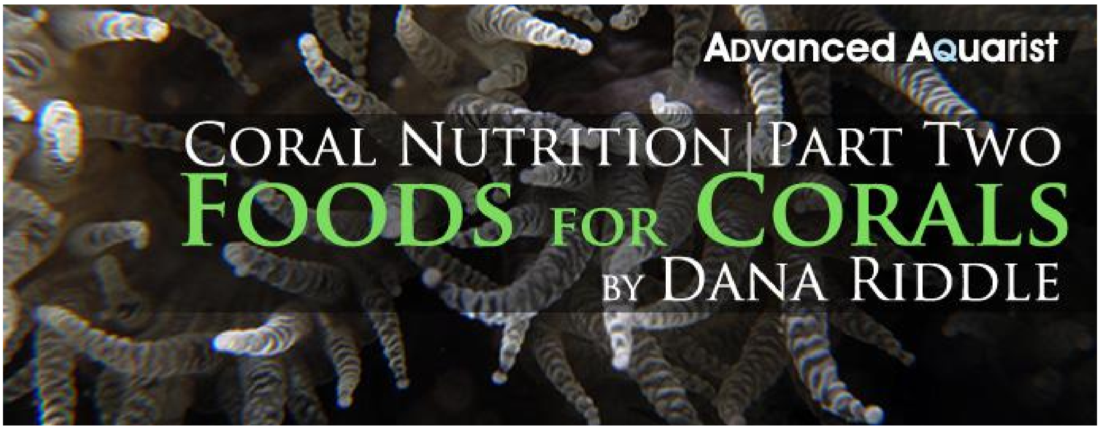

珊瑚营养:珊瑚食物（珊瑚营养系列文章第二部分）

作者：dana riddle（2015）　翻译：四川雅安benben

In Part One of this series, we discussed the care and feeding of corals' symbiotic dinoflagellates (Symbiodinium species, or zooxanthellae.) To recap, corals (as are all living things) are composed of proteins, carbohydrates, lipids, and ash (non-volatile, inorganic substances such as metals.) The coral animal obtains some of the organic substances through feeding (heterotrophy) or translocation from zooxanthellae (which are autotrophic.) Hence corals obtain sustenance from various sources in a process calledmixotrophy, a combination of heterotrophy and autotrophy.

在本系列文章的第一篇中，我们讨论了珊瑚共生藻(或称虫黄藻)的护理和饲养。概括地说，珊瑚(和所有生物一样)由蛋白质、碳水化合物、脂类和灰分(不挥发的无机物，如金属)组成。珊瑚动物通过摄食(异养)或从虫黄藻中转运(自养)来获得有机

物质。珊瑚从各种来源获得食物的过程称为兼性营养，兼性营养是异养和自养的结合。

In order for mixotrophy to work properly, light intensity (for the zooxanthellae) and water motion (primarily for the coral animal to feed and absorb nutriment through a diminished Momentum Boundary Layer, with zooxanthellae being indirectly affected) must be within upper and lower limits. The importance of this cannot be overstated. Generally, photosaturation (where the rate of photosynthesis is no longer proportional to light intensity) occurs for many corals at light levels less than 400 µmol·m^2·sec (or about ~20,000 lux.) See Part One for details: http://www.advancedaquarist.com/2014/11/aafeature

As a quick review, Figure 1 gives us a rough idea of nutritional sources and their proportions for photosynthetic corals.

为了使兼性营养机制正常工作，光强度(对于虫黄藻)和水流(主要是珊瑚通过动量减少的边界层进食和吸收营养物，虫黄藻受到间接影响)必须在上限和下限之内。这一点的重要性怎么强调都不为过。一般来说，多数珊瑚的光饱和(光合作用的速率不再随着光照强度的增加而增加)点低于 400 摩尔·米·秒(或约 20，000 勒克斯）详见本文章的第一部分。

