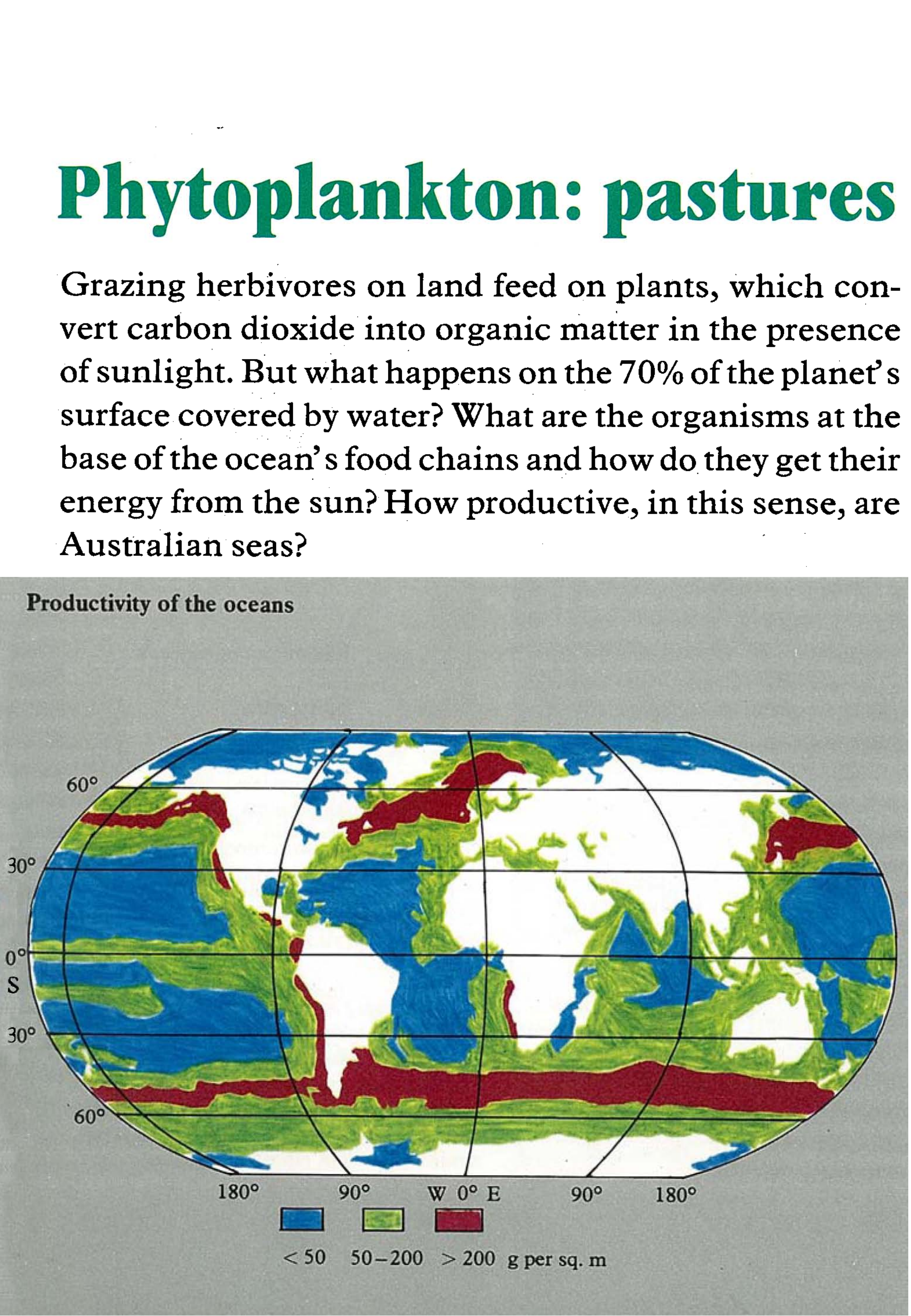
Phytoplankton: pastures of the ocean

Grazing herbivores on land feed on plants, which convert carbon dioxide into organic matter in the presence of sunlight. But what happens on the 70% of the planet's surface covered by water? What are the organisms at the base of the ocean's food chains and how do they get their energy from the sun? How productive, in this sense, are Australian seas?

Productivity of the oceans



Invisible pastures of microscopic floating plant cells contribute 74% of the marine production of organic carbon from photosynthesis. This represents 24% of the total global plant productivity.

By virtue of its size, the open ocean accounts for most marine photosynthesis. However, except in upwelling areas, coastal waters are much more productive on a unit-area basis: the near-shore kelp forests have productivities said to rival those of tropical rainforests, generally considered to be the world's most productive plant ecosystem.

The light-harvesting efficiency of the tiny drifting unicells is impressive. Whereas 90% of the world's chlorophyll in terrestrial plants fixes 64% of the world's carbon by photosynthesis, the 7% chlorophyll in unicellular marine plants fixes as much as 32% of the world's carbon. Marine plant chlorophyll appears six times more effective than terrestrial chlorophyll in fixing carbon.

The sea's primary productivity, in grams of dry matter produced per square metre per year. Areas of upwelling such as that off the western coast of South America and the sub-Antarctic Convergence to the south are among the most productive regions.

The phytoplankton roll-call

Phytoplankton are a diverse group, since they represent the entire evolutionary range of organisms from bacteria to higher plants. They span nine algal divisions, the best-studied being diatoms (12 000 species) and dinoflagellates (2000 species).

Early studies of phytoplankton centred on identification of diatom species, acid-washed to reveal the sculptured structural patterns of the silica walls. Diatoms have a wide variety of shapes and can exist as single cells or in chains. The outer, often pill-box-shaped shell is exquisitely patterned with holes, ribs, spines, and various processes, from which each species is identified. Chain-forming diatoms link up using interlocking processes, or central mucous threads. Diatoms are most successful in coastal waters and upwelling areas.

Pigments in diatoms — chlorophylls *a*, c_1, and c_2, and fucoxanthin with a dash of *beta*-carotene — give them a golden-brown colour.

The dinoflagellates are successful in the deeper oceanic waters because they can survive at lower nutrient levels.

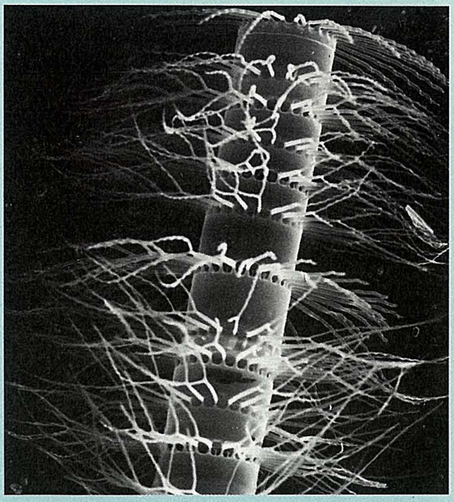
Dinoflagellates are characterized by two flagella, one in a transverse gutter-type girdle around the middle of the cell and one projecting towards the bottom of it. These flagella enable the cell to move up or down, and many species have 'eyespots' that help them move towards or away from light.

