Cyanobacteria and Fraser Island

All life on Earth owes its evolution to the creation of oxygen in the atmosphere and that oxygen owes its creation about 3 billion years ago to the evolution of microscopic organisms known as cyanobacteria (cyano). But cyanobacteria still exist and continue to play a vital but hitherto little understood role in the ecology of Fraser Island. This FIDO backgrounder (No 54) attempts to describe the role of cyanobacteria in (a) providing nitrogen to support the plant life on Fraser Island, (b) sequestrating carbon in Fraser Island's soil and turning the top 30 cms grey & (c) releasing iron to create Fraser Island's coloured sands and laterite.

The Nature of Cyanobacteria

While few people are aware of cyanobacteria, these primitive organisms that belong neither to the plant or animal kingdoms occur ubiquitously all around them. Cyanobacteria are arguably the most successful group of microorganisms on earth. They are the most genetically diverse; they occupy a broad range of habitats across all latitudes, widespread in freshwater, marine and terrestrial ecosystems, and they are found in the most extreme niches such as hot springs, salt works, and hypersaline bays. Cyanobacteria are often referred to as extremophiles as they have evolved and adapted to surviving in the harshest environments on Earth. They can survive in extremes of temperature and light, conditions of limited moisture (e.g. hot and cold deserts), and in nutrient-deficient environments. Cyano can be found in almost every conceivable environment, from oceans to fresh water to bare rock to soil. They can occur as plankton or films in fresh water and marine environments. They occur in damp soil, or even on temporarily moistened rocks in deserts.

Because many cyanobacteria contain chlorophyll they can photosynthesize. This enables them to take in atmospheric CO_2 and transpire oxygen. It was this facility that enabled cyano colonies formed as stromatolites to generate the Earth's atmosphere and allow the subsequent diversification of the myriads of life-forms on Earth.

Cyano contributes three essential elements to other life-forms on earth as a result of their existence — oxygen, nitrogen and carbon. They are credited with creating the oxygen which now constitutes just over 20% of the Earth's atmosphere about 3.5 billion years ago and this then allowed the evolution and diversification of all other forms of life on Earth.

While some cyanobacteria grow in colonies to form stromatolites as in the Shark Bay World Heritage area, on Fraser Island when there is adequate moisture they grow as mats on undisturbed firm surfaces just as they grow in rock faces or cement surfaces and look like mould. But on Fraser Island the loose sand lets light penetrate deeper and allows them to grow in thicker mats.

Fixing Nitrogen

Along with phosphorus, (P) potassium (K) and calcium (Ca) all plants require nitrogen (N) to survive and grow. Nitrogen is a critical component of all proteins and without nitrogen there would be no plant growth. While nitrogen constitutes roughly 78.09% (by volume) of dry air and is essential for plant growth, atmospheric nitrogen is not available to plants. Plants are unable to extract any of the nitrogen they need to from the atmosphere. While some plants such as legumes are able to extract atmospheric nitrogen with the aid of micro-organisms (rhizobium), most plants derive the nitrogen they need from what they can extract from the soil in the form of decomposed and recycled organic material.

It has been assumed that the nitrogen needed to produce the huge biomass and forests on Fraser Island had been derived from specialized plants including the legumes, the casuarinas and even cycads that were known to be able to obtain atmospheric nitrogen through root associations. However it now appears that the source of nitrogen to sustain Fraser's forests is produced on the surface of the soil by cyanobacteria that can extract nitrogen direct from the atmosphere.

Some cyano species are specialized for nitrogen fixation. They are able to convert nitrogen gas into ammonia (NH_3), nitrites or nitrates from the atmosphere that can then be absorbed by plants and converted to protein and nucleic acids. While cyanobacteria help form biological crusts (sometimes known as cryptobiotic crusts) in semi arid areas, these crusts had not been reported from Fraser Island. However it transpires that with careful observance they are surprisingly common, particularly in La Nina years when they may be seen forming on both impervious surfaces such as coffee rock and even the bare surfaces of sandblows.

This cryptobiotic mat as seen in Hammerstone Sandblow in July 2010 is full of cyanobacterial colonies. This mat arrests surface sand movement, traps moisture, stores carbon and generates nitrogen for plant growth. However when these unicellular organisms die they contribute other elements to the Fraser Island environment — carbon from their organic composition and the iron responsible for Fraser Island's coloured sands.

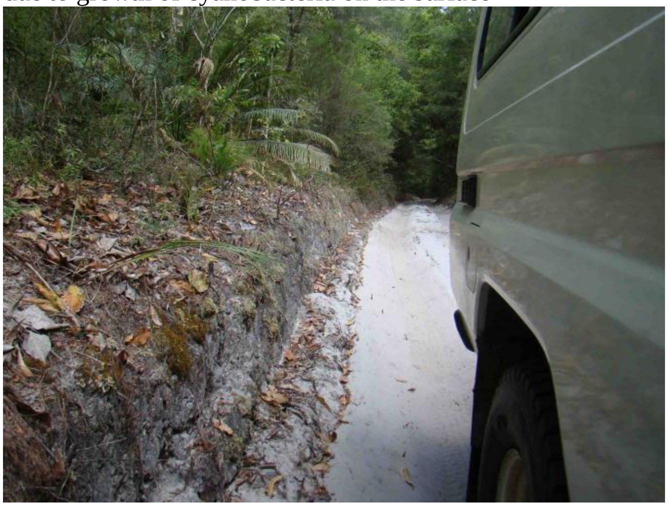
Illustrations in this FIDO Backgrounder can be better appreciated in colour on at www.fido.org.au. FIDO is indebted to Dr Wendy Williams whose initial survey of Fraser Island cyanobacteria first raised appreciation of the significant role these microscopic organisms have played and continue to play in both shaping and colouring Fraser Island. Her paper to the 2011 Fraser Island conference on forming the coloured sands can also be found on the FIDO web site.