作为一个快速回顾，图 1 给了我们显示了一个关于光合珊瑚营养来源及其比例的粗略概念。

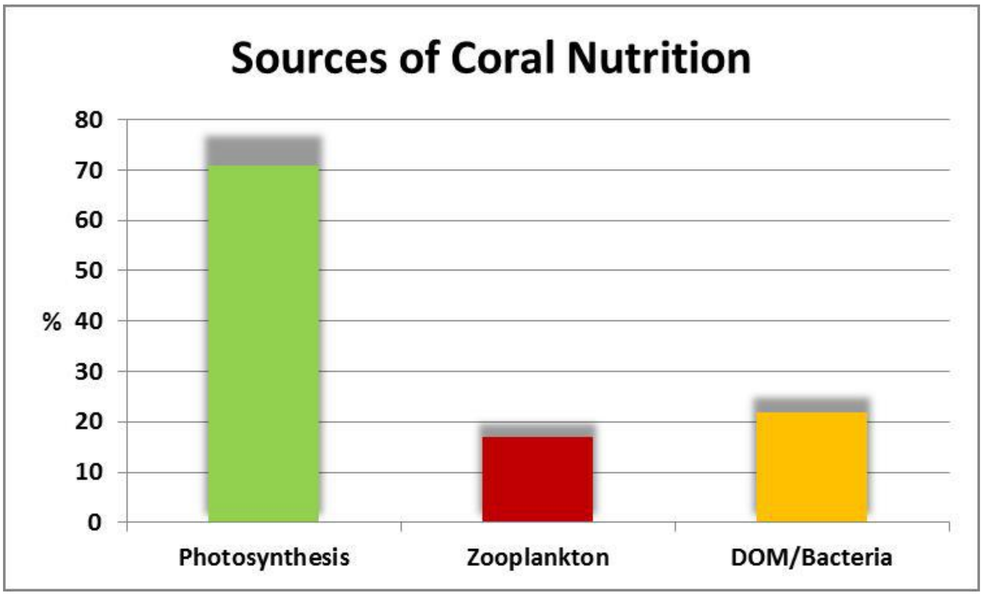

Figure 1. Photosynthesis can provide most of the carbon requirements for coral tissue growth. Other important sources are plankton (zooplankton and phytoplankton) as well as DOM (dissolved organic material) and bacteria.
图 1。光合作用可以提供珊瑚组织生长所需的大部分碳。其他重要来源是浮游生物(浮游动物和浮游植物)以及 DOM(溶解的有机物质)和细菌。

Water motion deserves a bit more examination. Research has shown that sessile invertebrates' feeding rates are related to water velocity. If insufficient prey is encountered, the coral, in order to conserve energy, might withdraw its polyps. At the other end of the spectrum, polyps will be withdrawn if water velocity is too high and danger of damage occurring is possible. Table 1 shows optimal water velocity rates for various invertebrates.

水流值得更多的关注。研究表明珊瑚等无法移动的腔肠动物的摄食率与水流速度有关。如果食物在珊瑚周围的密度不够，为了保存能量，可能会收回它的水螅体。相反的，如果水流速度过

高，水螅体和共肉也将会收缩以防止可能发生的损伤。表 1 显示了各种无脊椎动物的最佳水流速度。

Coral	Velocity (inches/sec)
Acanthogorgia vegae	3.1
Agaricia agaricites	7.1
Agaricia agaricites (bifacial)	11.8
Agaricia agaricites (horizontal)	7.1 to 19.7
Briareum asbestinum	2.3 to 4.7
Dendronephthya hemprichii	3.9 to 9.8
Eunicea tournefortis	2.4 to 4.72
Galaxea fascicularis	3.9
Lophelia petusa	1
Melithaea ochracea	3.1
Plexaura dichotoma	2.4 to 4.72
Porites porites	3.5 to 4.33
Pseudopterogorgia americana	2.4 to 4.72
Subergorgia suberasa	3.1

Related to water velocity/feeding rates is a concept called Functional Response. This idea was developed by ecologist C.S. Holling and examines the relationship between prey density and the rate at which prey is eaten. Holling’s Type I describes a relationship where the consumer’s ingestion of prey and prey density is linear. In other words, the time to digest food is considered negligible and eating doesn’t interfere with hunting (or in this case, capture of prey.) Holling’s Type II refers to situations where the consumer’s ‘attack time’ (or perhaps more accurately ‘encounter time’ in cases of corals) is limited by ‘handling time’ (‘digestion time’.) A Type III exists, but involves situations where the predator learns and adapts, or switches prey (the former is an interesting concept that might pertain to aquarium corals. There are reports that some corals have been ‘trained’ to open polyps for prey capture at certain times of the day, without tactile or chemical stimuli.) Figure 2 charts demonstrates relationships of Type I and II functional responses.