The 'armoured' members can be identified by the pattern of cellulose plates, which fit together like jigsaw pieces to encase the living cell. Tropical forms have extensively varied spines, horns, and wings. Some tropical forms with long spines can reach up to 10 times the length of normal cells.

Dinoflagellates have chlorophylls *a* and c_2, *beta*-carotene, and the red carotenoid peridinin. They are the main culprits behind the deadly 'red tides' — blooms of unicells, which are toxic to fish and other marine organisms.

However, only half of the dinoflagellate species are photosynthetic. Colourless dinoflagellates feed on dissolved organic material or graze on smaller cells. Others, containing chlorophyll, live symbiotically with other plants or animals.

The rest of the groups making up the phytoplankton belong largely to the smaller nanoplankton. The best-known are the golden-brown coccolithophorids, whose delicate calcite scales or coccoliths were first discovered in marine sediments as long ago as 1836. At the time, they were thought to be inorganic crystals.



Part of a chain of tropical diatoms, each 0·005 mm in diameter.

Coccoliths are important in the accurate dating of marine sediments in oil exploration. They provide a type of palaeontological indicator, as scientists more accurately estimate the production, transportation, and sedimentation rates of coccoliths from the surface layers of the ocean to the sea floor.

Nobody really knows what value the coccolith scales are to the cell. Candidate theories include a skeleton for the cell, easily discarded ballast for helping it rise through the water, a light-scattering function, or simply God's gift to taxonomists!

Marine plant unicells include the blue-green algae. They are a mainly tropical group, but may form blooms in brackish water such as the Baltic Sea. *Trichodesmium* is a typical species; members of the group resemble bacteria in their lack of membranes around cell components, particularly the DNA; they have no nucleus. They appear blue-green when their blue phycocyanin pigment predominates and pink-beige when the red phycoerythrin predominates. Disintegrating blooms of *Trichodesmium* sp. may colour water pink by releasing the red pigment.

Some blue-green algae can fix atmospheric nitrogen, making them a valuable partner in symbiotic associations with other algae.

It is thought that a process of serial symbioses underlies the evolution of all algae. The theory suggests that mitochondria and chloroplasts inside the cell have evolved from ancient symbiotic associations of bacteria and blue-green algae with colourless cells.

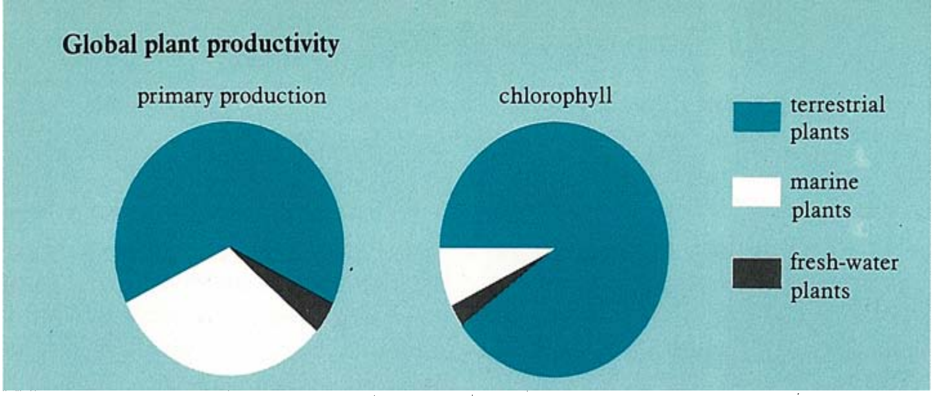
Biochemical evidence supports the theory and further studies of the many examples existing today (involving dinoflagellates, small brown, green, and blue-green algae) may throw more light on the origin of plant cells.

The phytoplankton — systematics, morphology and ultrastructure. S.W. Jeffrey and M. Vesk. In 'Marine Botany', ed. M.N. Clayton and K.J. King. Pages 138–79. (Longman Cheshire: Melbourne 1981.)

Algae found in the marine phytoplankton and their major light-harvesting pigments.

The phytoplankton groups

division	common name	chlorophylls *a*	*b*	*c*	major accessory light-harvesting pigments
Procaryotic					
Cyanophyta	blue-green algae (cyanobacteria)	+			biliproteins
Eucaryotic					
Rhodophyta	red algae	+			biliproteins
Cryptophyta	cryptomonads	+		+	biliproteins
Dinophyta	dinoflagellates	+		+	peridinin
Chrysophyta	golden-brown flagellates, silicoflagellates, chloromonads	+		+	fucoxanthin
Prymnesiophyta	golden-brown flagellates with haptonema, coccolithophorids	+		+	fucoxanthin
Bacillariophyta	diatoms	+		+	fucoxanthin
Euglenophyta	euglenoids	+	+		
Chlorophyta	scaly green flagellates, green algae	+	+		siphonaxanthin (some species only)



Marine plants are more efficient photosynthesizers than are their terrestrial relatives, their 7% of the world's chlorophyll accounting for more than 30% of total plant productivity.

Phytoplankton range in diameter from about one-thousandth of a millimetre up to 2 mm. They can only live in the upper 200 m of the ocean, where light is available for photosynthesis. They have an immense diversity and often bizarre shapes, sometimes carrying long spines, horns, wings, or extended plates. They can be leaf- or needle-shaped, and may occur in ribbon-like chains and colonies.

The most conspicuous groups are the silica-walled 'pillbox' diatoms; the armoured cellulose-walled dinoflagellates, which have whip-like flagella used to propel them through the water; and the beautifully sculptured calcareous coccolithophorids.

Made to wander

Phytoplankton productivity is influenced by light and temperature gradients, the availability of nutrients such as nitrates and phosphates, and the inherent biological rhythms of the unicellular algae themselves. And, of course, grazing animals, such as shrimp-like zooplankton and fish larvae, affect the density of phytoplankton populations.

Plankton comes from the Greek 'planktos' meaning 'made to wander'. All phytoplankton are passengers of the surface currents and upwellings of the great ocean basins, although some, such as dinoflagellates, can move using their flagella.

