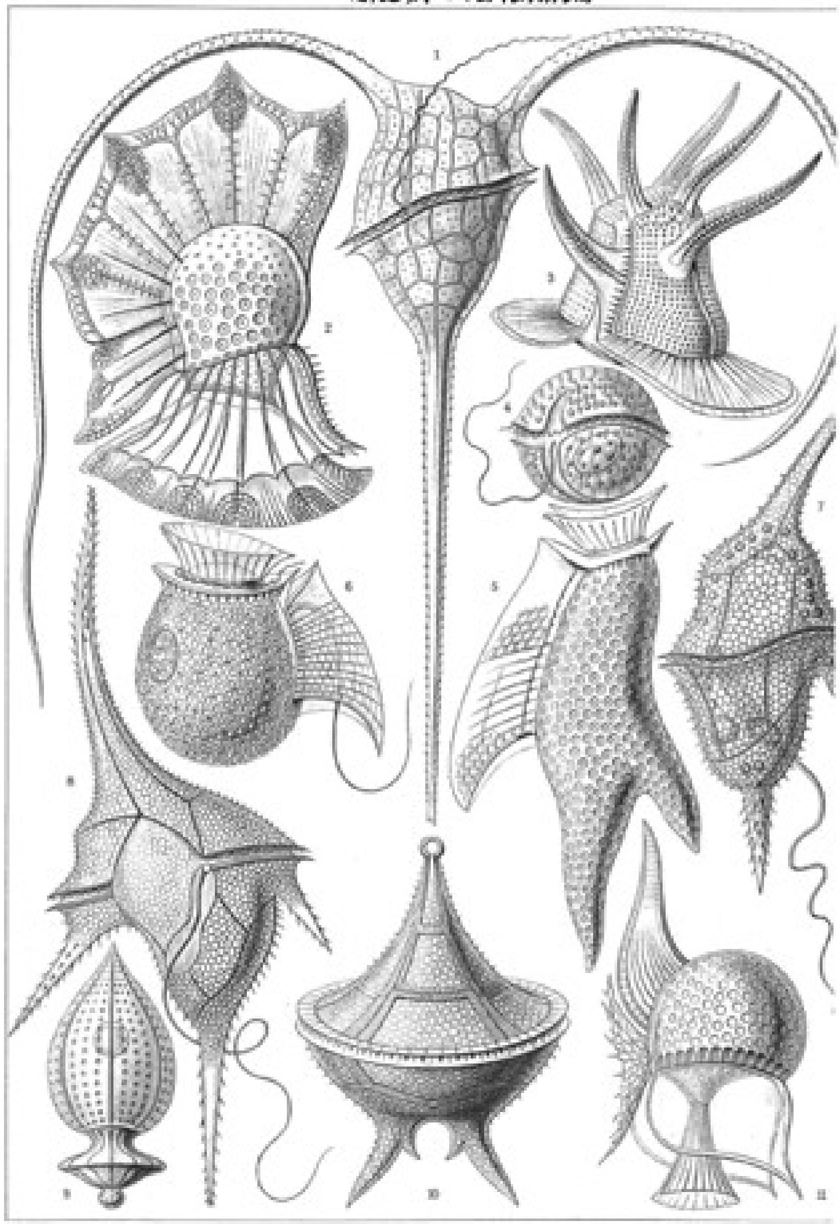


What is the function of these forms?

Shape does not determine whether an organism is photoauto- or phagotrophic.

My suggestions:
Shape is a signal to would-be predators, sensed by proprioception (body sense) and equivalent to colour and shape for visual predators.

Hence, there will also be mimicry, interpreted as convergence of form, or conservation of shape, or why so many cryptic species.



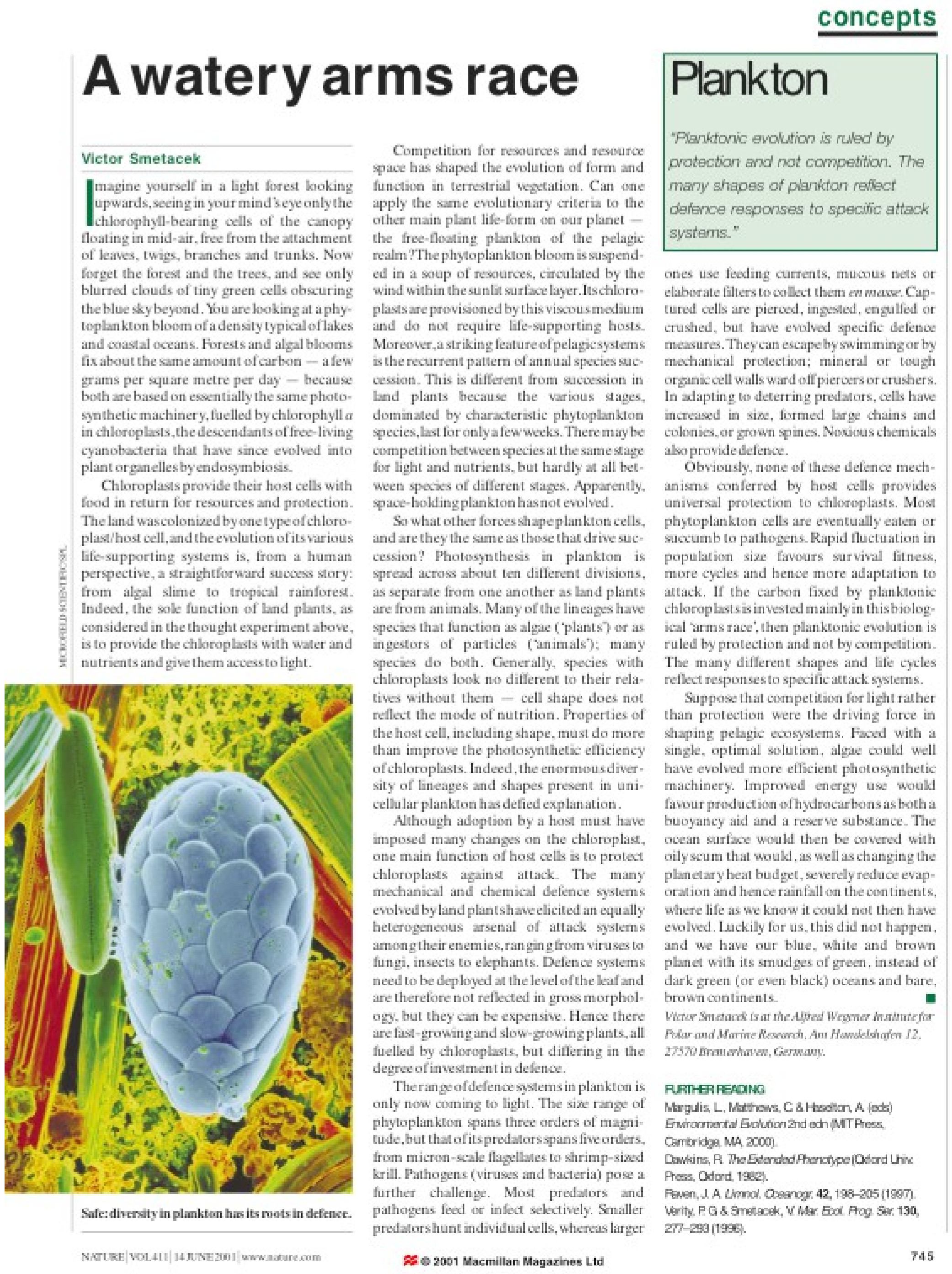
Tafel 14 - Peridinium

Peridinea. Geißelhütchen.

If there is a shape, there must be something to sense it.

Proprioceptors of the protozoo- and metazooplankton have shaped phytoplankton and hence the climate of the planet.

Plankton evolution is ruled by protection and not competition. The many shapes of plankton reflect defence responses to specific attack systems ranging from pathogens, parasitoids to predators.



A watery arms race

Victor Smetacek

Imagine yourself in a light forest looking upwards, seeing in your mind's eye only the chlorophyll-bearing cells of the canopy floating in mid-air, free from the attachment of leaves, twigs, branches and trunks. Now forget the forest and the trees, and see only blurred clouds of tiny green cells obscuring the blue sky beyond. You are looking at a phytoplankton bloom of a density typical of lakes and coastal oceans. Forests and algal blooms fix about the same amount of carbon — a few grams per square metre per day — because both are based on essentially the same photosynthetic machinery, fuelled by chlorophyll *a* in chloroplasts, the descendants of free-living cyanobacteria that have since evolved into plant organelles by endosymbiosis.

Chloroplasts provide their host cells with food in return for resources and protection. The land was colonized by one type of chloroplast/host cell, and the evolution of its various life-supporting systems is, from a human perspective, a straightforward success story: from algal slime to tropical rainforest. Indeed, the sole function of land plants, as considered in the thought experiment above, is to provide the chloroplasts with water and nutrients and give them access to light.

MICROFIELD SCIENTIFIC/SPL

Safe: diversity in plankton has its roots in defence.

Competition for resources and resource space has shaped the evolution of form and function in terrestrial vegetation. Can one apply the same evolutionary criteria to the other main plant life-form on our planet — the free-floating plankton of the pelagic realm? The phytoplankton bloom is suspended in a soup of resources, circulated by the wind within the sunlit surface layer. Its chloroplasts are provisioned by this viscous medium and do not require life-supporting hosts. Moreover, a striking feature of pelagic systems is the recurrent pattern of annual species succession. This is different from succession in land plants because the various stages, dominated by characteristic phytoplankton species, last for only a few weeks. There may be competition between species at the same stage for light and nutrients, but hardly at all between species of different stages. Apparently, space-holding plankton has not evolved.

So what other forces shape plankton cells, and are they the same as those that drive succession? Photosynthesis in plankton is spread across about ten different divisions, as separate from one another as land plants are from animals. Many of the lineages have species that function as algae ('plants') or as ingestors of particles ('animals'); many species do both. Generally, species with chloroplasts look no different to their relatives without them — cell shape does not reflect the mode of nutrition. Properties of the host cell, including shape, must do more than improve the photosynthetic efficiency of chloroplasts. Indeed, the enormous diversity of lineages and shapes present in unicellular plankton has defied explanation.

Although adoption by a host must have imposed many changes on the chloroplast, one main function of host cells is to protect chloroplasts against attack. The many mechanical and chemical defence systems evolved by land plants have elicited an equally heterogeneous arsenal of attack systems among their enemies, ranging from viruses to fungi, insects to elephants. Defence systems need to be deployed at the level of the leaf and are therefore not reflected in gross morphology, but they can be expensive. Hence there are fast-growing and slow-growing plants, all fuelled by chloroplasts, but differing in the degree of investment in defence.

> ## Plankton
>
> *"Planktonic evolution is ruled by protection and not competition. The many shapes of plankton reflect defence responses to specific attack systems."*

The range of defence systems in plankton is only now coming to light. The size range of phytoplankton spans three orders of magnitude, but that of its predators spans five orders, from micron-scale flagellates to shrimp-sized krill. Pathogens (viruses and bacteria) pose a further challenge. Most predators and pathogens feed or infect selectively. Smaller predators hunt individual cells, whereas larger ones use feeding currents, mucous nets or elaborate filters to collect them *en masse*. Captured cells are pierced, ingested, engulfed or crushed, but have evolved specific defence measures. They can escape by swimming or by mechanical protection; mineral or tough organic cell walls ward off piercers or crushers. In adapting to deterring predators, cells have increased in size, formed large chains and colonies, or grown spines. Noxious chemicals also provide defence.

Obviously, none of these defence mechanisms conferred by host cells provides universal protection to chloroplasts. Most phytoplankton cells are eventually eaten or succumb to pathogens. Rapid fluctuation in population size favours survival fitness, more cycles and hence more adaptation to attack. If the carbon fixed by planktonic chloroplasts is invested mainly in this biological 'arms race', then planktonic evolution is ruled by protection and not by competition. The many different shapes and life cycles reflect responses to specific attack systems.

Suppose that competition for light rather than protection were the driving force in shaping pelagic ecosystems. Faced with a single, optimal solution, algae could well have evolved more efficient photosynthetic machinery. Improved energy use would favour production of hydrocarbons as both a buoyancy aid and a reserve substance. The ocean surface would then be covered with oily scum that would, as well as changing the planetary heat budget, severely reduce evaporation and hence rainfall on the continents, where life as we know it could not then have evolved. Luckily for us, this did not happen, and we have our blue, white and brown planet with its smudges of green, instead of dark green (or even black) oceans and bare, brown continents. ■

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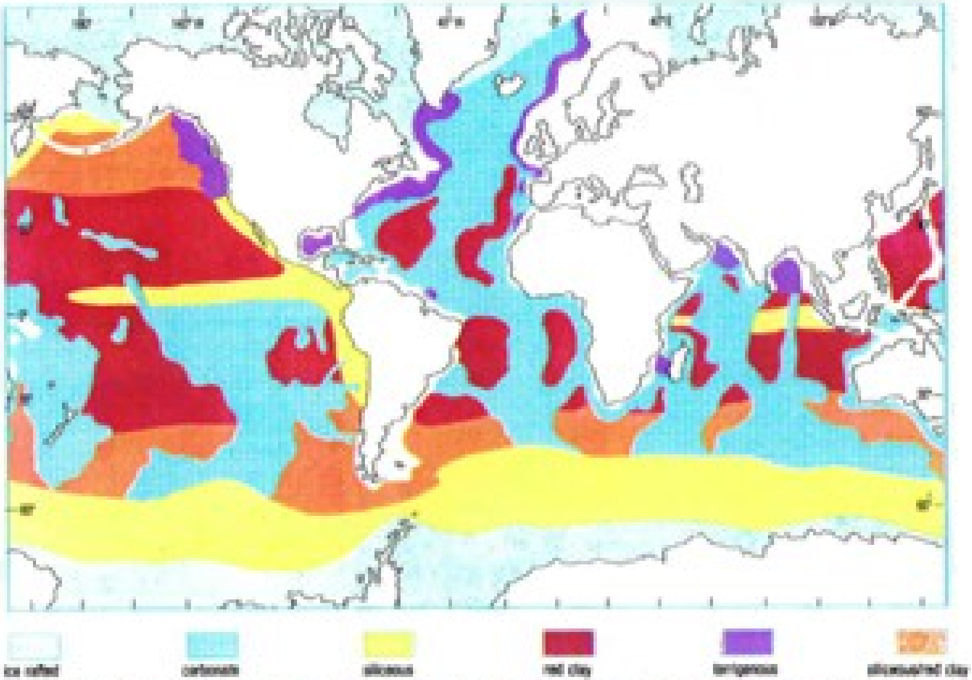


Figure 1.4 Distribution of dominant sediment types on the floor of the present-day oceans. Note that red clays are also terrigenous sediments.