与水流速度/摄食率相关的是一个称为功能反应的概念。这个想法是由生态学家 c. s. holling 提出的，他研究了猎物密度和猎物被捕食者吃掉的速度之间的关系。这种关系在自然界中分为三种类型（I 型和 II 型和 III 型，主要是前两种类型）（这三种类型由 holling 分类，所以一般称为 holling 的 xxx 型），holling 的 I 型描述了一种关系，其中捕食者对猎物的摄入和猎物密度是线性的。换句话说，消化食物的时间被认为是忽略不计的，吃东西不会干扰狩猎(边吃东西边捕猎。)holling 的 II 型是指捕食者的“攻击时间”(或者更准确地说，珊瑚的“遭遇时间”)受到“处理时间”(消化时间)的限制（吃东西需要消化，消化影响捕食）。iii 型在自然界中也存在，但涉及捕食者学习和适应（这个应该是一种相对高级一点的方式，但是我们知道在珊瑚这种腔肠动物中也存在，训练，带一点条件反射的感觉），或转变捕食猎物的情况(前者是一个有趣的概念，可能与水族馆珊瑚有关。有报道称，一些珊瑚已经被“训练”在没有触觉或化

学刺激的情况下，在一天中的特定时间打开珊瑚虫捕捉猎物。）图 2 的图表展示了 I 型和 II 型功能反应和猎物密度的关系。

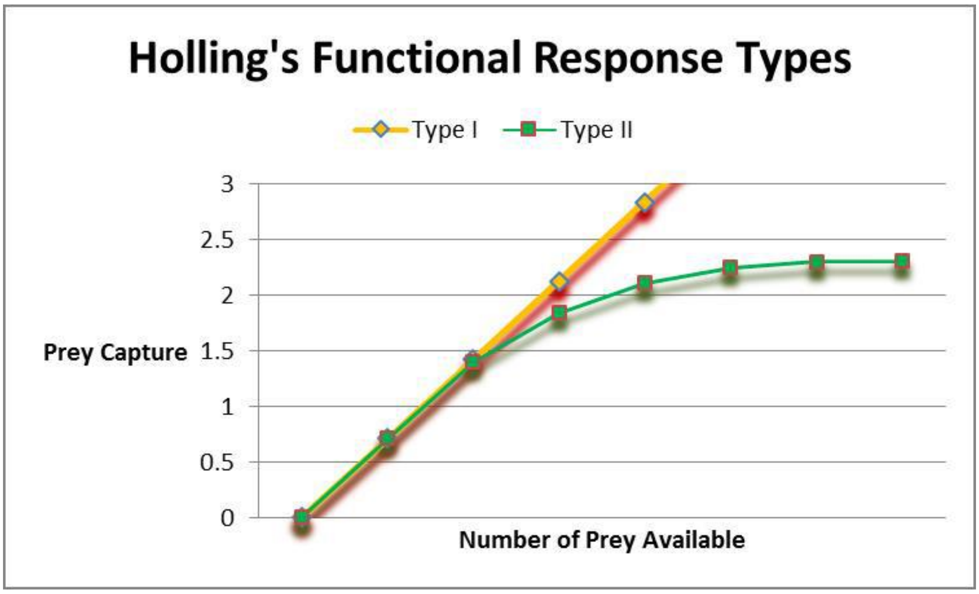

Figure 2. Corals' feeding responses are dependent upon water motion and number of prey. Holling's Functional Responses describe the latter.