Water movements occur over a range of scales — from huge currents like the South Equatorial Current wandering vertically and horizontally like huge conveyor belts, through thousands of kilometres, to minute capillary waves, measuring a few centimetres. These movements determine where different phytoplankton communities are found on both vast and minute scales.

Work done by CSIRO and the Royal Australian Naval Research Laboratory between 1960 and 1980 has shown that Australia's near-shore circulation pattern has the eddies and currents shown in the diagram. Most of the waters surrounding Australia are tropical and subtropical. Australia's particular geographic location isolates it from the colder, nutrient-rich sub-Antarctic waters to the south.

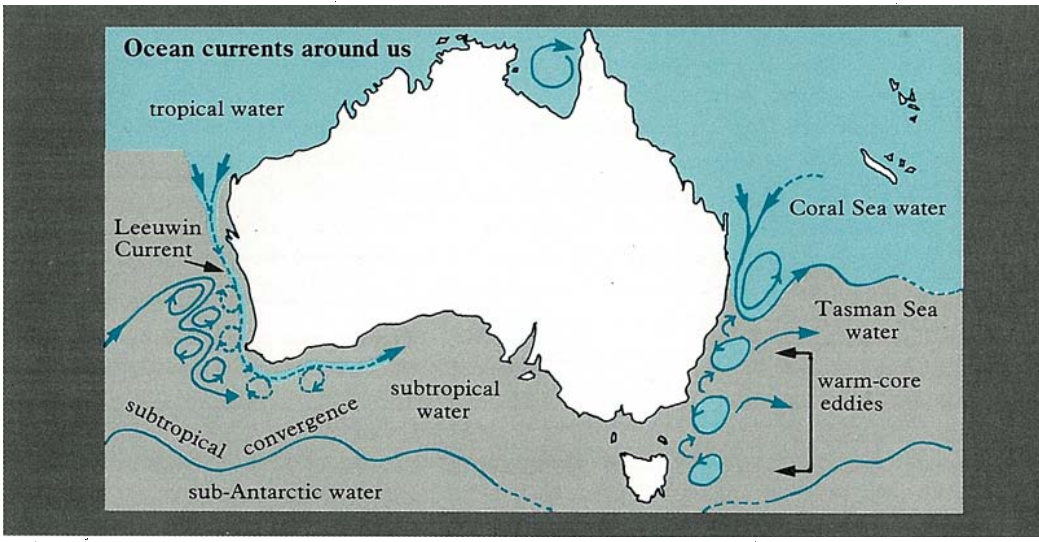
The surface temperature differences over the whole region are thus small compared with the sharp 8–10°C vertical drop in the top 200 metres of the ocean. Relatively sharp temperature gradients can greatly affect the depth at which planktonic plants and animals are found.

The prime stimulus for phytoplankton growth is the continual replenishment of nutrients like inorganic nitrates into the upper lighted layers of the ocean by upwellings or intrusions of some kind. Nutrients are also recycled; studies by Dr Jim McCarthy and Dr Joel Goldman — from Harvard University and Woods Hole Oceanographic Institution, respectively — indicate that organic nitrogen, in the form of urea and ammonium molecules from animal excretion and microbial decomposition, can account for up to 50% of the nitrogen that phytoplankton assimilate.

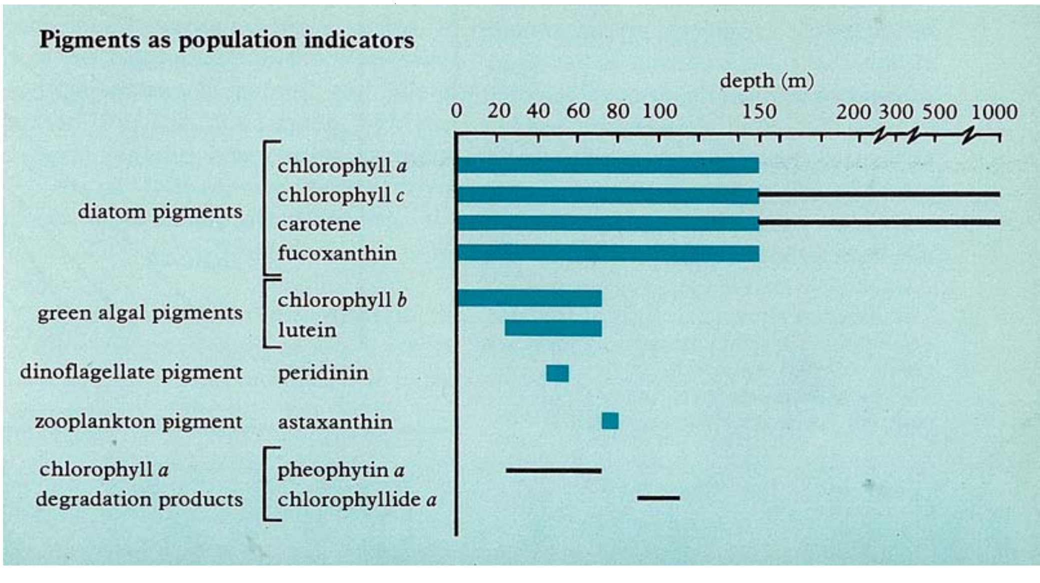
Just as land plants derive nitrates, phosphates, and trace metals from the soil, their planktonic relatives absorb them from the surrounding water. However, as Mr David Rochford, a former scientist of the CSIRO Marine Laboratories, points out, Australian waters are generally low in nutrients compared with seas elsewhere.

A CSIRO study in 1978 showed that one of the main causes of this deficiency was the fact that Australian soils are pretty poor by world standards. Little nutrient en-

How water circulates around Australia during autumn. The East Australian Current flows down the coast and then towards Norfolk Island after eddies have pinched off and moved further south. In the Indian Ocean, the southerly-flowing Leeuwin Current moves between the coast and an eddy field to the west.



Data from chromatograms taken at an eddy centre show the depths at which pigments associated with algae (diatoms, green algae, and dinoflagellates) and zooplankton (copepods) are found. The black bars indicate detrital material, from senescent diatoms and zooplankton faecal pellets.



richment of coastal waters occurs from rivers and surface run-off, which can make a significant contribution in other parts of the globe. Further, large-scale upwellings, which are responsible for many of the world's productive fisheries, do not occur around Australia; and our isolation from the bountiful sub-Antarctic waters has been mentioned.

'Fingerprinting' plankton

Measuring the biomass of innumerable microscopic cells scattered throughout the top layer of the sea would appear to present a problem to marine botanists. Chlorophyll *a*, a green pigment present in all phytoplankton, has become the indicator. Dr Shirley Jeffrey and her team at the CSIRO Division of Fisheries Research developed and applied a number of techniques that measure chlorophyll, using either living plankton in the water or extracts of pigments from filtered cell samples.