Distribution of dominant sediment types on the sea floor: pale blue: ice rafted sediments. Blue: carbonate (note effect of water depth and age). Yellow: siliceous (note no relation to depth). Red: Red clay (note strong relation to depth). Violet: terrigenous. Orange: siliceous/red clay.

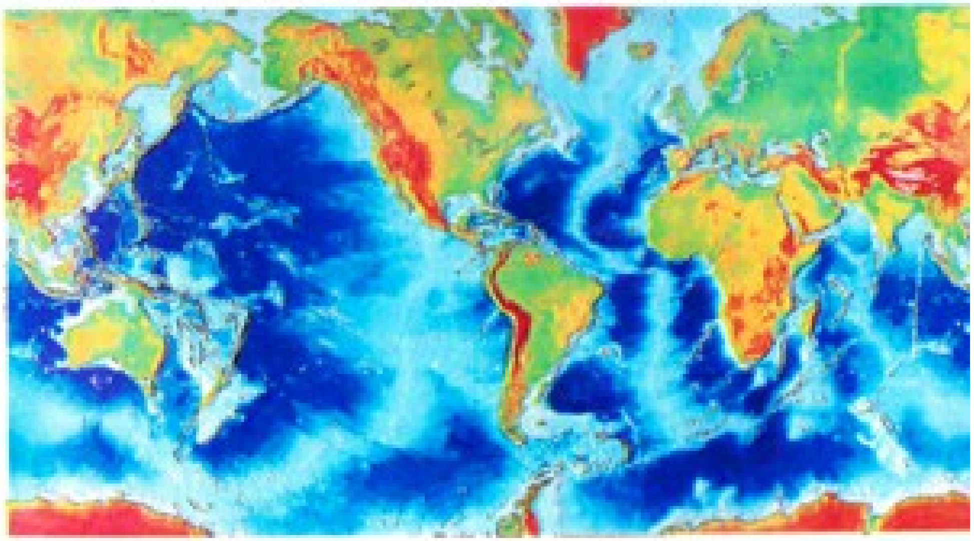
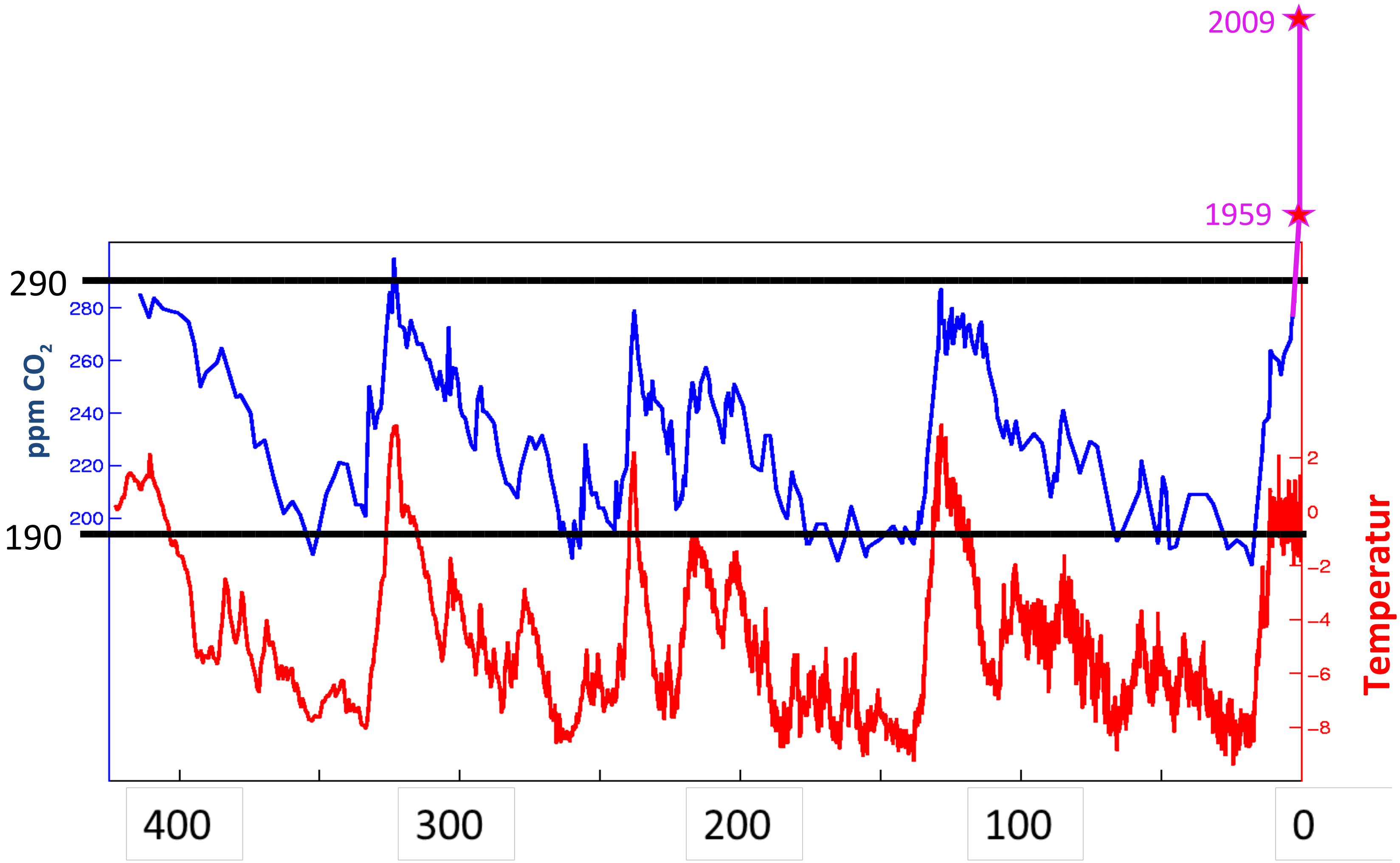


Figure 1.5 Shaded relief map of the Earth's solid surface. In oceanic areas, the deeper the blue, the deeper the water.

Shaded relief map showing abyssal plains and mid-oceanic ridges.

The human factor



Jahrtausende vor heute

Slide courtesy S. Rahmstorf

Magic numbers in the biosphere

Glacial/interglacial CO2 concentrations (180 – 290 ppmv)

Glacial/interglacial methane concentrations (350 – 650 ppbv)

Redfield ratios (Pelagic C:N:P 106:16:1)

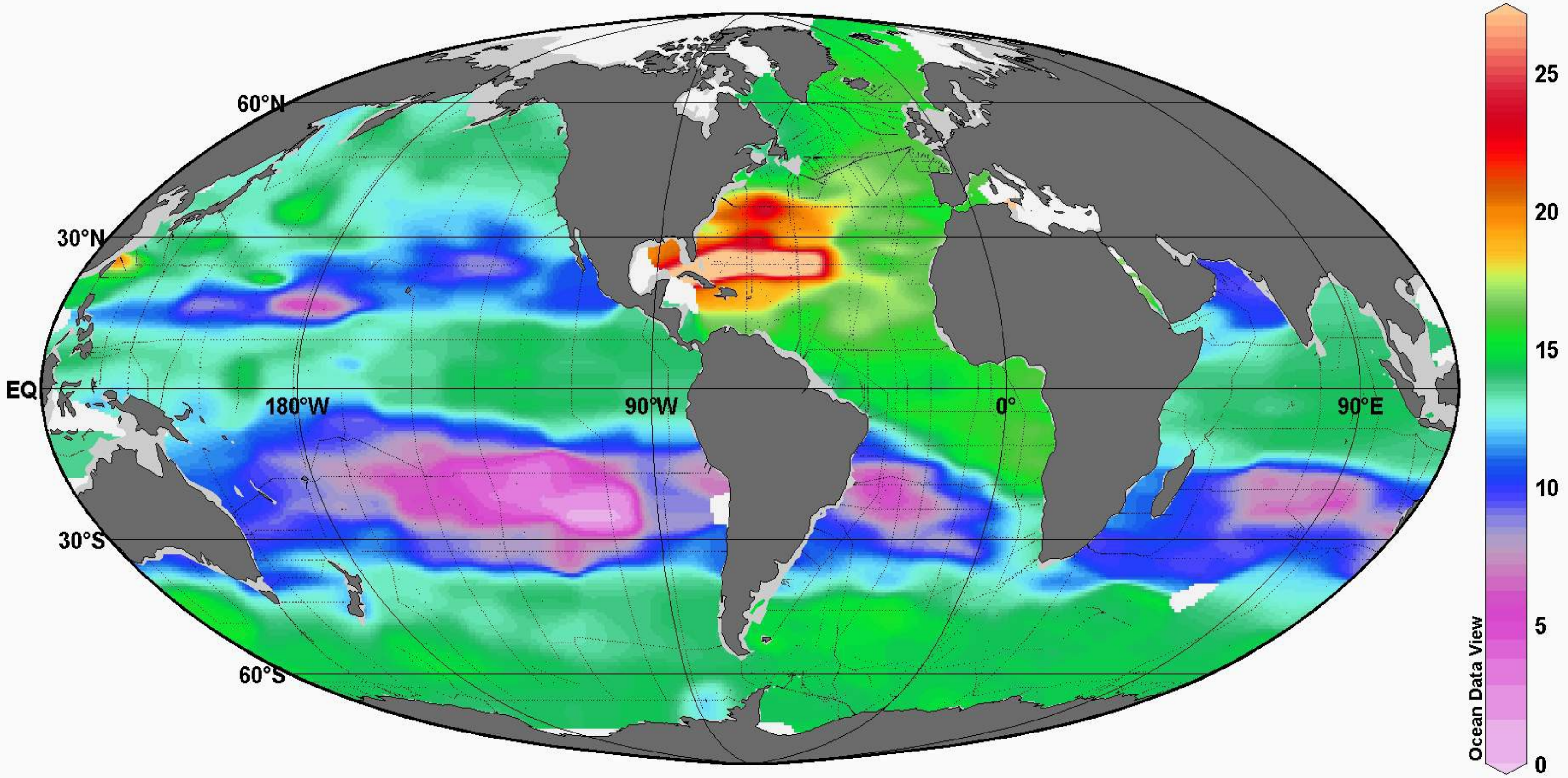
Deep-sea DOC concentrations (42 µmol l^{-1})

Surface ocean bacterial numbers (10^6 ml^{-1})

Virus:Bacteria ratio (10:1)

Non-sea-salt-sulphate (biogenic) flux to Antarctica (3 mg m^{-2} yr^{-1})

N:P ratio on Depth [m]=200



Climate Change and European Marine Ecosystem Research

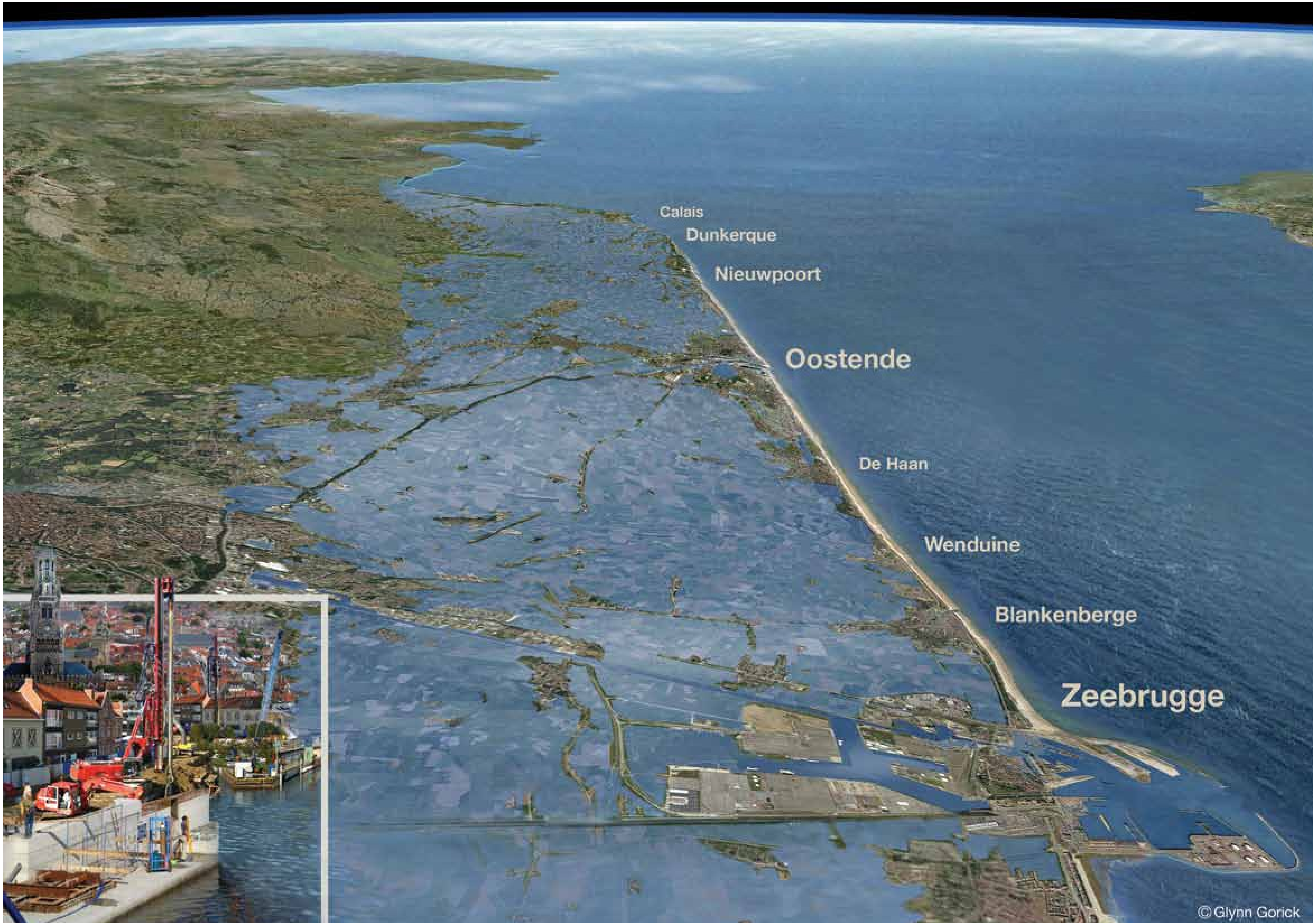
2011

European Commission's Seventh Framework Programme: *Climate Change and European Marine Ecosystem Research (CLAMER)*