图 2.珊瑚的进食反应取决于水的运动和猎物的密度。holling 的所谓功能反应描述了后者的情况。

（这个 holling 的功能反应非常重要，我们可以看到，I 型的捕食反应几乎就是和食物密度成正比，II 型在食物密度到达一定大小之前也是正比，我理解的这也是为什么珊瑚粮制造商往往都是按照水体大小来写计算珊瑚粮投入的密度，这是为了达到一定的猎物密度，当然，有时我们的水族箱里面珊瑚数量低或是蛋白质分离器不够强劲，虽然高食物密度可以让我们的珊瑚捕食更为频繁，但是过多的剩余食物也有导致水质的恶化风险，所以我们要综合商家按水体大小计算的应该投喂的珊瑚食物量和水族箱内珊瑚密度的大小应该投喂的珊瑚食物量来考虑投喂量，仅仅依据其中一个方面都是不科学的。打个比方就很好理解，如果一个 400L 的缸，里面放置的珊瑚数量和一个 800L 的缸的珊瑚数

量是一样的时候，那 800L 的缸加入珊瑚粮的数量在常规情况下应该要大于 400L 的缸，这是为了提高猎物密度，但是又不能完全按照厂家给的 800L 水体应该加入多少来添加，因为这个 800L 的缸珊瑚密度明显比较低，消耗不了这么多珊瑚粮，可能会造成水体的营养盐负担。当然，这还需要综合考虑这个水族箱处于建缸的哪一个阶段，水流，蛋白质分离器大小等等。。）

Anthony (1999) found the stony coral Porites cylindrica conformed to Holling's Type II, with particle capture peaking at relatively low concentrations of 'prey'. On the other hand, several SPS coral genera (Pocillopora damicornis, Montipora digitata, and Acropora millepora) showed feeding responses that were linear to particle concentration (Type I response at concentrations of 1 to 30 mg/l.) However, assimilation by the corals was inversely proportional to concentration. With that said, Anthony reported suspended matter could cover up to ½ of carbon requirements and 1/3 of the nitrogen.

anthony (1999) 发现圆筒滨珊瑚捕食方式（孔珊瑚科滨珊瑚属的一种珊瑚）符合 holling 的 II 型，捕食反应在“猎物”浓度到达一定的时候就不再增加。相反的，其他很多 SPS 珊瑚（鹿角杯形珊瑚、指状蔷薇珊瑚、多孔鹿角珊瑚）（其实就是大部分的 sps 珊瑚）表现出捕食反应和“猎物”浓度成线性关系（holling 的 I 型，测试的猎物浓度是 1 毫克/L 到 30 毫克/L）。然而，珊

瑚的消化速度却和浓度成反比。尽管如此，anthony 的文章报道说悬浮物质可以为珊瑚提供高达 1/3 的碳需求和 1/3 的氮需求。

The Smaller the Mouth, The Smaller the Prey

This is a simple concept yet one commonly ignored when we examine particle size of some commercially available coral foods. We will examine the size of particles ingested by small polyped stony corals in this article. There has been relatively little research conducted on single- or large-polyp stony corals.

嘴越小，猎物越小

这是一个简单的概念，但当我们检查一些市售珊瑚食物的颗粒大小时，这一点常常被忽略。在这篇文章中，我们将重点研究 SPS 珊瑚（小水螅体石珊瑚）摄取的颗粒大小。对单个或大水螅体石珊瑚的研究相对较少。

Micrometers

A micrometer is 1/1,000,000th of a meter. To put this in perspective, a fine human is as little as 17 micrometers in diameter. We’ll use micrometers (abbreviated as μm) as the standard for describing size of coral prey organisms.

Particulate prey include a number of animate and inanimate objects ranging in size from the size of bacteria (perhaps 0.5 micrometers) to 200 micrometers and even larger.