To determine 'the lie of the land', scientists use *in vivo* fluorescence, which measures the light energy emitted by chlorophyll during photosynthesis. Water is pumped from the sea surface to an 'on-deck' fluorometer while the research vessel is under way.

This method can be used to scan wide areas for phytoplankton. Vertical measurements can be taken by lowering a special fluorometer to various depths. Satellites are also being used to measure 'ocean colour' over wide areas.

Other more accurate methods require the researcher to extract the pigments from cells. The green chlorophyll *a* can be measured by a spectrophotometer or by chromatography. Chromatography relies on the differences in solubility of pigments in a solvent moving over a thin layer of cellulose — each pigment separates out into a characteristically coloured spot on a chromatogram that displays the cell's full complement of yellow and green pigments. This is the most precise technique of all.

Dr Jeffrey has used thin-layer chromatography to analyse phytoplankton populations at two oceanic sample sites off the New South Wales coast: the CSIRO Port Hacking coastal sample site 30 km from Sydney, which has been studied regularly for 30 years; and East Australian Current eddies off the south-eastern coast.

Because some pigments are specific to the taxonomic divisions of algae, sample

Light on phytoplankton

Imagine living in a world where the sky changed to violet or blue or green when you moved. This effectively happens to phytoplankton as currents continually shift them through variously hued environments.

As soon as it hits the surface of the ocean, white light is scattered and absorbed until, even at a few metres depth, the sea reduces both its colours and its intensity. The total spectrum of radiation at the surface ranges in wavelength from 290 to 3000 nanometres (nano = 10^{-9}); the 350-nm (UV) to 750-nm (far red) region activates photosynthesis. Most of the infra-red and visible red light (wavelengths greater than 700 nm) disappears in the first half metre, then yellow is absorbed, leaving violet and blue-green light (wavelengths less than 480 nm) to reach a maximum depth of 200 m in the clearest ocean water, the 'desert' blue water of the Sargasso Sea.

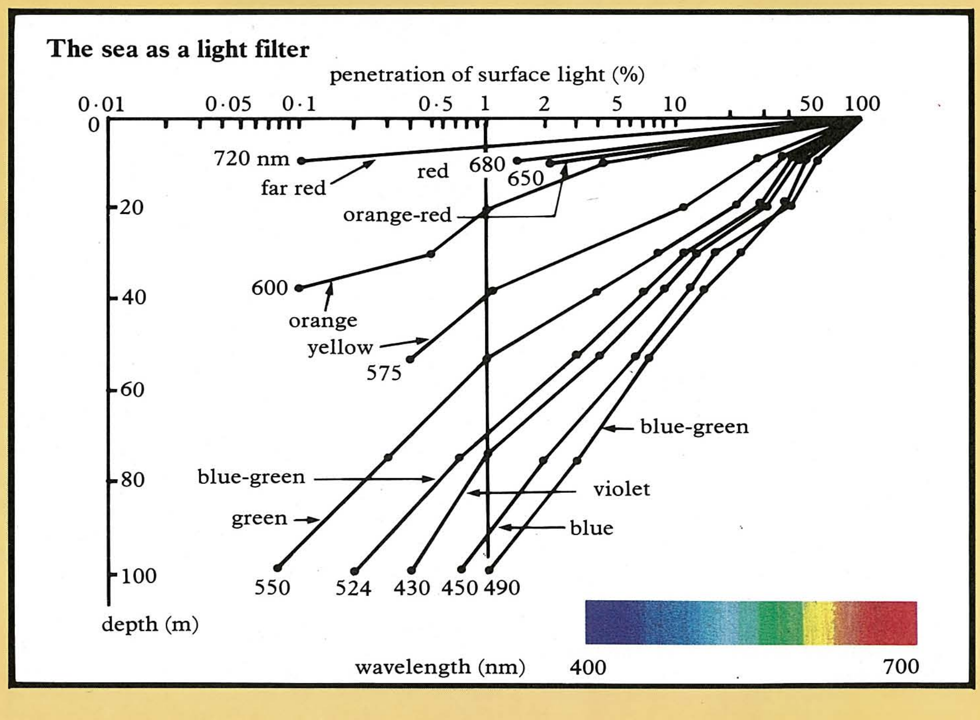
In areas of turbulence, such as upwelling regions, suspended organic matter (including phytoplankton) can strongly absorb the violet and blue-green light, shifting underwater light from blue-green to green and yellow wavelengths, and can reduce the depth of the 'photosynthetic' zone to a few metres.

Dr Jeffrey and Dr Heron have studied the light climate of many coastal and oceanic areas around Australia. All of our offshore waters are similar and, unlike those of other parts of the world, are predominantly blue-green.