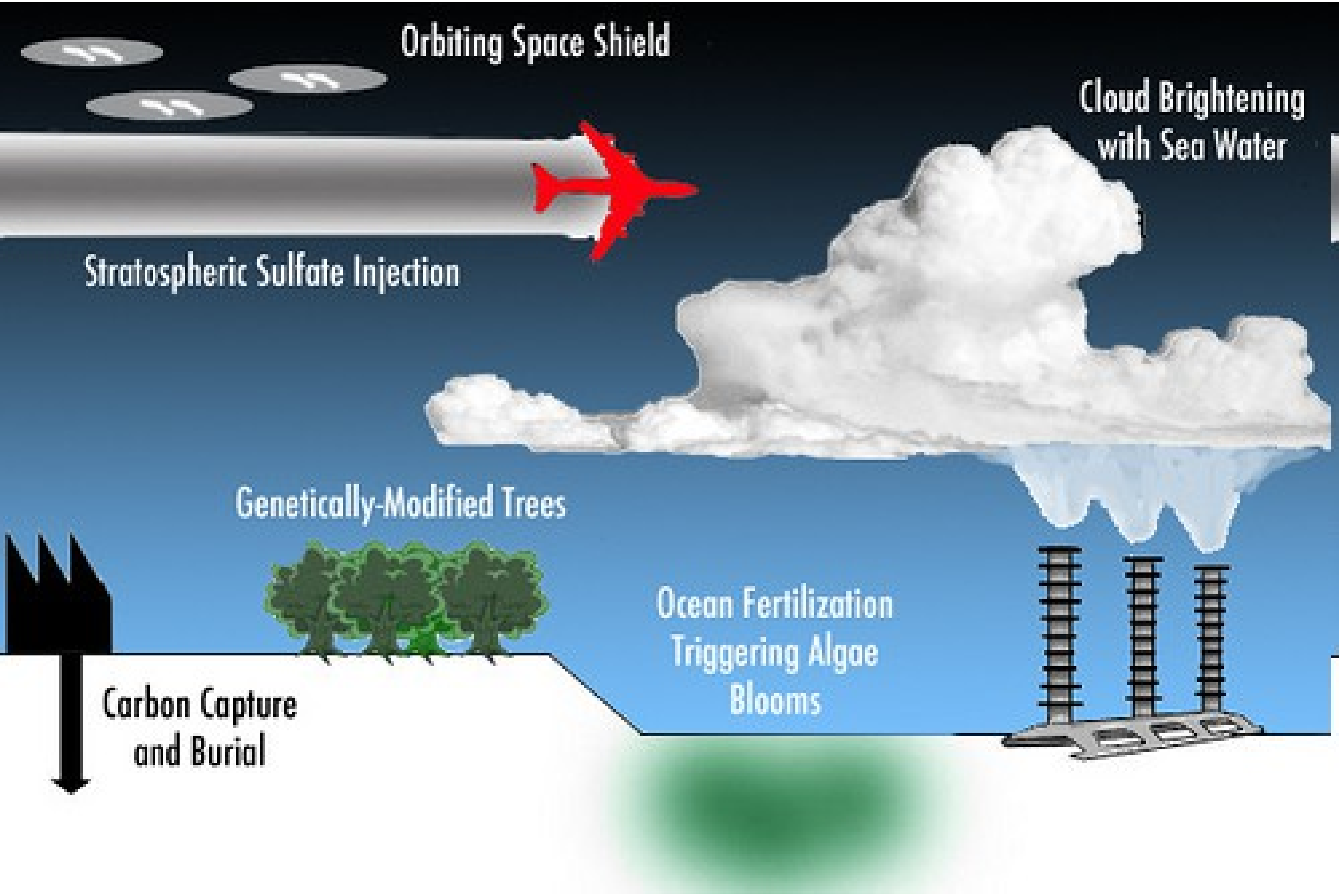
Sir Alister Hardy Foundation for Ocean Science

Chris Reid, Glynn Gorick & Martin Edwards

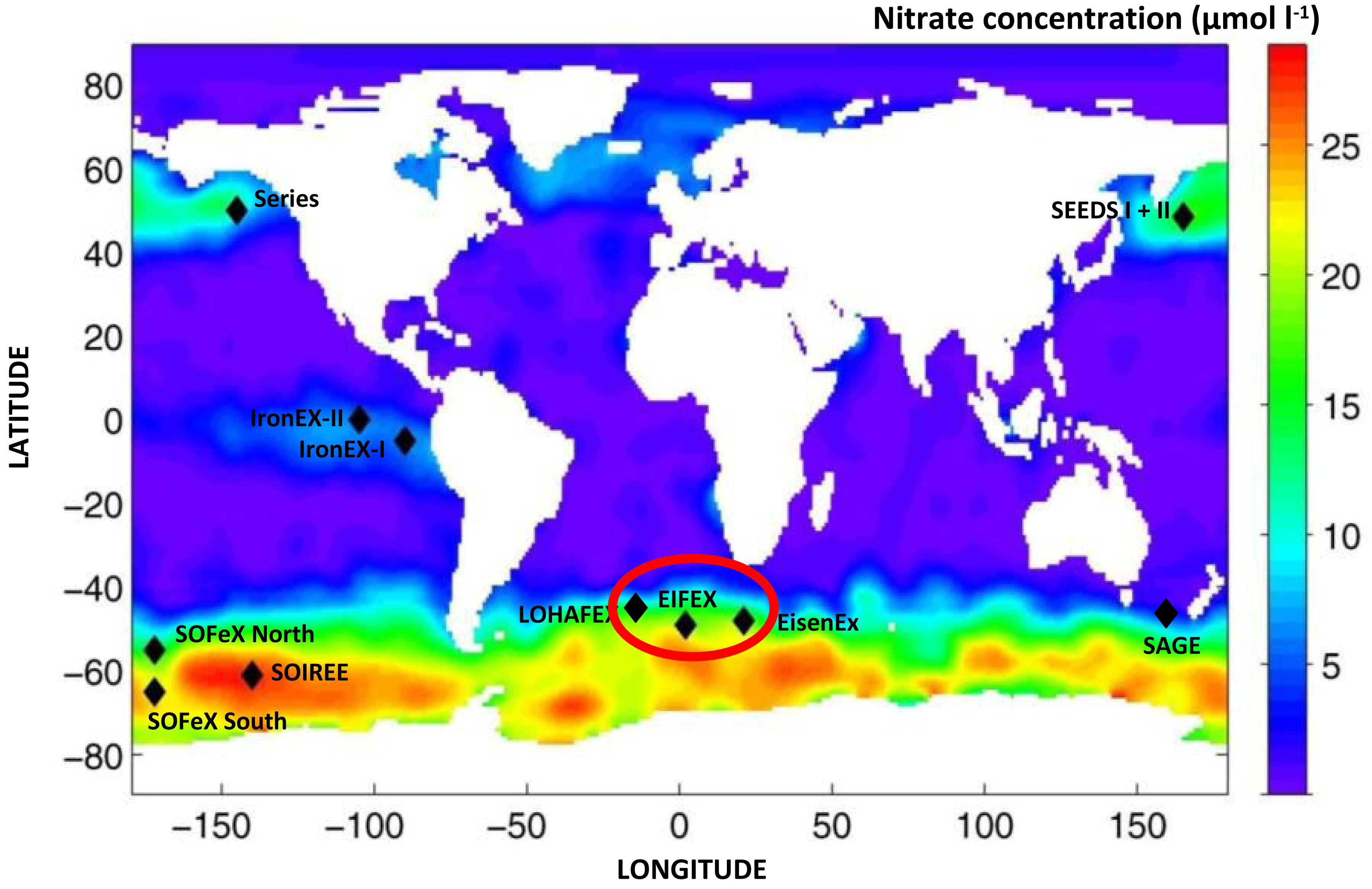
The image shows the potential effect of a sea level rise of 1m by 2100 for the coastline between Zeebrugge and Calais. Developing appropriate sea defences will prevent flooding.



Geoengineering the climate



In situ iron fertilization experiments have confirmed the first tenet of John Martin's iron hypothesis



First evidence for the second tenet of the iron hypothesis

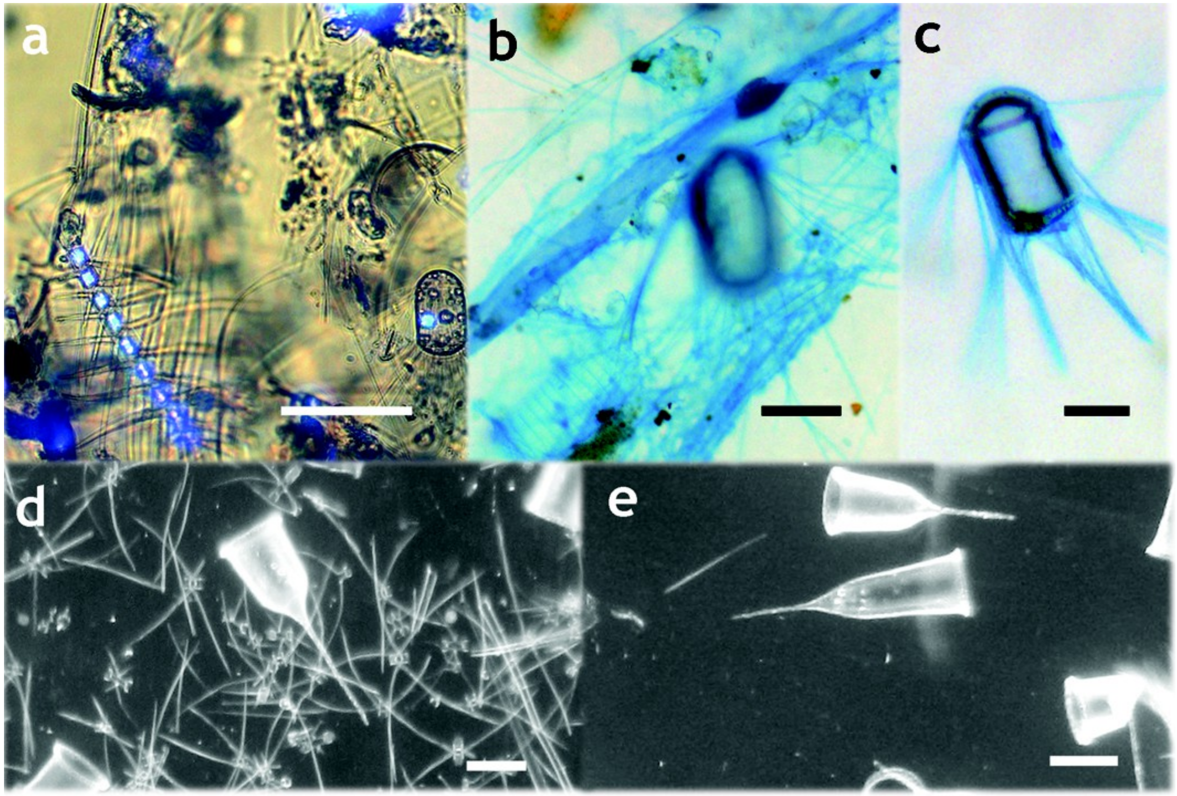
ARTICLE

Nature 2012

doi:10.1038/nature11229

Deep carbon export from a Southern Ocean iron-fertilized diatom bloom

Victor Smetacek[1,2]*, Christine Klaas[1]*, Volker H. Strass[1], Philipp Assmy[1,3], Marina Montresor[4], Boris Cisewski[1,5], Nicolas Savoye[6,7], Adrian Webb[8], Francesco d'Ovidio[9], Jesús M. Arrieta[10,11], Ulrich Bathmann[1,12], Richard Bellerby[13,14], Gry Mine Berg[15], Peter Croot[16,17], Santiago Gonzalez[10], Joachim Henjes[1,18], Gerhard J. Herndl[10,19], Linn J. Hoffmann[16], Harry Leach[20], Martin Losch[1], Matthew M. Mills[15], Craig Neill[13,21], Ilka Peeken[1,22], Rüdiger Röttgers[23], Oliver Sachs[1,24], Eberhard Sauter[1], Maike M. Schmidt[25], Jill Schwarz[1,26], Anja Terbrüggen[1] & Dieter Wolf-Gladrow[1]