This month, we'll examine various food sources for the coral animal. These involve organic and inorganic substances, both particulate and dissolved. But first:

微米

一微米等于 1/1000000 米，从长远来看，一个优秀的人直径只有 17 微米。（这一句是机翻，我实在没搞明白这句啥意思。。）我们将使用微米(缩写为 um)作为描述珊瑚捕食生物大小的单位。

珊瑚的猎物包括许多有生命和无生命的物体，大小从细菌大小(差不多 0.5 微米大小)到 200 微米甚至更大。

本月，我们将研究珊瑚的各种食物来源。这些食物包括有机物和无机物，既有颗粒物也有溶解物。但是首先:

Predation of Cyanobacteria, Bacteria, and Algae by Symbiodinium spp. (Zooxanthellae)!

Before continuing our study of coral nutrition, we'll begin by examining the consumption of cyanobacteria, bacteria, and algae byzooxanthellae. Cyanobacteria, or cyanophyta, are a group of photosynthetic bacteria. They are sometimes called blue-green algae due to their color (cyan = blue.)

Synechococcusspp. are small (0.6 to1.5 microns) cyanobacteria that inhabit shallow-water marine environments (although some freshwater species have been described.) They are plentiful and can number from 50 to as many as 4,000 per drop (assuming 20 drops per milliliter.) There is some reason to believe some species could 'fix' nitrogen gas and convert it into organic nitrogen compounds. Their main photopigment is chlorophyll a, but they also contain other pigments, including phycoerythrin (a red, light-harvesting photopigment.) See Figure 3.

共生藻（虫黄藻）对蓝细菌等各种细菌的捕食！

在继续我们对珊瑚营养的研究之前，我们将从研究虫黄藻对蓝细菌、细菌和藻类的消耗开始。蓝藻，或蓝藻门，是一类光合细菌的统称。由于它们的颜色(青（绿）色=蓝色)，它们有时也被

称为蓝绿藻。

聚球菌属是一种小型(0.6 到 1.5 微米)的蓝细菌，主要栖息在浅水海洋环境中(也报道过一些淡水品种)它们数量丰富，每滴水中可以有 50 到 4000 个(假设每毫升 20 滴，也就是一滴 50 微升)。有理由相信其中一些品种可以“固定”氮气，并将其转化为有机氮化合物。它们的主要光色素是叶绿素 a，但它们也含有其他色素，包括藻红蛋白(一种红色的、可利用光的光合色素)。参见图 3。

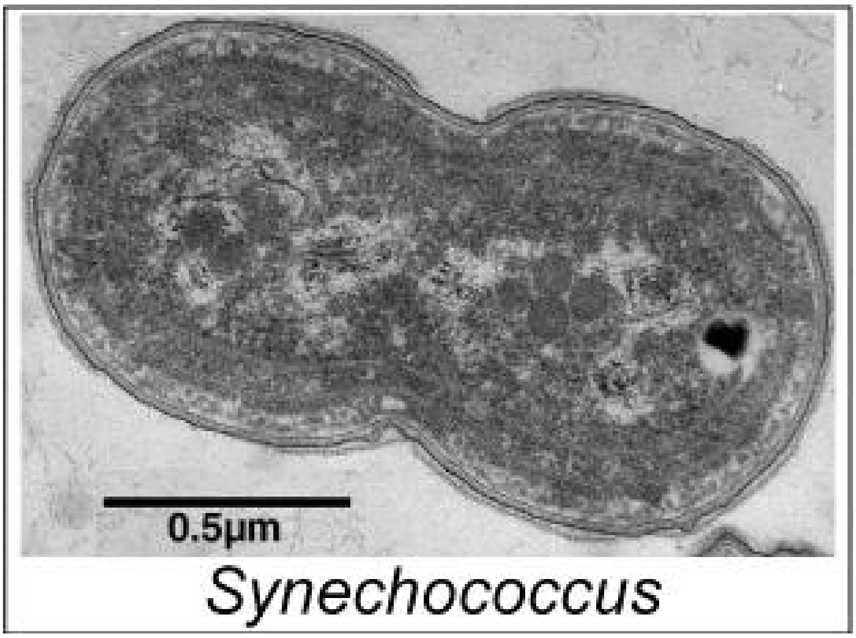

图 3。蓝细菌可以被虫黄藻食用

Jeong et al. (2012) found free-living Symbiodinium, as well as symbiotic zooxanthellae (acquired from the stony coral Alveopora japonica), have the ability to feed on heterotrophic bacteria, cyanobacteria (Synechococcusspp.), and microalgae (through a process known as phagocytosis.) Free-living dinoflagellates did not grow when denied a these nitrogen sources, but grew when fed with any of these prey. This discovery alters the concepts of how dinoflagellates thrive in nutrient-depleted environments.