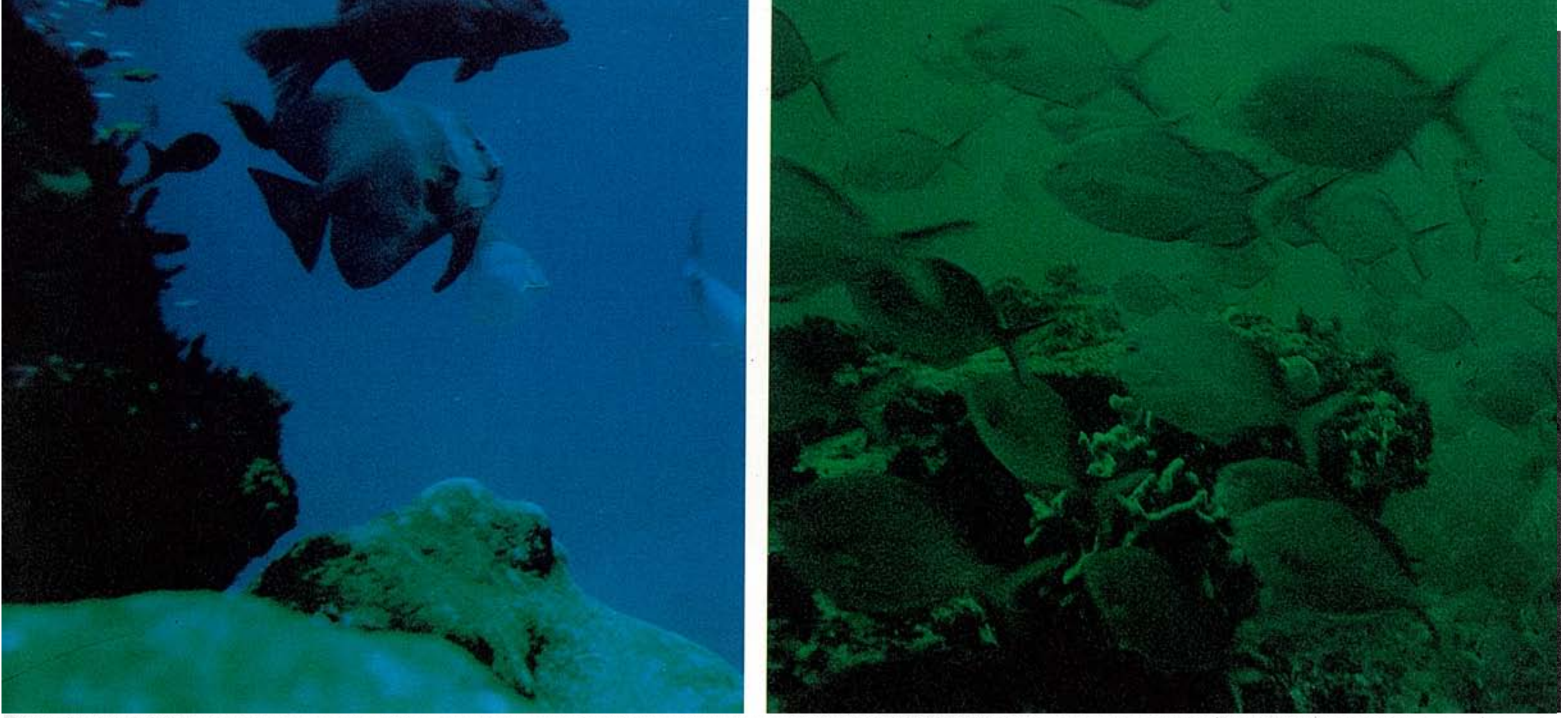
Zones dominated by blue, blue-green, green, yellow, or red exist in different waters. Phytoplankton can drift in and out of any of these regions, so their photosynthetic apparatus needs to adapt quickly to changes in light quality and intensity. In contrast, terrestrial plants bask in the full visible spectrum of white light and utilize only one light-harvesting pigment system.

When they photosynthesize, plants convert carbon dioxide and water to oxygen, carbohydrate, and water, in the presence of light-harvesting pigments and sunlight. In land plants, the photosynthetic pigments involved are the two chlorophylls, *a* and *b*. Chlorophyll *a* is not restricted to land plants, but occurs in all photosynthetic organisms, including seaweeds and phytoplankton.

Phytoplankton prefer to live at depths between 25 and 150 m, levels receiving from 0·01 to 10% of the surface light. The deepest populations live at 90–130 m in areas like the Central North Pacific Gyre. In the more enriched waters of warm-core eddies off eastern Australia, they flourish at depths of 50–80 m. In coastal regions



The diagram shows that light at the blue end of the spectrum penetrates to much greater depths than light at the red end. The measurements were made in an eddy off Australia's eastern coast.



The filter effect of sea water on light, leaving predominantly blue (left) and blue-green (right) wavelengths.

experiencing seasonal blooms, such as the CSIRO Port Hacking offshore study area, phytoplankton live at depths between 15 and 20 m.

With such a range of light environments, more than one photosynthetic pigment system must be at work. In fact, together with seaweeds, phytoplankton have pigment systems that can harvest the entire range of wavelengths of the visible spectrum, trapping blue, blue-green, green, and yellow light.

How do they do it? In addition to chlorophyll *a*, which absorbs mainly red and blue light, algae have accessory pigments such as the yellow carotenoids found in brown algae, the water-soluble blue and red biliproteins in blue-green and red algae (which give them their colour), and chlorophylls c_1 and c_2 found in the brown and yellow algal classes.

Most phytoplankton contain one or other or both of chlorophylls c_1 and c_2 and one of the carotenoids fucoxanthin and peridinin. These pigments absorb strongly in blue or blue-green light.

In each phytoplankton cell, chlorophyll and carotenoid molecules are complexed to proteins and organized into functional photosynthetic units within the multilayered membrane system of the chloroplast. For example, the major light-harvesting complex of the dinoflagellates consists of peridinin, chlorophyll *a*, and protein, with either four peridinin molecules and one chlorophyll *a* per protein or nine peridinin and two chlorophyll *a* molecules per protein. The peridinin traps blue-green light and transfers the energy to chlorophyll *a* with 100% efficiency.

What happens in the chloroplast as the unicellular planktonic alga enters a blue-light environment? In 1981, Dr Jeffrey and Dr Maret Vesk of the University of Sydney conducted laboratory experiments on various red, brown, and golden-brown algal classes that make up the phytoplankton. They grew 'control' cells in white light and 'experimental' cells in light filtered through blue glass. The organisms they used spanned five different taxonomic divisions of phytoplankton.

At the end of the experiment, they found that the phytoplankton cells in blue-green light had produced an astonishing 20–500% more pigment than the white-light 'control' cells. Pigment analyses showed that both chlorophyll *a* and chlorophyll *c* concentrations increased in the blue-green-light environment.

Electron micrcopy revealed the structural basis of these pigment increases. The membranes containing the pigments were more numerous and densely packed inside the chloroplasts of the blue-green-light algae than in 'control' cell chloroplasts. Further, blue-green light increased (among other things) protein, RNA, and DNA contents, and photosynthetic carbon fixation. It also reduced the onset of chlorophyll degradation in older cells.

Another feature of the electron micrographs was small areas of DNA associated with the stacks of membrane in the chloroplasts. Whether this DNA promotes the blue-green-light response is an area for future research.

Dr Jeffrey hopes to discover how the blue-green-light response is 'switched on'. She suspects that the mechanism originated in ancestral cells, prokaryotes (cells without nuclei) that evolved in the ancient aquatic environment. These blue-green-light mechanisms probably became less effective as plants invaded the high-intensity, white-light terrestrial environment.

Remnants of these mechanisms are still found in higher plants, green algae, fungi, and yeasts. Blue light exerts control over a number of processes in these organisms.

Blue-green-light effects in marine microalgae: enhanced thylakoid and chlorophyll synthesis. S.W. Jeffrey and M. Vesk. In 'Photosynthesis VI. Photosynthesis and Productivity, Photosynthesis and Environment', ed. G. Akoyunoglou. Pages 435–42. (Balaban ISS: Philadelphia 1981.)

Algal pigment systems. S.W. Jeffrey. In 'Primary Productivity in the Sea', ed. P.G. Falkowski. Pages 33–58. (Plenum: New York 1980.)