European Iron Fertilisation Experiment

EIFEX

ANT XXI/3

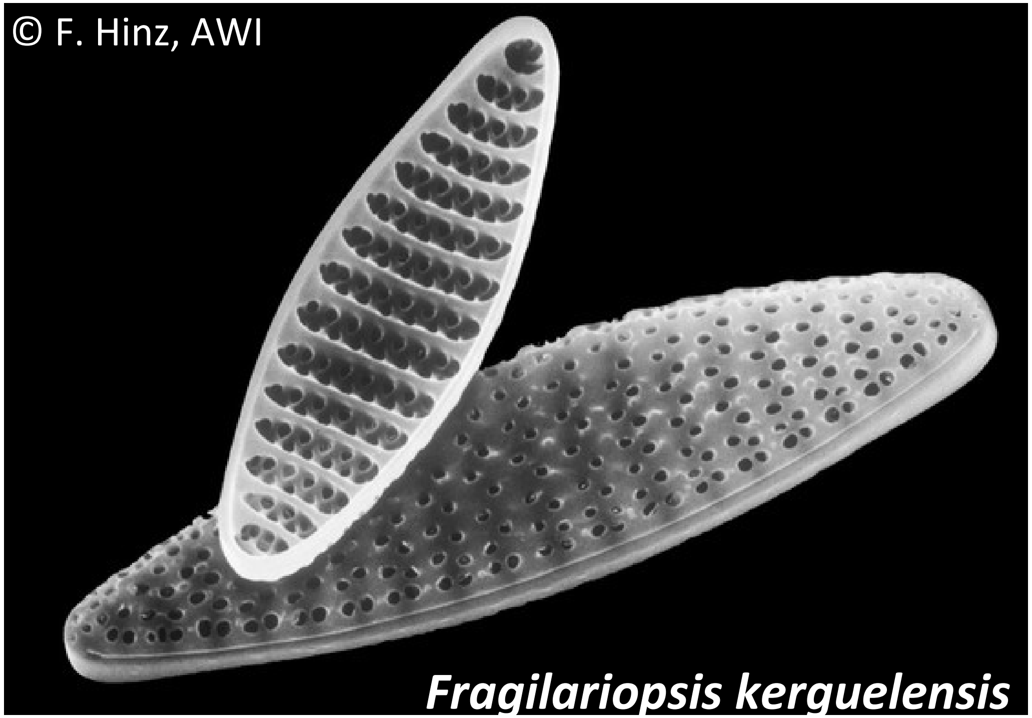
21.01.-25.03.2004

AWI - BCCR - GKSS - ICM-CSIC - IFM-GEOMAR- NIOZ - NTNU - SZN - TU-HH - UCT - UEA - Uni-L - VUB

Thick-shelled, grazer-protected diatoms decouple ocean carbon and silicon cycles in the iron-limited Antarctic Circumpolar Current

PNAS 2013

Philipp Assmy[a,b,1], Victor Smetacek[b,c,1], Marina Montresor[d], Christine Klaas[b], Joachim Henjes[b], Volker H. Strass[b], Jesús M. Arrieta[e,f], Ulrich Bathmann[b,g], Gry M. Berg[h], Eike Breitbarth[i], Boris Cisewski[b,j], Lars Friedrichs[b], Nike Fuchs[b], Gerhard J. Herndl[e,k], Sandra Jansen[b], Sören Krägefsky[b], Mikel Latasa[l,m], Ilka Peeken[b,n], Rüdiger Röttgers[o], Renate Scharek[l,m], Susanne E. Schüller[p], Sebastian Steigenberger[b,q], Adrian Webb[r], and Dieter Wolf-Gladrow[b]



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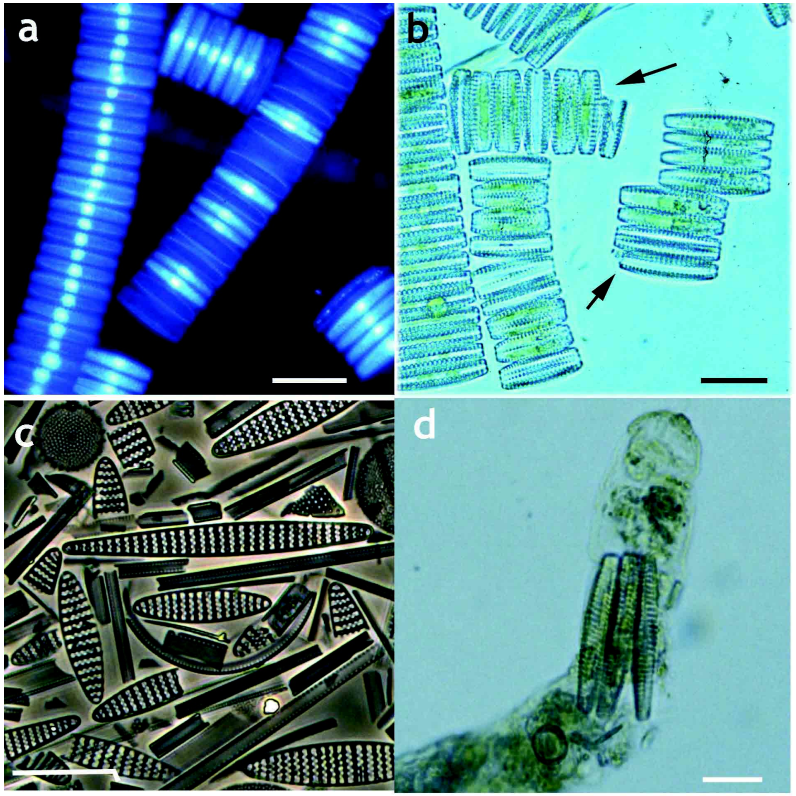
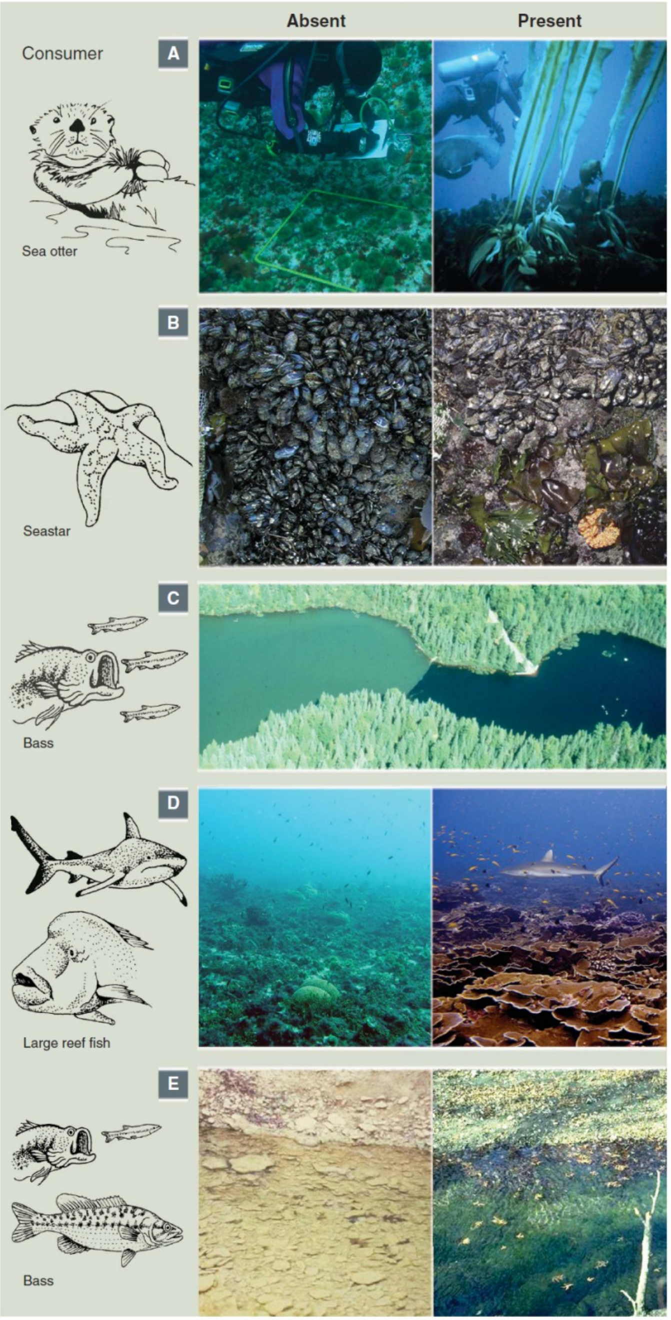
Fragilariopsis kerguelensis





The loss of apex consumers reduces food chain length, thus altering the intensity of herbivory and the abundance and composition of plants in largely predictable ways (*10*). The transitions in ecosystems that characterize such changes are often abrupt, are sometimes difficult to reverse, and commonly lead to radically different patterns and pathways of energy and material flux and sequestration.

The Cryptic Nature of Trophic Downgrading

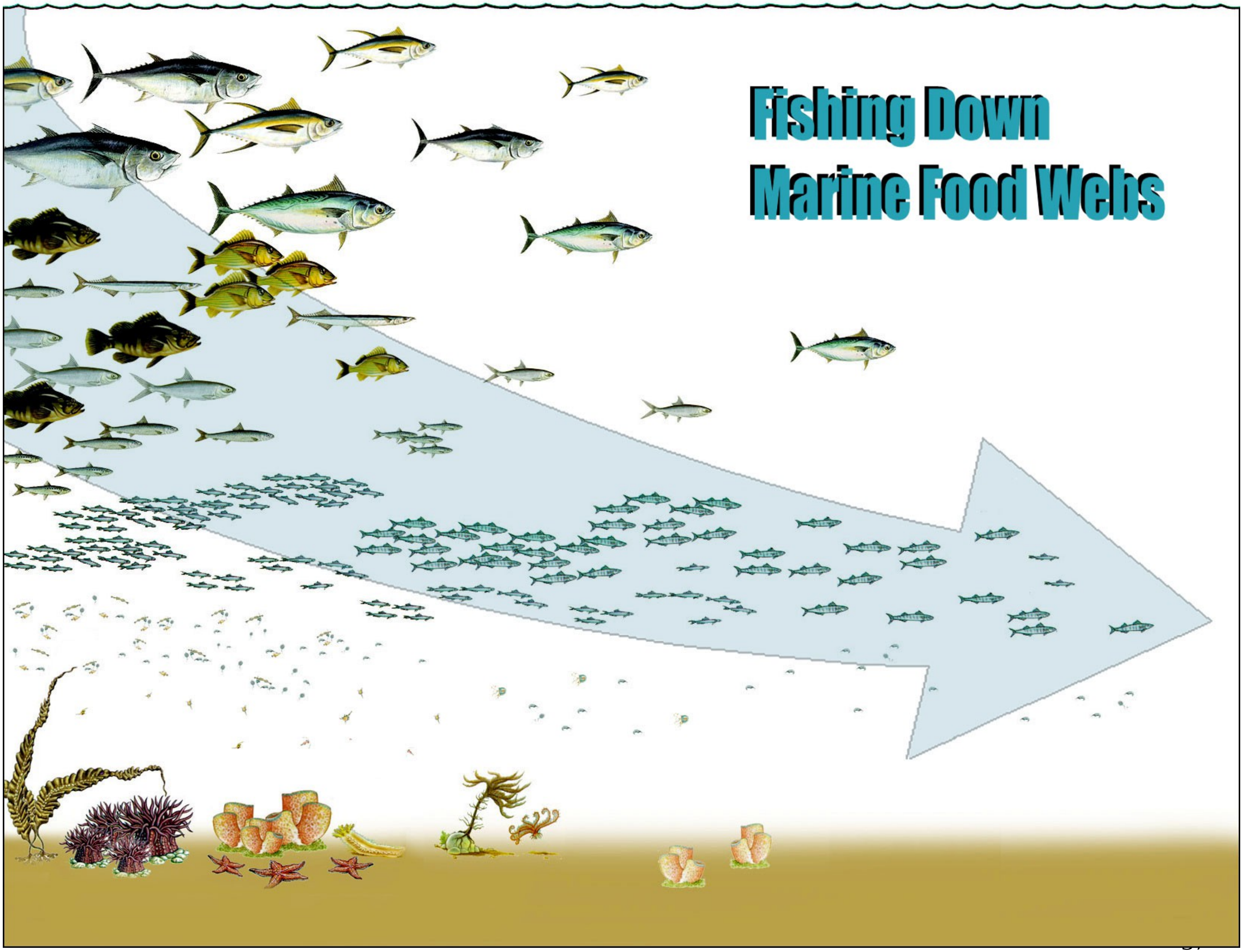
The omnipresence of top-down control in ecosystems is not widely appreciated because several of its key components are difficult to observe. The main reason for this is that species interactions, which are invisible under static or equilibrial conditions, must be perturbed if one is to witness and describe them. Even with such perturbations, responses to the loss or addition of a species may require years or decades to become evident because of the long generation times of some species. Adding to these difficulties is the fact that populations of large apex consumers have long been reduced or extirpated from much of the world. The irony of this latter situation is that we often cannot unequivocally see the effects of large apex consumers until after they have been lost from an ecosystem, at which point the capacity to restore top-down control has also been lost. Another difficulty is that many of the processes associated with trophic downgrading occur on scales of tens to thousands of square kilometers, whereas most empirical studies of species interactions have been done on small or weakly motile species

Fig. 1. Landscape-level effects of trophic cascades from five selected freshwater and marine ecosystems. (**A**) Shallow seafloor community at Amchitka Island (Aleutian archipelago) before (1971; photo credit: P. K. Dayton) and after (2009) the collapse of sea otter populations. Sea otters enhance kelp abundance (right) by limiting herbivorous sea urchins (left) (*20*). (**B**) A plot in the rocky intertidal zone of central California before (September 2001, right) and after (August 2003, left) seastar (*Pisaster ochraceous*) exclusion. *Pisaster* increases species diversity by preventing competitive dominance of mussels. [Photo credits: D. Hart] (**C**) Long Lake (Michigan) with largemouth bass present (right) and experimentally removed (left). Bass indirectly reduce phytoplankton (thereby increasing water clarity) by limiting smaller zooplanktivorous fishes, thus causing zooplankton to increase and phytoplankton to decline (*26*). (**D**) Coral reef ecosystems of uninhabited Jarvis Island (right, unfished) and neighboring Kiritimati Island (left, with an active reef fishery). Fishing alters the patterns of predation and herbivory, leading to shifted benthic dynamics, with the competitive advantage of reef-building corals and coralline algae diminished in concert with removal of large fish (*66*). (**E**) Pools in Brier Creek, a prairie margin stream in south-central Oklahoma with (right) and lacking (left) largemouth and spotted bass. The predatory bass extirpate herbivorous minnows, promoting the growth of benthic algae (*67*).