jeong 等人(2012 年)发现，处于自由生活状态下的共生藻以及和珊瑚共生的虫黄藻(从 *Alveopora japonica* 珊瑚中获得)能够以异养细菌蓝细菌和微藻为食(通过称为吞噬作用的过程）。当没有氮源时（缺乏营养的环境），自由生活的甲藻不会生长，但当其以这些猎物为食时，则会生长。这一发现让我们了解了共生藻如何在营养缺乏的环境中茁壮成长（ULNS 环境下，共生藻也能“捕食”）。

How Corals Feed

Corals have evolved a number of ways to feed – their food can be dissolved and absorbed through their ectoderm (skin), by capturing particles in a mucus net, creating currents around their mouths with cilia-like structures, or harpooning or entangling prey with cnidocytes and nematocysts. Nematocysts ‘fire’ by either tactile or chemical stimuli.

Some coral species feed by tentacular capture only (such species found Poritidae and Pocilloporidae), while others feed by ‘suspension capture’ (or culture) of bacteria and other fine particulates in a mucus net. Others use both strategies.

珊瑚如何进食

珊瑚已经进化出多种进食方式——它们的食物可以通过外胚层(皮肤)被溶解和吸收，通过分泌粘液捕捉食物颗粒，用纤毛状结构在它们的嘴周围制造水流，或者用刺丝胞和刺囊细胞像鱼叉一样将猎物捕获。刺丝胞通过生物和化学武器向猎物“开火”。一些珊瑚仅通过触须捕获来进食（Poritidae 和 Pocilloporidae 这两个科)，而另一些则通过粘液网中细菌和其他细颗粒的“悬浮捕获”来进食。有一些珊瑚则同时采用这两种方式捕食。

Mucus Net

Some corals cast a net or network of filaments composed of internally-generated mucus in order to capture prey. In a study of Atlantic corals, Lewis and Price (1975) found corals within the Family of Agariciidae secreted mucus from the epidermis of the oral disk. Hence, corals with retracted polyps, either during the day or night, could continue to capture prey by acting as mucus broadcasters, suspension feeders, and predatory feeding on plankton. See Figure 4.

粘液网

一些珊瑚为了捕食，会分泌粘液形成粘液网。在一项对大西洋珊瑚的研究中，lewis 和 price (1975)发现一些 Agariciidae 科（一种石珊瑚）的珊瑚从口腔附近的表皮分泌粘液。因此，无论是白天还是晚上，即便是珊瑚虫缩回后，依然可以继续通过粘液来捕获猎物。参见图 4。（这是一种类似蜘蛛网的机制）

图 4　黏液网覆盖了部分珊瑚的表面，它就像蛛网一样成为猎物的陷阱和细菌食物的来源

Note: Corals of Family Agariciidae are found in the Atlantic and Pacific and include genera Agaricia, Coeloseris, Gardineroseris, Helioseris, Leptoseris, Pachyseris, and Pavona. Mucus nets are also seen with Fungia and some other corals of Family Fungiidae. Mucus coatings are common among many soft and stony corals, especially those of genera Sarcophyton and Porites.

注：Agariciidae 科的珊瑚在太平洋和大西洋都有发现，包

括 Agaricia, Coeloseris, Gardineroseris, Helioseris, Leptoseris, Pachyseris, 和 Pavona。（都是属名），粘液网在 Fungia 属和 Fungiidae 科的其他珊瑚中也都有发现，粘液被膜在许多软珊瑚和石珊瑚中很常见，特别是 Sarcophyton 属和 Porites 属。

Bacteria and the Mucus Net

Coral mucus consists mostly of excess carbon fixed by photosynthesis or obtained heterotrophically. As Figure 5 shows, mucus discharged by at least some corals contains lipids (fats) and carbohydrate (glucose, a simple sugar.) Both are energy rich and excellent food sources for bacteria. Hence, a corals' mucus net could be expected to contain bacteria as well as particulate matter.