Responses to light in aquatic plants. S.W. Jeffrey. In 'Physiological Plant Ecology I', ed. O.L. Lange, P.S. Nobel, C.B. Osmond, and H. Zeigler. Pages 249–76. (Springer-Verlag: Berlin, Heidelberg 1981.)

'The Blue-Light Syndrome', ed. H. Senger. (Springer-Verlag: Berlin, Heidelberg 1980.)

The nutrient ferris wheel

In the upper lighted layers of the ocean, phytoplankton material is recycled through the food chain and through bacterial breakdown of dead matter. However, a net loss of detrital material to the abyssal depths takes place as it sinks and becomes remineralized, adding to the stockpile of nitrates, phosphates, silicates, and other nutrients in the dark depths.

Life back up at the top can develop vigorously only when these rich waters are pumped to the lighted zone from below. The process that brings cool nutrient-rich waters to the surface is known to marine scientists as upwelling.

The most important upwelling areas are in currents off Oregon and California, off Peru and Chile, around the Canary Islands off north-western Africa, and in the Benguela Current off southern Africa. In addition, there are many areas where upwelling occurs on a smaller scale.

Upwelling occurs by many mechanisms, mostly driven by winds interacting with currents or continental shelf slopes. Generally, large upwellings begin when a wind blows equatorwards with a coastline on its right in the Southern Hemisphere. The resulting surface current is deflected by the rotation of the earth and the surface water is moved offshore.

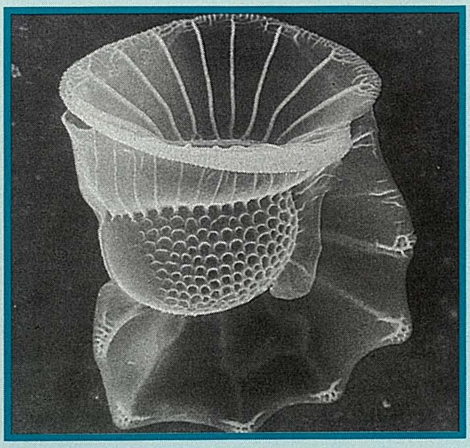
This movement does not extend far in depth, and water is drawn from deeper richer layers into the surface layer to compensate for the surface, offshore movement. The horizontal movement complementing the vertical one also aids plankton dispersal.

Regions of upwelling cover about 0·1% of the earth's surface but can yield up to 50% of the world's fish catches. Off Peru, upwelling occurs throughout the year and the larvae of the commercially important anchovy graze directly on the phytoplankton. In other upwelling systems, which are seasonal and less predictable, zooplankton are the intermediate food link between phytoplankton and fish.

Upwellings are often linked with oceanic 'fronts', analogous to the atmospheric fronts that bring the promise of sun or a shower. Oceanic fronts are formed where two water masses with distinctly different properties (such as temperature or salinity) meet at a sharp boundary. They are all biologically rich regions — sea birds, fish, dolphins, and whales tend to cluster around them.

One scientist speculates that the story of the miraculous draft of fishes in the Gospels may refer to a situation on the Sea of Galilee when the disciples' boat was on a type of front. The disciples may have been unwittingly fishing on the unproductive side of the front, but when the Master ordered them to cast their net on the other, productive side '. . . they enclosed a great multitude of fishes: and their net brake'.

Boundary currents on the eastern edges of the Pacific and Atlantic Oceans initiate conditions for extensive upwelling off North and South America and Africa: unfortunately, no similar current originating in cold southern latitudes in the Indian Ocean bathes Australia's western coast. And studies by Mr Rochford indicate that wind-induced upwellings, which enhance the productivity of equatorial Pacific and Atlantic waters, are absent in northern Australian waters because of the confused array of closely packed land masses and islands with their confined seas.



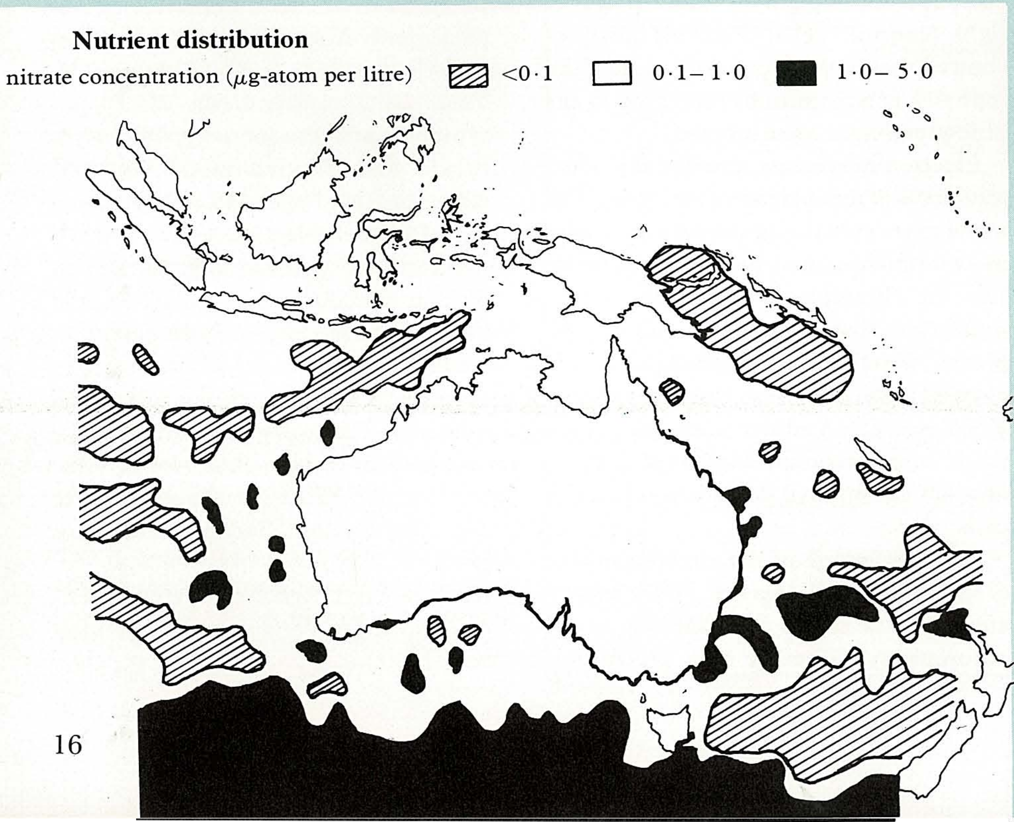
A tropical dinoflagellate from the Coral Sea.