Trophic Downgrading of Planet Earth

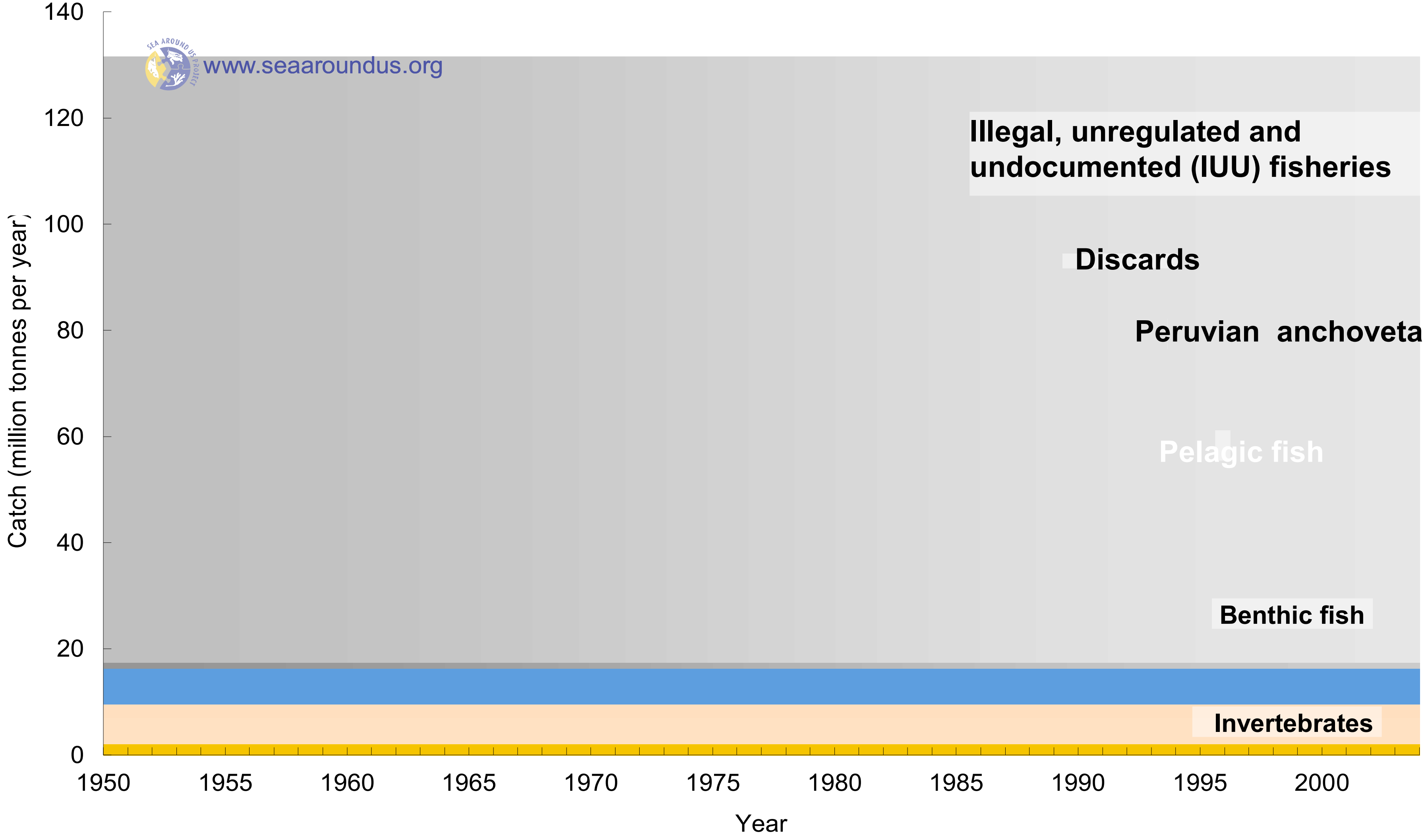
James A. Estes,[1*] John Terborgh,[2] Justin S. Brashares,[3] Mary E. Power,[4] Joel Berger,[5] William J. Bond,[6] Stephen R. Carpenter,[7] Timothy E. Essington,[8] Robert D. Holt,[9] Jeremy B. C. Jackson,[10] Robert J. Marquis,[11] Lauri Oksanen,[12] Tarja Oksanen,[13] Robert T. Paine,[14] Ellen K. Pikitch,[15] William J. Ripple,[16] Stuart A. Sandin,[10] Marten Scheffer,[17] Thomas W. Schoener,[18] Jonathan B. Shurin,[19] Anthony R. E. Sinclair,[20] Michael E. Soulé,[21] Risto Virtanen,[22] David A. Wardle[23]

Fishing Down Marine Food Webs



Slide courtesy Daniel Pauly

World fishery yields



Slide courtesy Daniel Pauly

COMMENTARY

When will we tame the oceans?

In fisheries across the world, fish stocks are declining fast. Future preservation and management of the ocean's resources will require a transformation of our relationship with the seas, argues **John Marra**.

KONA BLUE WATER FARMS

Fishing in the ocean is no longer sustainable. Worldwide, we have failed to manage the ocean's fisheries — in a few decades, there may be no fisheries left to manage[1]. So what should be done?

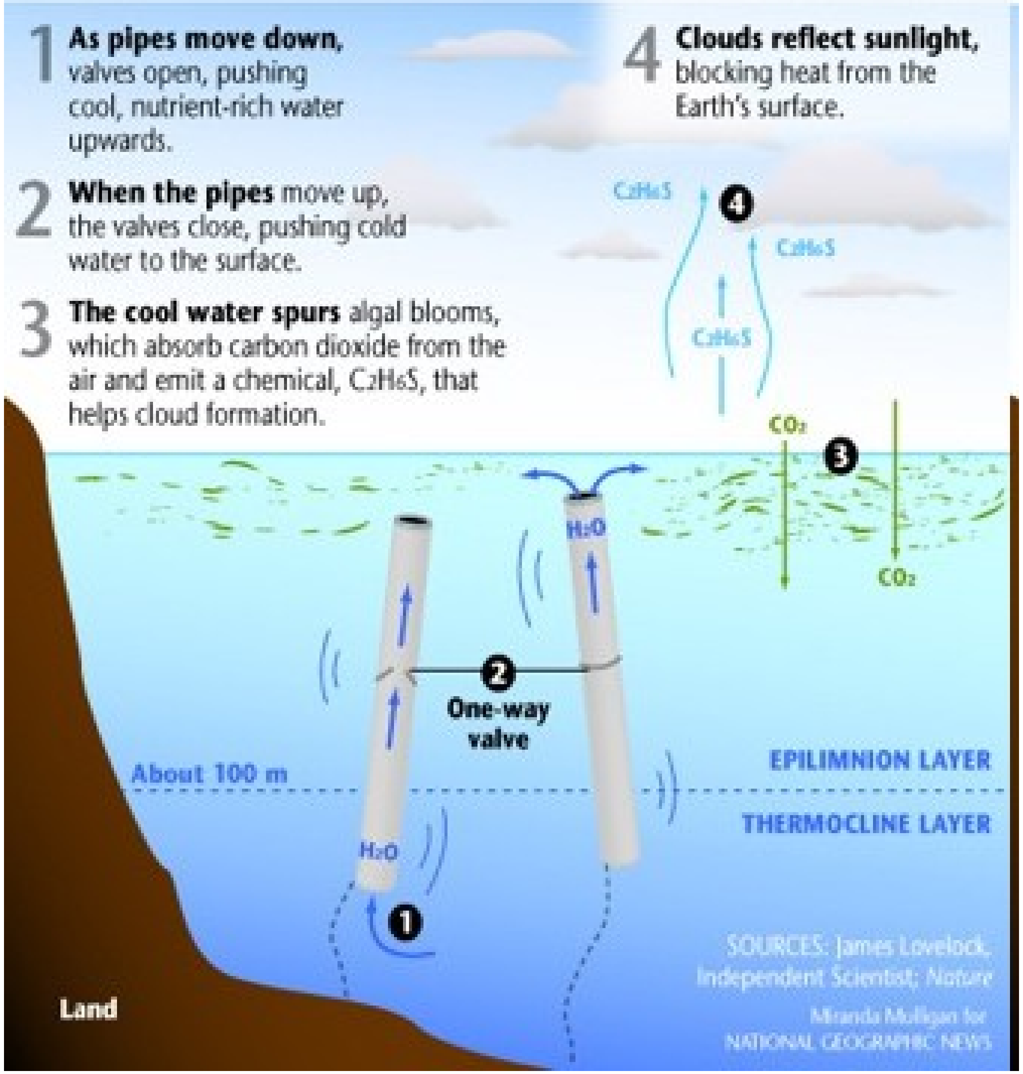
Following the cultivation of land for food, society must take the next step: largescale domestication of the ocean. Last month, the US National Oceanographic and Atmospheric Administration proposed legislation to expand fish farming in US federal waters up to 200 miles from the coast, and to increase the numbers of species that can be farmed. Many reacted with dismay to this announcement[2]. But I believe these people are ignoring the inevitable.

Aquaculture is entirely responsible for the increase in world fish harvests that has occurred in the past 18 years[3]. We have already accepted domestication of the land; now is the time to accept the same for the seas. The land

ONAL

Warming Fix Proposed: Giant Ocean Tubes

Two British scientists say putting thousands of giant pipes in the ocean can fix global warming. But many experts say the proposal may make the problem worse.



1 **As pipes move down,** valves open, pushing cool, nutrient-rich water upwards.

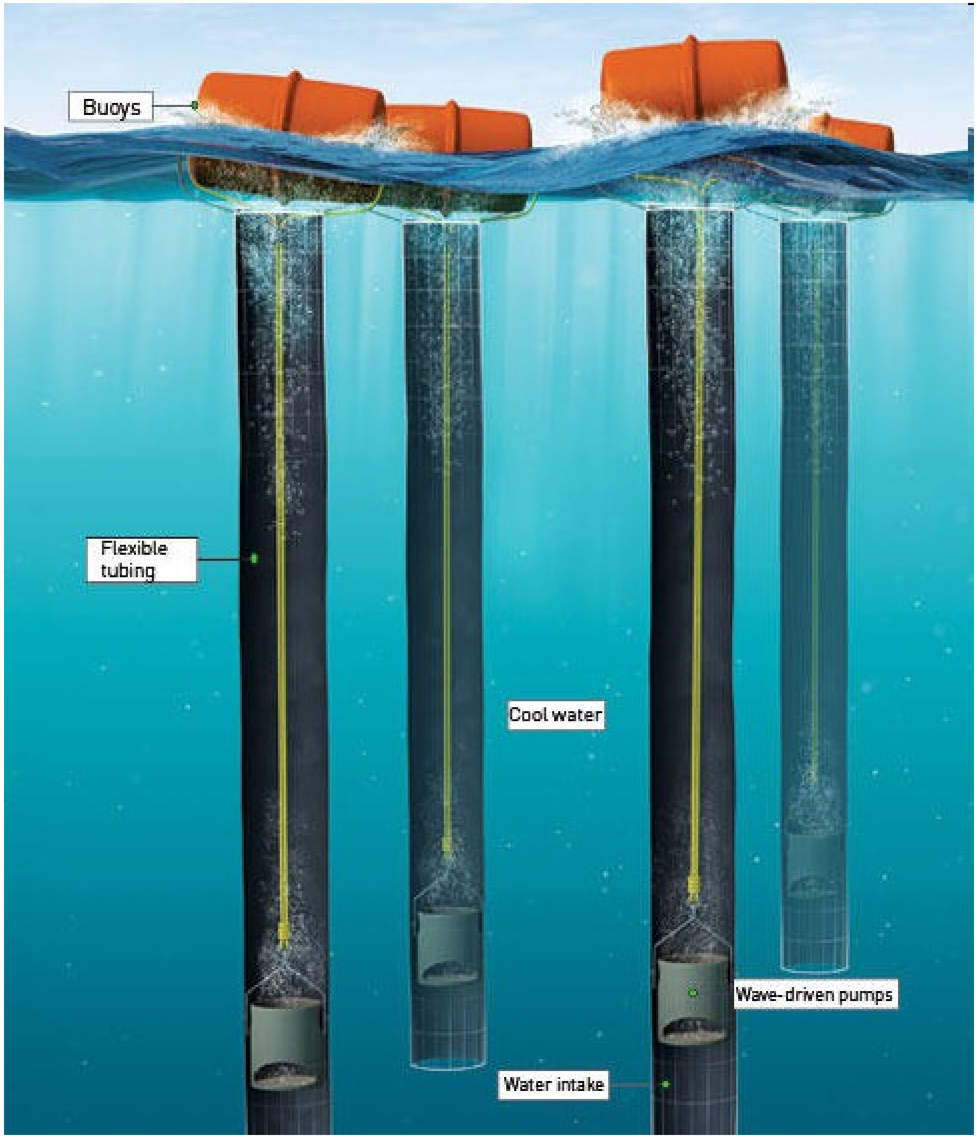
2 **When the pipes** move up, the valves close, pushing cold water to the surface.

3 **The cool water spurs** algal blooms, which absorb carbon dioxide from the air and emit a chemical, C_2H_6S, that helps cloud formation.

4 **Clouds reflect sunlight,** blocking heat from the Earth's surface.