Sequestration of Carbon

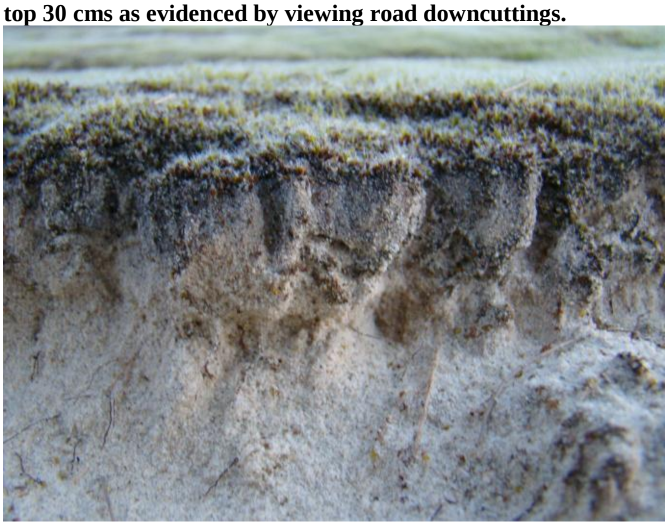
Although the atmosphere contains only 0.039% carbon dioxide (CO_2), the global community now knows that when those levels increase through various man-made emissions, it has a profound impact on both global temperatures and on climate. Therefore it is vital to counter the excessive emissions of CO_2 by storing it (sequestration). Naturally carbon is stored in various minerals (including coal, petroleum and limestone) as well as plants and animals (biomass). A surprising amount of carbon is stored in soils. Biological soil crusts are natural carbon sinks as well as providing nitrogen to assist larger plants to grow.

While the role of cyano in storing carbon in the soil is now a little better appreciated, little attention has been given to the carbon stored in Fraser Island's sands. However wherever down-cutting has occurred through the soil profile as along many roads, the top 30 centimetres is a dark grey, indicating carbon storage and it is so cohesive that this often forms a shelf over-hanging the substrates. The cause of this carbon is now better understood to be cyanobacteria.

It can also now be demonstrated that volume of Fraser Island coffee rock under the right conditions progressively grows due to growth of cyanobacteria on the surface



Fraser Island sands store an enormous amount of carbon in the top 30 cms as evidenced by viewing road downcuttings.



The source of the carbon in Fraser Island's soil comes from the thin crypto-biotic crust growing almost invisibly on the soil surface. Here in a sandblow it can be seen colouring sand below

Releasing Iron to colour the sand

Like all forms of life cyanobacteria are very vulnerable to the damaging UV rays of the sun, particularly as they occur on outer surfaces. To protect themselves from UV, cyanobacteria use ferrous iron to aid in pigmentation. This is their sunscreen. On Fraser Island sesqui-oxides form films around the fine grains of silica until they are leached away by acids. These sequi oxide films gives the beaches their colour, more yellow than white. Iron from these sesqui-oxides becomes the source of iron in the cyanobacteria cell walls.

Iron becomes a component of the pigment that gives cyano a black appearance in life. When those cyano cells die, the iron is then leached from the dead cells' walls. Then cyanobacteria alter oxygen concentrations and raise the pH on a micro-scale basis. Some of the leached iron compounds then colours the substrate. Some coalesce to form ironstone pebbles and in some cases even cement the surface sand into an iron impregnated sheets up to 10 centimetres thick. Remnants of these sheets can be seen as layers in Fraser Island's exposed coloured sand cliffs and can also be seen as broken fragments littering the surface of some sandblows or even forming strange sculptures.

Leaching of iron oxides occurs when cyanobacteria alter oxygen concentrations and raise the pH on a micro-scale basis. This then stains the substrate below

The vast deposits of iron ore in Australia's Pilbara are largely the result of cyanobacteria that once occurred in stromatolites there. The formation of stromatolites supports the origin of oxygenic photosynthesis. So the connection between cyanobacteria and iron has been well established.

As well as playing an important part in the formation of the coloured sands, cyanobacteria also plays a significant role in the stabilization of the surface of the sand through the establishment of mats. This is particularly critical on Fraser Island and where the loose siliceous sand surfaces are easily eroded by wind or water.

In this Hammerstone sandblow site coloured sand and ironstone pebbles have formed in less than two decades. The photo shows the biogeochemical interactions occurring between cyanobacterial colonization and underlying or exposed iron sediment layer with its weathered pedestal formations and ridgelines as well as the intense colouring that has occurred immediately below the surface crust. This demonstrates how actively cyanobacteria still are shaping and colouring landforms