The big gyres of the Pacific and Indian Ocean basins flanking our continent flow anti-clockwise, forming the East and West Australian Currents adjacent to our coasts. To the south, the Subtropical Convergence and the Subpolar Convergence zones isolate the nutrient-laden sub-Antarctic waters from the essentially tropical and subtropical Australasian waters of the Southern Ocean.

In the tropics, vertical temperature discontinuities, or thermoclines, separate warmer less-dense surface waters from the cooler denser layers beneath.

Mr Rochford showed that nutrients in the East Australian Current were two to three times more plentiful at 100 m depth than at the surface. However, compared with those for other regions, the nitrate depth profile for the East Australian Current shows little variation and phytoplankton productivity is correspondingly low.

Upwellings apparently do occur on a small scale in some coastal areas — Mr Rochford has identified three off our eastern coast and one off South Australia. Researchers at the Australian Institute of Marine Science have recently added another to the list: an upwelling in the Great Barrier Reef region that accounts for the unusually high levels of nutrients in this tropical ecosystem.



Nutrient levels in Australian waters are generally low. The map shows the distribution of nitrates in surface waters.

pigments or groups of pigments can act as markers for the various phytoplankton populations present in the sea. Not only algal types, but also biological processes can show up in these analyses — for example, the presence of zooplankton pigments or pigmented faecal material may indicate grazing.

Phytoplankton blooms

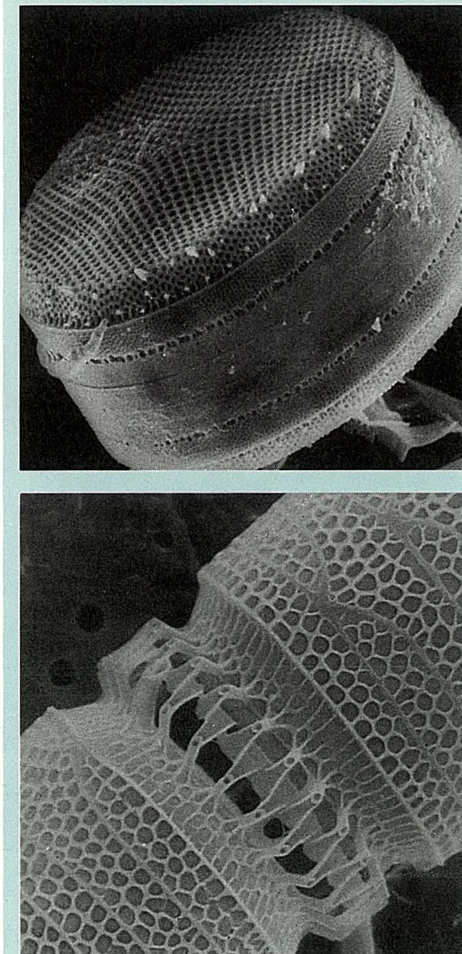
From the Port Hacking data, Dr Jeffrey and her colleague Dr Gustaaf Hallegraeff identified a succession of sharp chlorophyll peaks (more than 10 times normal) in spring, early summer, and autumn. These peaks coincided with the occurrence of tongues of cold nutrient-rich water that, for some unknown reason, periodically rise over the continental slope off the eastern Australian coast into the sunlit surface waters.

Dr Jeffrey and Dr Hallegraeff identified the seasonal chlorophyll peaks as being due to phytoplankton diatom blooms. Other very tiny unicells called nanoplankton (measuring less than one-fiftieth of a millimetre) constitute a stable background of species upon which the blooms of larger species are superimposed.

Dr Jeffrey and Ms Sue Carpenter, currently with the Division of Mathematics and Statistics, found that the cycle begins in spring, with a burst of small chain-forming diatoms, followed in early summer by the larger solitary-cell species. Over summer, the diatoms thin out and mixed populations of nanoplankton species take over. A final pulse of diatoms occurs in autumn before the winter months, when the populations return to a minimum.

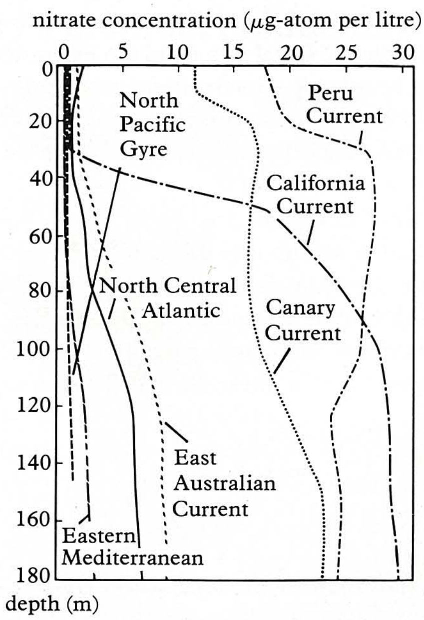
This pattern resembles those observed off the coast of Norway, the eastern coast of the United States, and Spain. What makes the Australian phenomenon so remarkable is its regularity and repeatability despite the constantly changing patterns of the East Australian current, with its off-the-shelf eddies and counter-currents.

The blooms are initiated by increased levels of nutrients from the slope water intrusions. But what regulates the sequence of species? According to one school of thought, espoused by Dr Luigi Provasoli of Yale University, U.S.A., vitamins may be responsible for species dominance. For example, a species needing vitamin B_{12} soon depletes the supplies in the water and might itself secrete thiamine and biotin (algae can make and secrete their own vitamins); thiamine- and biotin-requiring species would follow, and so on.



Highly magnified electron microscope views of two diatoms from the East Australian Current. The bottom picture shows the connections between two cells of a chain-forming species.

Vertical nitrate variations



Figures on variation of nitrate concentrations (measured in micrograms of nitrogen per litre) with depth show that the East Australian Current is not nearly as rich in nutrients as currents off the western coasts of America and Africa.

However, the picture is more complicated than this — the very algae that release the vitamins also secrete vitamin inactivators. Obviously, very complex interactions involving vitamin availability exist among the members of the phytoplankton community.

A characteristic physical phenomenon in Australian waters is the pinching off of warm-core eddies from large currents, such as the East Australian Current (see *Ecos* 38). These lenses of warm water from the tropics remain isolated from the cooler water of the surrounding subtropical Tasman Sea for periods of up to 12 months. The CSIRO studies have shown that frontal regions associated with eddy boundaries are regions rich in fish such as tuna, which are attracted to the increased supply of food organisms at the frontal zone but cannot tolerate the higher temperature inside the eddy itself.

Dr Jeffrey and Dr Hallegraeff looked at the phytoplankton species in two eddy systems. They found that, for both, the phytoplankton massed in the eddy centre where the deep mixing processes that bring nutrients to the surface are most pronounced. At the edges they found tropical dinoflagellates, coccolithophorids, and the tropical blue-green alga *Trichodesmium* sp.