SOURCES: James Lovelock, Independent Scientist; *Nature*

Miranda Mulligan for NATIONAL GEOGRAPHIC NEWS



gcaptain.com/maritime/blog/tubes-in-the-ocean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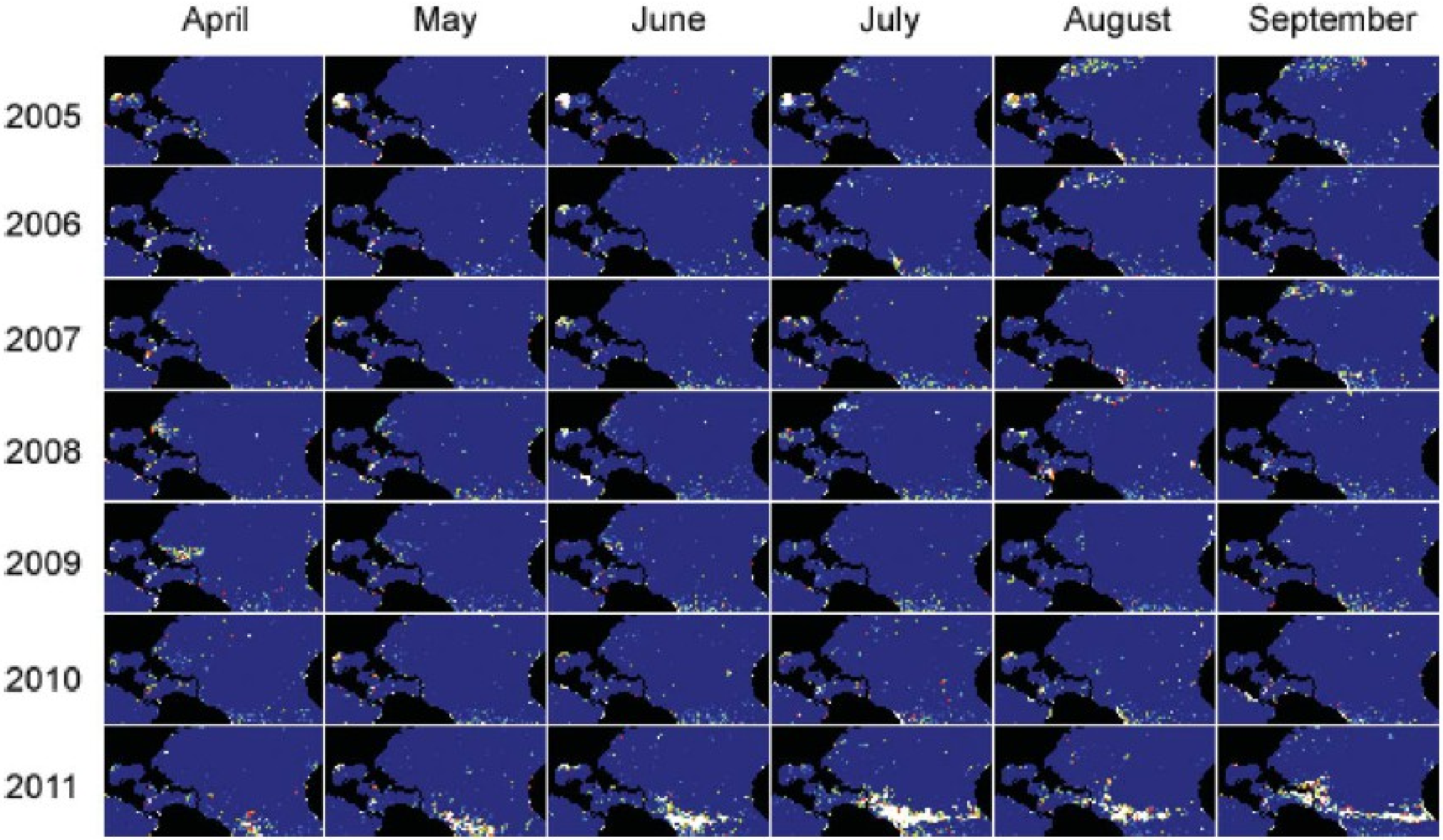
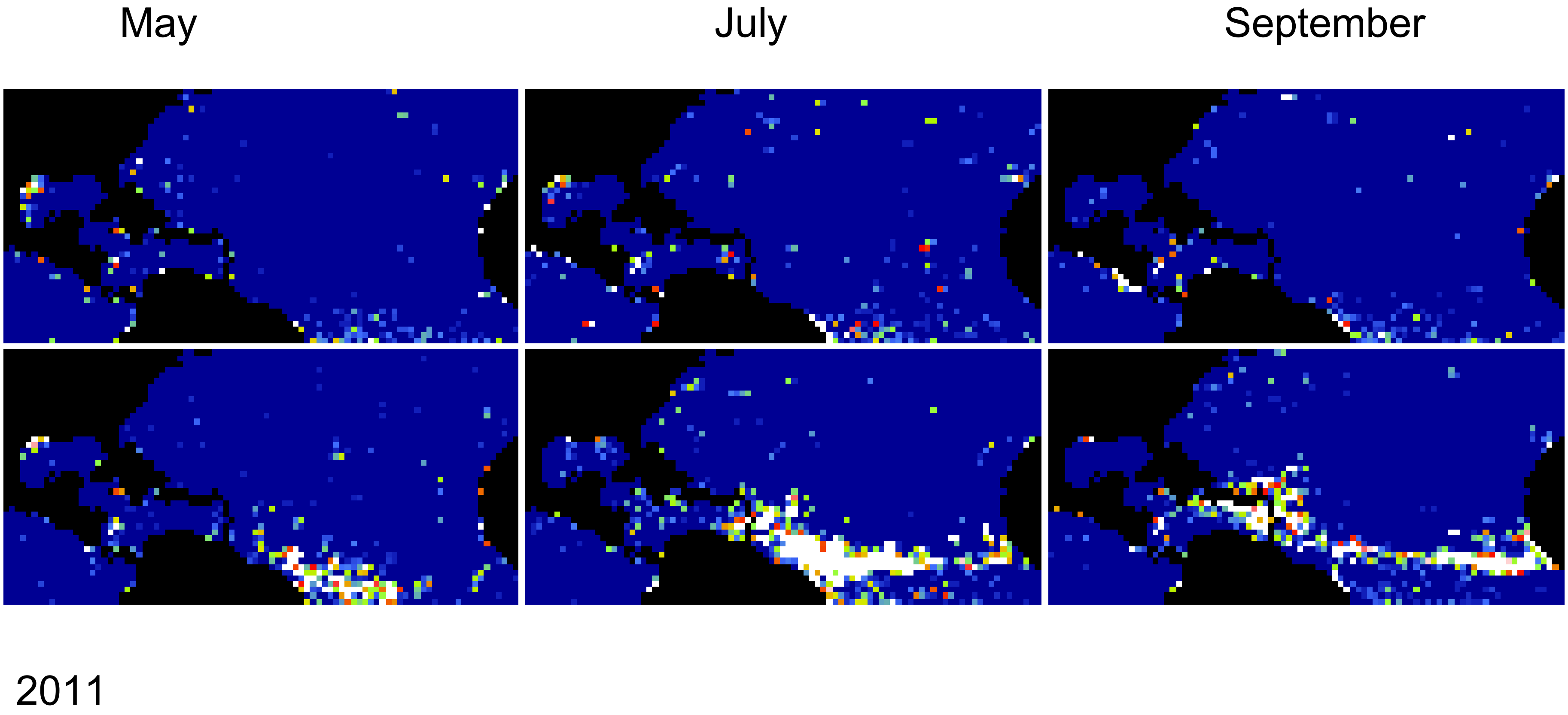


JIM GOWER*†, ERIKA YOUNG‡ and STEPHANIE KING§

Remote Sensing Letters, 2013

Sargassum concentrations measured by satellite



New Sargassum source

Gower et al. 2013

AGU ASLO Ocean Sciences Meeting 21 – 26 February 2016

Special Session: OCEAN-ATMOSPHERE SYSTEM GEOENGINEERING: BENEFITS AND DETRIMENTS

Further topics include but are not limited to:

Advances in the methodology of artificial upwelling with potential applications in marine aquaculture and fisheries;

Ocean iron fertilization for CO2 sequestration;

Cooling the ocean for hurricane mitigation and climate modification.

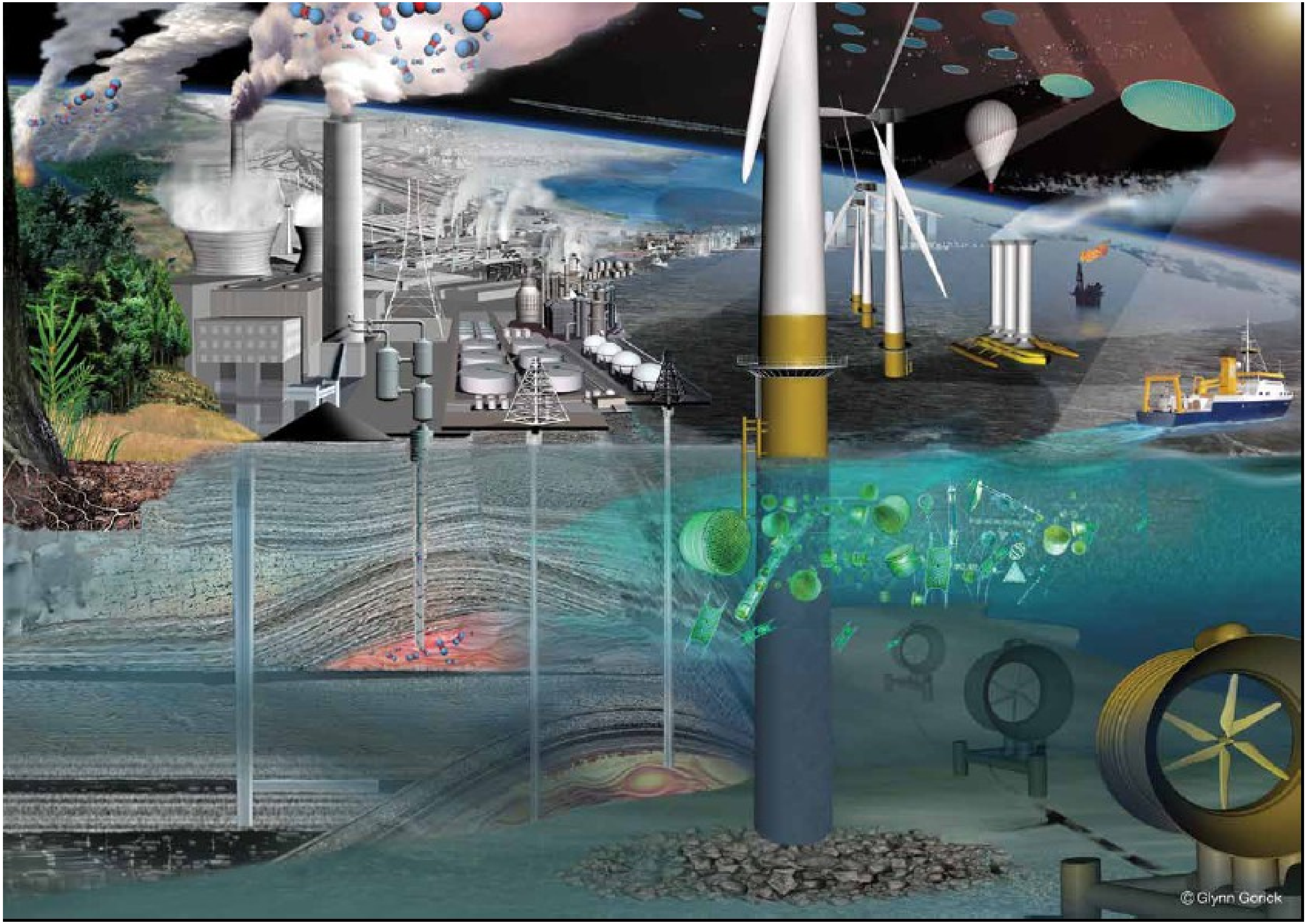
Vol 466|29 July 2010|doi:10.1038/nature09268

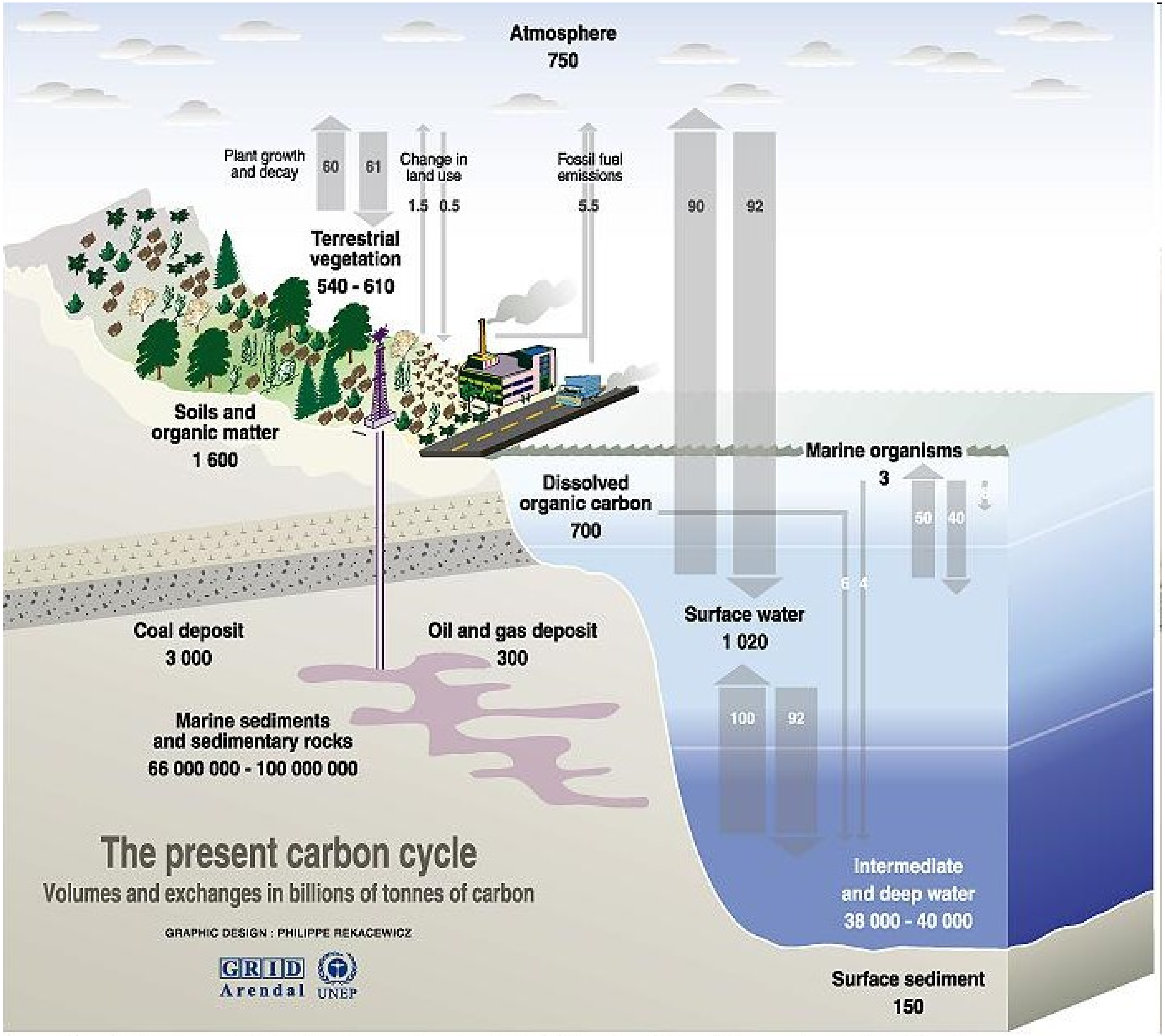
Global phytoplankton decline over the past century

Daniel G. Boyce[1], Marlon R. Lewis[2] & Boris Worm[1]

In the oceans, ubiquitous microscopic phototrophs (phytoplankton) account for approximately half the production of organic matter on Earth. Analyses of satellite-derived phytoplankton concentration (available since 1979) have suggested decadal-scale fluctuations linked to climate forcing, but the length of this record is insufficient to resolve longer-term trends. Here we combine available ocean transparency measurements and *in situ* chlorophyll observations to estimate the time dependence of phytoplankton biomass at local, regional and global scales since 1899. We observe declines in eight out of ten ocean regions, and estimate a global rate of decline of ~1% of the global median per year. Our analyses further reveal interannual to decadal phytoplankton fluctuations superimposed on long-term trends. These fluctuations are strongly correlated with basin-scale climate indices, whereas long-term declining trends are related to increasing sea surface temperatures. We conclude that global phytoplankton concentration has declined over the past century; this decline will need to be considered in future studies of marine ecosystems, geochemical cycling, ocean circulation and fisheries.

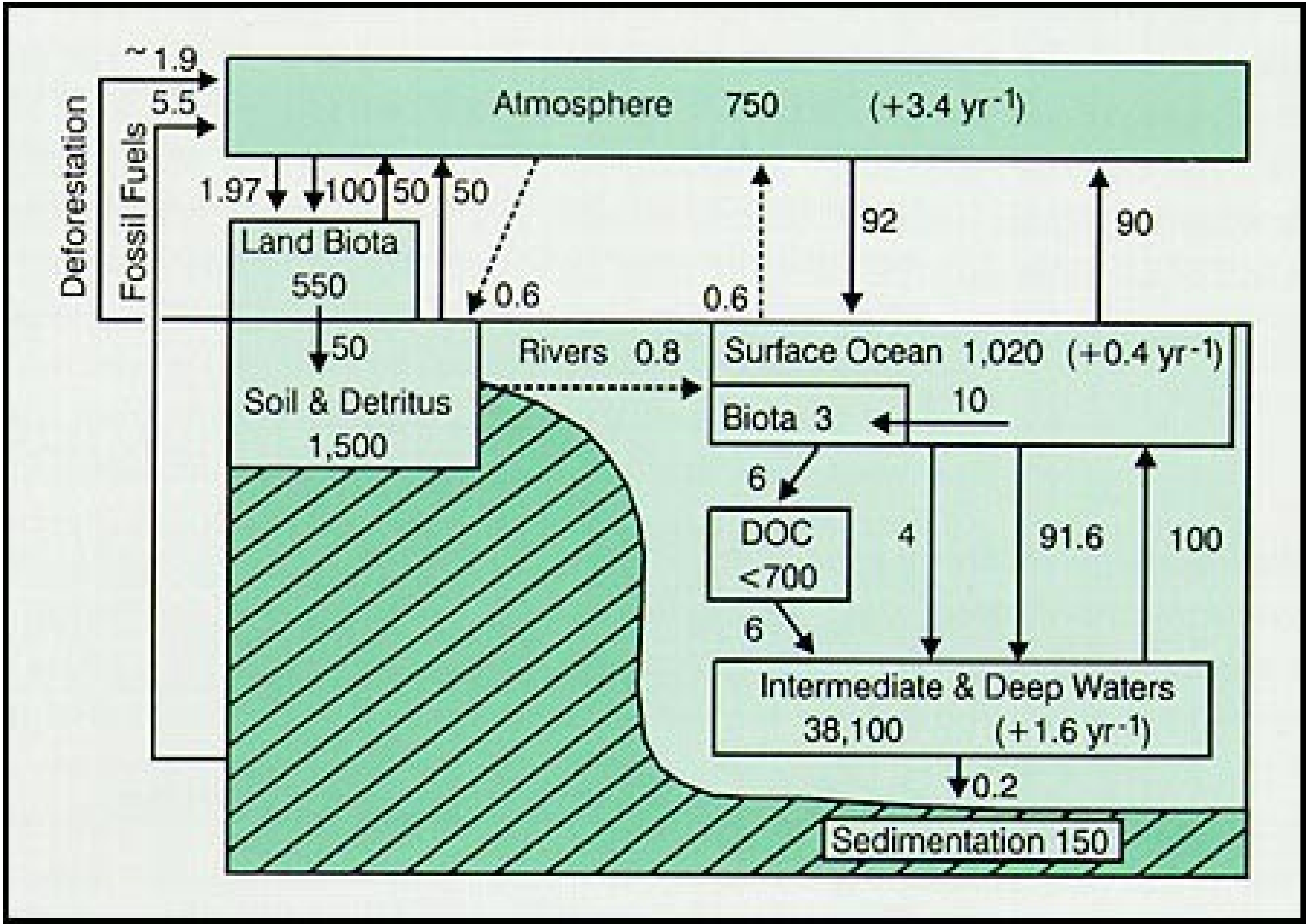
Marine energy and geoengineering





Sources: Center for climatic research, Institute for environmental studies, university of Wisconsin at Madison; Okanagan university college in Canada, Department of geography; World Watch, November-December 1998; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

Current global carbon cycle in billion tonnes (10^9 = Gigatonnes)



WORLD VIEW *A personal take on events*

Be persuasive. Be brave. Be arrested (if necessary)

A resource crisis exacerbated by global warming is looming, argues financier **Jeremy Grantham**. *More scientists must speak out.*

I have yet to meet a climate scientist who does not believe that global warming is a worse problem than they thought a few years ago. The seriousness of this change is not appreciated by politicians and the public. The scientific world carefully measures the speed with which we approach the cliff and will, no doubt, carefully measure our rate of fall. But it is not doing enough to stop it. I am a specialist in investment bubbles, not climate science. But the effects of climate change can only exacerbate the ecological trouble I see reflected in the financial markets — soaring commodity prices and impending shortages.

My firm warned of vastly inflated Japanese equities in 1989 — the grandmother of all bubbles — US growth stocks in 2000 and everything risky in late 2007. The usual mix of investor wishful thinking and dangerous and cynical encouragement from industrial vested interests made these bubbles possible. Prices of global raw materials are now rising fast. This does not constitute a bubble, however, but is a genuine paradigm shift, perhaps the most important economic change since the Industrial Revolution. Simply, we are running out.

The price index of 33 important commodities declined by 70% over the 100 years up to 2002 — an enormous help to industrialized countries in getting rich. Only one commodity, oil, had been flat until 1972 and then, with the advent of the Organization of the Petroleum Exporting Countries, it began to rise. But since 2002, prices of almost all the other commodities, plus oil, tripled in six years; all without a world war and without much comment. Even if prices fell tomorrow by 20% they would still on average have doubled in 10 years, the equivalent of a 7% annual rise.

IT IS CRUCIAL THAT **SCIENTISTS** SOUND A MORE **REALISTIC,** MORE **DESPERATE,** NOTE ON GLOBAL WARMING.

This price surge is a response to global population growth and the explosion of capital spending in China. Especially dangerous to social stability and human well-being are food prices and food costs. Growth in the productivity of grains has fallen to 1.2% a year, which is exactly equal to the global population growth rate. There is now no safety margin.

Then there is the impending shortage of two fertilizers: phosphorus (phosphate) and potassium (potash). These two elements cannot be made, cannot be substituted, are necessary to grow all life forms, and are mined and depleted. It's a scary set of statements. Former Soviet states and Canada have more than 70% of the potash. Morocco has 85% of all high-grade phosphates. It is the most important quasi-monopoly in economic history.

What happens when these fertilizers run out is a question I can't get satisfactorily answered and, believe me, I have tried. There seems to be only one conclusion: their use must be drastically reduced in the next 20–40 years or we will begin to starve.

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go.nature.com/k8mrbe

The world's blind spot when it comes to the fertilizer problem is seen also in the shocking lack of awareness on the part of governments and the public of the increasing damage to agriculture by climate change; for example, runs of extreme weather that have slashed grain harvests in the past few years. Recognition of the facts is delayed by the frankly brilliant propaganda and obfuscation delivered by energy interests that virtually own the US Congress. (It is not unlike the part played by the financial industry when investment bubbles start to form … but that, at least, is only money.) We need oil producers to leave 80% of proven reserves untapped to achieve a stable climate. As a former oil analyst, I can easily calculate oil companies' enthusiasm to leave 80% of their value in the ground — absolutely nil.

The damaging effects of climate change are accelerating. James Hansen of NASA has screamed warnings for 30 years. Although at first he was dismissed as a madman, almost all his early predictions, disturbingly, have proved conservative in relation to what has actually happened. In 2011, Hansen was arrested in Washington DC, alongside Gus Speth, the retired dean of Yale University's environmental school; Bill McKibben, one of the earliest and most passionate environmentalists to warn about global warming; and my daughter-in-law, all for protesting over a pipeline planned to carry Canadian bitumen to refineries in the United States, bitumen so thick it needs masses of water even to move it. From his seat in jail, Speth said that he had held some important positions in Washington, but none more important than this one.

President Barack Obama missed the chance of a lifetime to get a climate bill passed, and his great environmental and energy scientists John Holdren and Steven Chu went missing in action. Scientists are understandably protective of the dignity of science and are horrified by publicity and overstatement. These fears, unfortunately, are not shared by their opponents, which makes for a rather painful one-sided battle. Overstatement may generally be dangerous in science (it certainly is for careers) but for climate change, uniquely, understatement is even riskier and therefore, arguably, unethical.

It is crucial that scientists take more career risks and sound a more realistic, more desperate, note on the global-warming problem. Younger scientists are obsessed by thoughts of tenure, so it is probably up to older, senior and retired scientists to do the heavy lifting. Be arrested if necessary. This is not only the crisis of your lives — it is also the crisis of our species' existence. I implore you to be brave. ■

Jeremy Grantham *is co-founder and chief investment strategist at GMO, and co-chair of the Grantham Foundation for the Protection of the Environment, in Boston, Massachusetts.*
e-mail: jeremy@granthamfoundation.org

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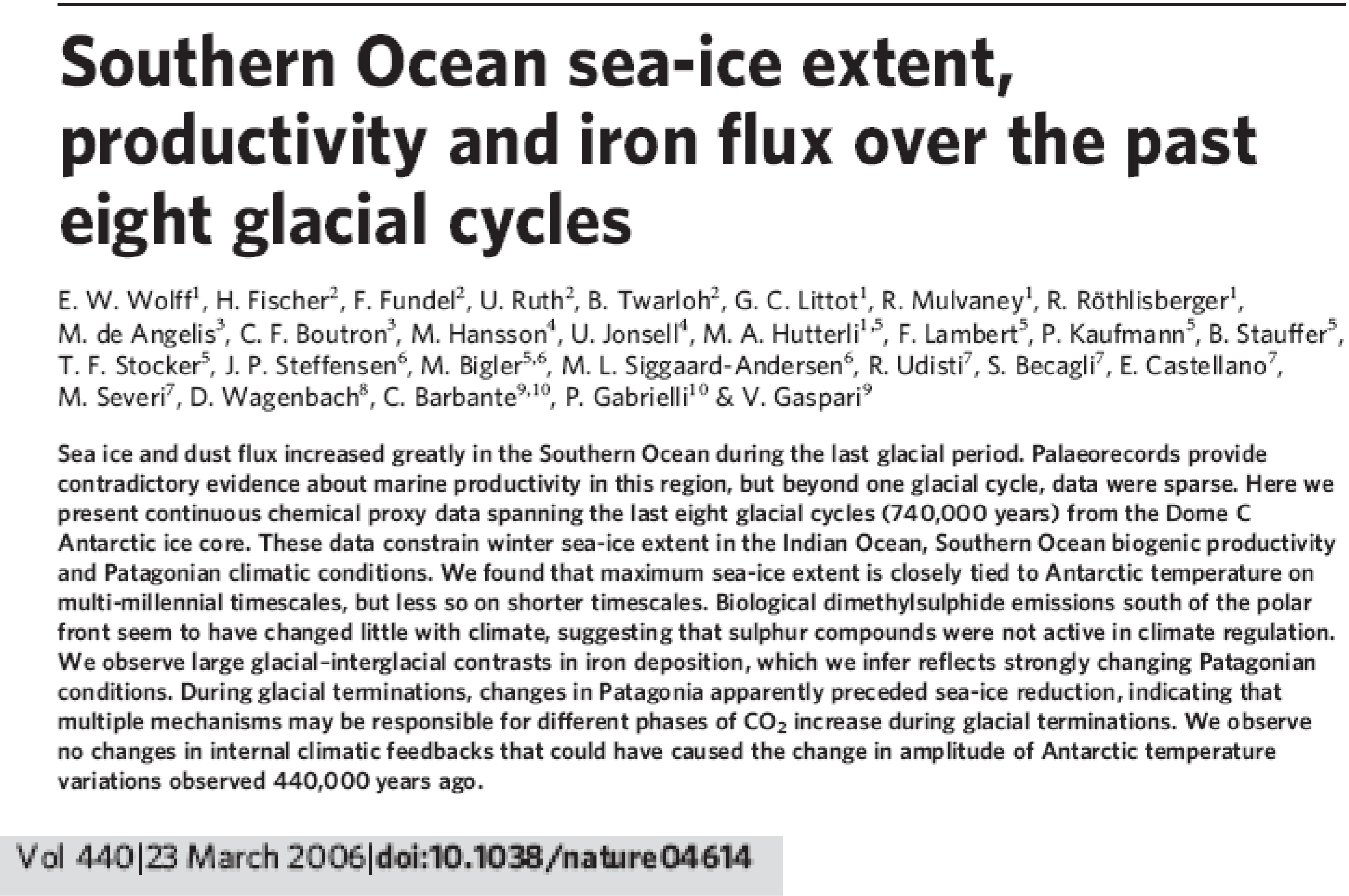

Southern Ocean sea-ice extent, productivity and iron flux over the past eight glacial cycles

E. W. Wolff[1], H. Fischer[2], F. Fundel[2], U. Ruth[2], B. Twarloh[2], G. C. Littot[1], R. Mulvaney[1], R. Röthlisberger[1], M. de Angelis[3], C. F. Boutron[3], M. Hansson[4], U. Jonsell[4], M. A. Hutterli[1,5], F. Lambert[5], P. Kaufmann[5], B. Stauffer[5], T. F. Stocker[5], J. P. Steffensen[6], M. Bigler[5,6], M. L. Siggaard-Andersen[6], R. Udisti[7], S. Becagli[7], E. Castellano[7], M. Severi[7], D. Wagenbach[8], C. Barbante[9,10], P. Gabrielli[10] & V. Gaspari[9]

Sea ice and dust flux increased greatly in the Southern Ocean during the last glacial period. Palaeorecords provide contradictory evidence about marine productivity in this region, but beyond one glacial cycle, data were sparse. Here we present continuous chemical proxy data spanning the last eight glacial cycles (740,000 years) from the Dome C Antarctic ice core. These data constrain winter sea-ice extent in the Indian Ocean, Southern Ocean biogenic productivity and Patagonian climatic conditions. We found that maximum sea-ice extent is closely tied to Antarctic temperature on multi-millennial timescales, but less so on shorter timescales. Biological dimethylsulphide emissions south of the polar front seem to have changed little with climate, suggesting that sulphur compounds were not active in climate regulation. We observe large glacial–interglacial contrasts in iron deposition, which we infer reflects strongly changing Patagonian conditions. During glacial terminations, changes in Patagonia apparently preceded sea-ice reduction, indicating that multiple mechanisms may be responsible for different phases of CO_2 increase during glacial terminations. We observe no changes in internal climatic feedbacks that could have caused the change in amplitude of Antarctic temperature variations observed 440,000 years ago.