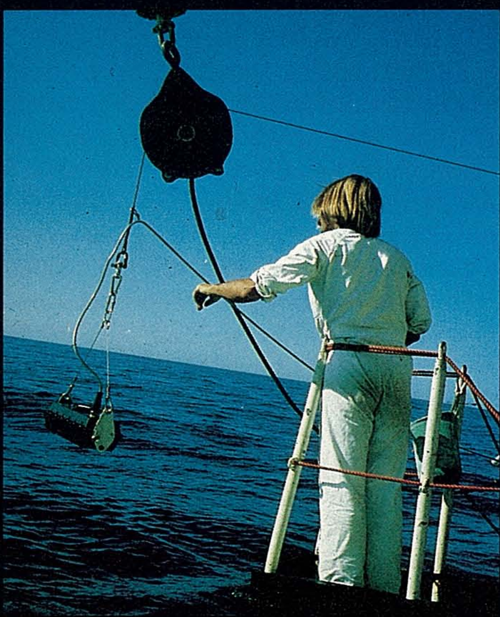
Future studies will seek to find out whether these introduced tropical species can remain for more than 12 months as part of the phytoplankton in the Tasman Sea.

Trichodesmium's reputation precedes its mention here. The alga was at the centre of a pollution scare at Sydney's famous Bondi Beach a few years ago and more recently, in 1982, at Manly and inner Sydney beaches. What was mistaken for sewage scum turned out to be massive windrows of *Trichodesmium* filaments!

Tropical deserts

Tropical seas are typically stratified, having a sun-warmed surface layer lying on top of deeper nutrient-rich cool water. In November 1980, researchers from the Division of Fisheries Research investigated the phytoplankton in the Coral Sea, off the Great Barrier Reef. They found that total cell numbers were low but the proportion of nanoplankton (70–95% of the total chlorophyll) was high. At stations near the outer reef barrier, they observed significant increases in chlorophyll near the sea floor. This finding correlates with a report by Dr John Andrews and Dr Patrick Gentien, of the Australian Institute of Marine Science in Townsville, of


Phytoplankton sampling at sea.


A researcher measuring marine underwater light with a spectroradiometer.


Chains of diatoms in a phytoplankton sample taken during a spring bloom off Sydney.

upwellings in the region induced by wind, wave, and tide.

On the other side of the continent is the North-West Shelf, the site of a productive demersal trawl fishery. Here, nutrient enrichment may occur as tidally induced internal waves interact with the bottom slope. The Division's studies in the area again indicated low cell numbers and a high proportion of nanoplankton, as in the Coral Sea, but in contrast, it supports a greater diversity of large tropical diatoms. This community scheme was repeated in both the Gulf of Carpentaria and the Arafura Sea.

Dr Hallegraeff and Dr Jeffrey are continuing the task of identifying the exotic-looking tropical species. Their long hairs and hornlike or winglike extensions belong to the realm of fantasy.

Marine botanists believe that phytoplankton have evolved these adaptations to help them float, to ward off prospective grazers, and to improve nutrient uptake through enhancement of rotational movements. In the tropics, these morphological adaptations may become monstrous, as staying afloat is a more serious problem in the warmer water, which is less viscous than cold water. Some algae, like *Trichodesmium* sp., have gas bubbles that expand or contract to allow the cell to rise or sink, while other phytoplankton stay afloat because they are small.

Another peculiar feature of tropical plankton is their 'I'll scratch your back if you'll scratch mine' existence. Dr Jeffrey and Dr Hallegraeff noticed that living samples of Coral Sea plankton examined on board ship contained many colourless dinoflagellates harbouring symbiotic blue-green algal cells, which probably help feed the host cell.

In other regions, such as the North-West Shelf, a diatom may be tenanted by a ciliate (an animal-type unicell) or studded with minute coccolithophorids. In these marriages of convenience, the participants are thought to benefit through exchange of nutrients and organic compounds — commonly, a non-photosynthetic plankton will carry a pigmented hitch-hiker.

Bloom–fish links

How does an algal bloom affect fish stocks? Dr Ruben Lasker from the South-West Fisheries Centre, La Jolla, California, identified the dinoflagellate *Gymnodinium splendens* as the crucial food organism for the first feeding larval stage of the Californian anchovy. He found that large numbers of larvae died if the water contained less than 20–40 phytoplankton cells per millilitre, causing a complete collapse of the fishery in subsequent years.

In Australasian waters, little is known about the specific nutritional requirements of any fishery, nor how different food webs can result from phytoplankton dominated by large-celled diatoms or small-celled flagellate populations. In 1972, Dr Andrew Heron of the Division of Fisheries Research found that swarming zooplankton herbivores called salps can grow 10–100 times faster than other zooplankton organisms, enabling them to rapidly capitalize on phytoplankton blooms. These animals swarm at enrichment sites, such as eddy fronts, where tuna quickly queue up for a salp smorgasbord.

Fisheries management authorities in Australia need to know more about relations between growth rates and feeding in the plankton and about associated physical processes in order to understand the early survival and later food supplies of fish stocks.

Mary Lou Considine

More about the topic

Phytoplankton, marine food chains, and their relation to ocean dynamics. S.W. Jeffrey, G.M. Hallegraeff, and A.C. Heron. *CSIRO Marine Laboratories Research Report*, 1979–81, 63–74.

Phytoplankton ecology — with particular reference to the Australasian region. S.W. Jeffrey. In 'Marine Botany', ed. M.N. Clayton and R.J. King. Pages 241–91. (Longman Cheshire: Melbourne 1981.)

Seasonal study of phytoplankton pigments and species at a coastal station off Sydney: importance of diatoms and the nanoplankton. G.M. Hallegraeff. *Marine Biology*, 1981, **61**, 107–18.

Studies of phytoplankton species and photosynethic pigments in a warm-core eddy of the East Australian Current. I. Summer populations. II. A note on pigment methodology. S.W. Jeffrey and G.M. Hallegraeff. *Marine Ecology, Progress Series*, 1980, **3**, 285–94; 295–301.

Seasonal succession of phytoplankton at a coastal station off Sydney. S.W. Jeffrey and S.M. Carpenter. *Australian Journal of Marine and Freshwater Research*, 1974, **25**, 361–9.

Upwelling as a source of nutrients for the Great Barrier Reef ecosystem: a solution to Darwin's question? J.C. Andrews and P. Gentien. *Marine Ecology, Progress Series*, 1982, **8**, 257–69.

Cultivating tiny sea plants. A. Bell. *Ecos* No. 29, 1981, 22–5.