Vol 440|23 March 2006|**doi:10.1038/nature04614**

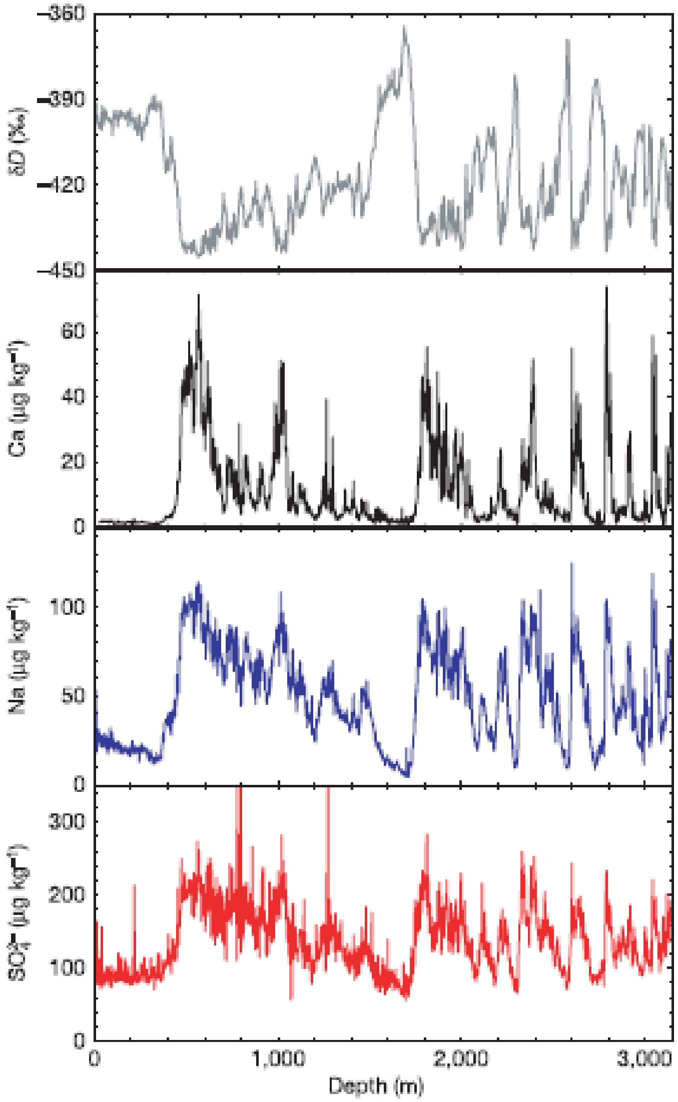

Figure 1 | Measured concentrations from the EPICA Dome C ice core. Data are on an ice depth scale. δ*D* are averaged over 3.85-m sections[6]; chemical concentrations are averaged over 2.2-m sections.

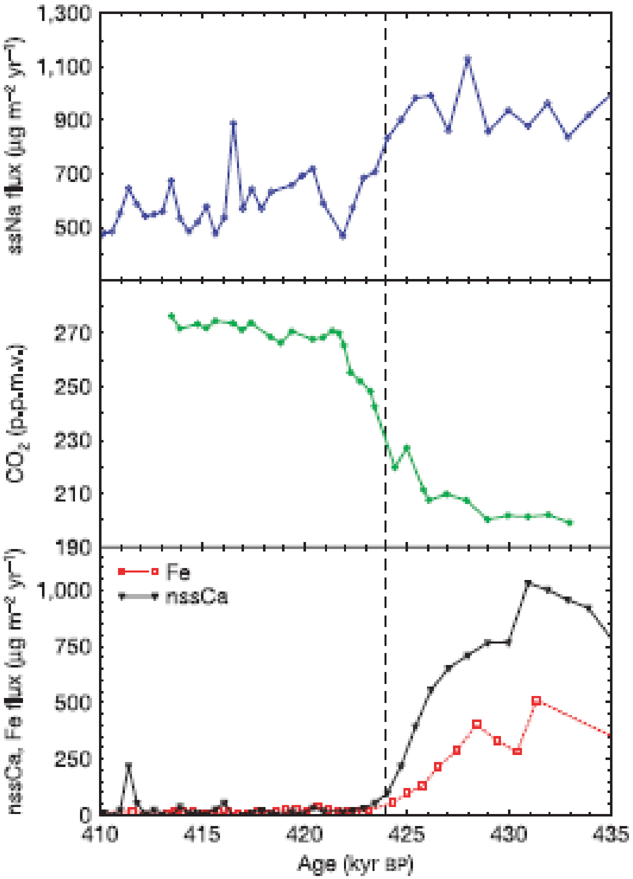

Figure 4 | Chemistry and CO_2 across Termination V. Chemical fluxes (averaged over 1.1 m depth increments, equivalent to a few hundred years at this depth, except for Fe, which consists of spot values at irregular intervals), and CO_2 concentration[6], across Termination V, between MIS12 and MIS11. Uncertainty in the alignment of the timescales for the CO_2 and chemical records is caused by the calculation of the gas-age/ice-age difference[6], and could be several centuries. The vertical dashed line indicates 424 kyr BP (see text).

Wolff et al. Nature 2006

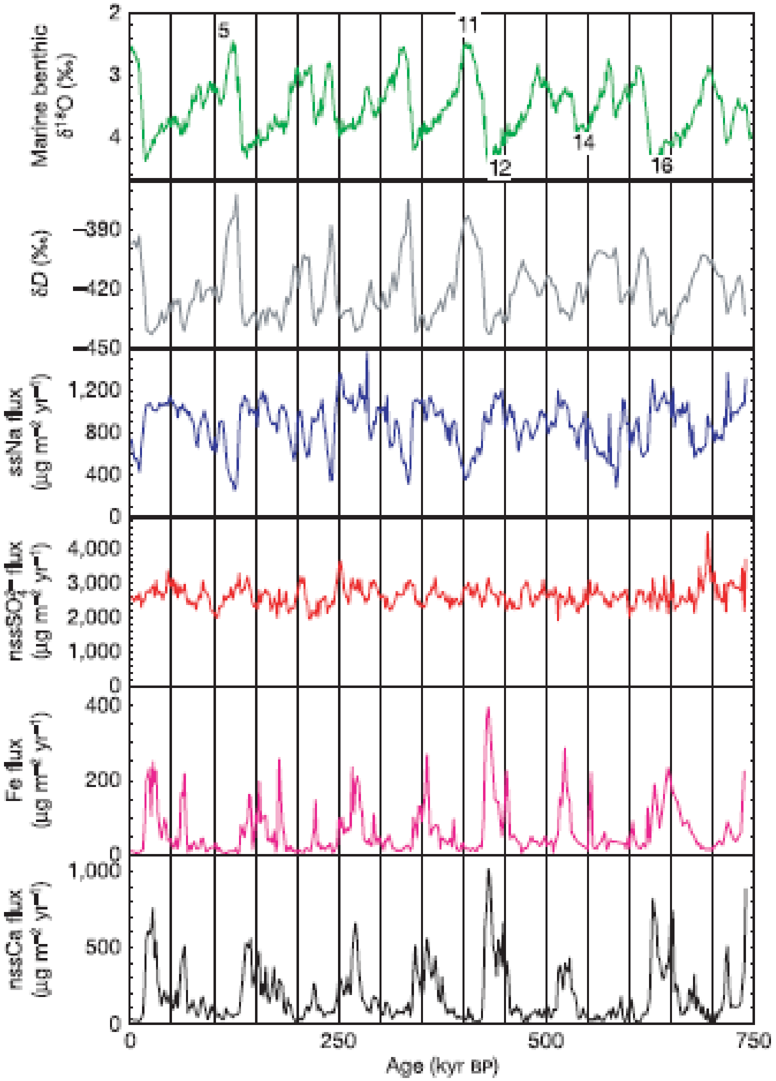

Figure 2 | Chemical measurements from the EPICA Dome C core, on an age scale. Chemical components (2-kyr averages) and δD (3-kyr averages)[6] are from the EDC core; oxygen isotope values (1 kyr averages) from the marine benthic stack (on the LR04 timescale and with selected MIS numbers shown)[39]. While nssCa data represent almost continuous averages within each 2-kyr period, Fe data are averages of a few discrete samples. In the deeper ice, many 2-kyr periods have no Fe data, or are based on a single data point representing only a few decades. The obvious timing mismatch between EDC and the benthic stack around MIS14 is not yet resolved[39].

Wolff et al. Nature 2006

Magic numbers in the biosphere

Glacial/interglacial CO2 concentrations (180 – 290 ppmv)

Glacial/interglacial methane concentrations (350 – 650 ppbv)

Redfield ratios (Pelagic C:N:P 106:16:1)

Deep-sea DOC concentrations (42 μmol l^{-1})

Surface ocean bacterial numbers (10^6 ml^{-1})

Virus:Bacteria ratio (10:1)

Non-sea-salt-sulphate (biogenic) flux to Antarctica (3 mg m^{-2} yr^{-1})

Pallium-feeding by Protoperidinium on Chaetoceros chain

DEAN M. JACOBSON AND DONALD M. ANDERSON

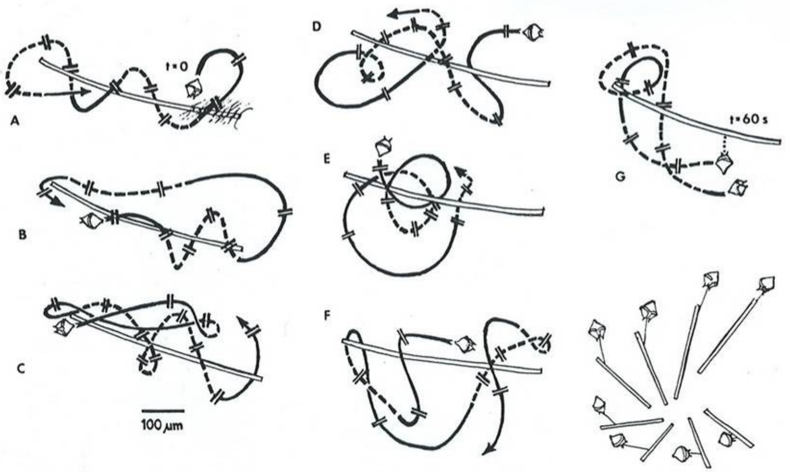

Fig. 1A–F. Sequence of 60 s duration showing swim path of *Protoperidinium spinulosum* immediately prior to capture of *Chaetoceros* chain. Frame A depicts portion of diatom spines. Dashes signify one second intervals. Each frame commences at dinoflagellate symbol (drawn to scale) and concludes with arrow. Dashed lines indicate sawtooth swimming behavior (see text for details). Frame G indicates location of pseudopod attachment. Last frame shows dinoflagellate with slender pseudopodal attachment slowly pulling (foreshortened) diatom.

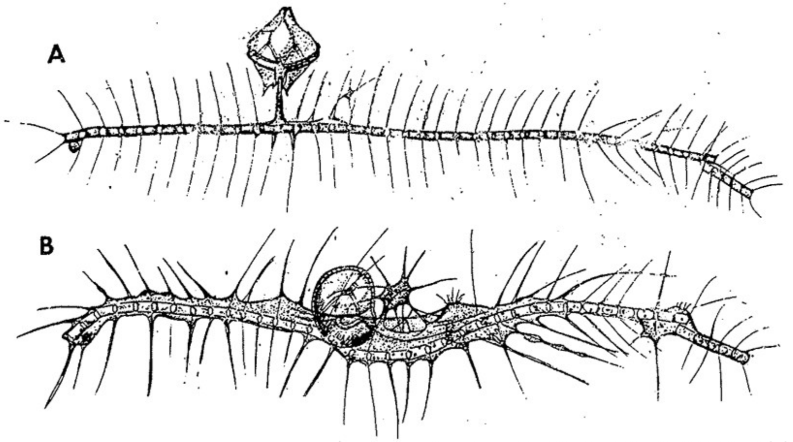

Fig. 22A, B. *Protoperidinium spinulosum* feeding on *Chaetoceros* sp. as drawn from video recording. (*A*) Soon after capture, early in deployment phase. (B) Approx. 15 min later; note formation of lamellipod surrounding 2-cell diatom to right of dinoflagellate.