细菌和粘液网

珊瑚的粘液主要由通过光合作用或异养获得的过量碳组成。如图 5 所示，至少一些珊瑚排出的粘液含有脂类(脂肪)和碳水化合物(葡萄糖，一种简单的糖)。两者都富含能量，是细菌的绝佳食物来源。因此，珊瑚的粘液网可能会同时包含细菌和颗粒物质。

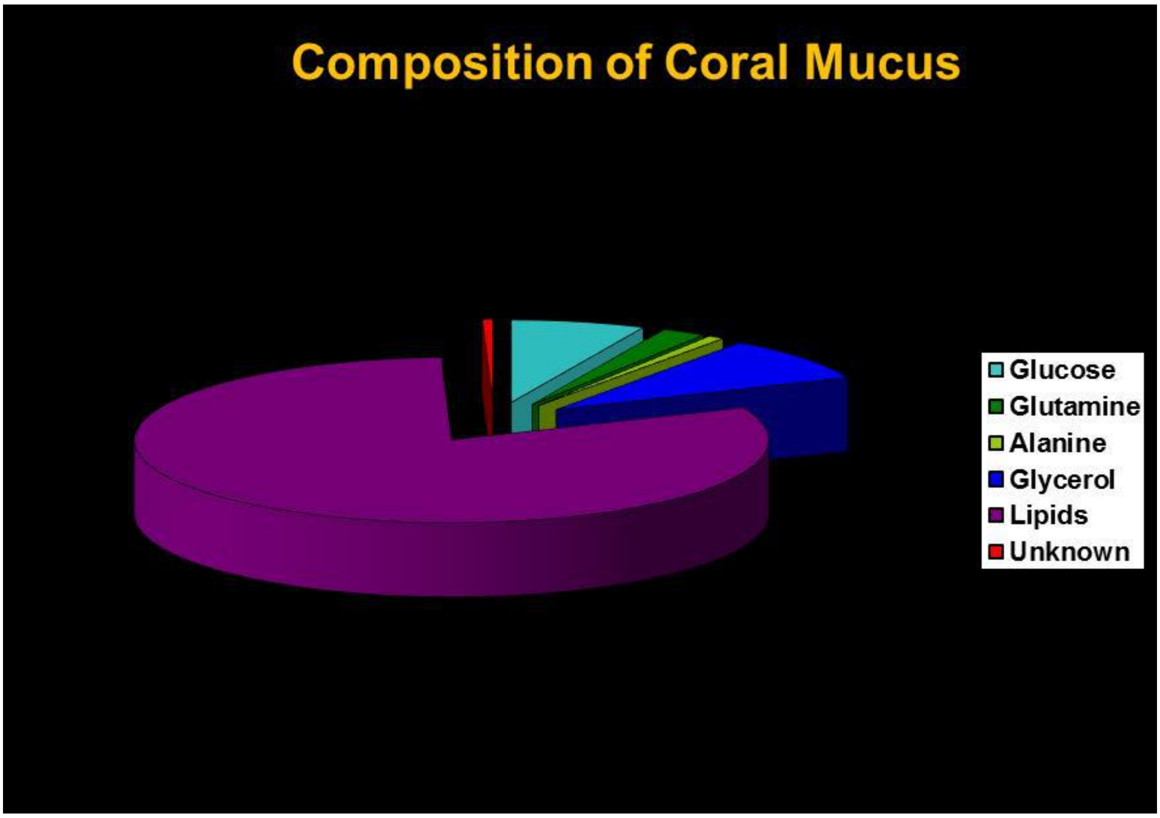

图 5　珊瑚粘液含有极好的细菌食物

Nematocysts and Cnidocytes – Nature’s Harpoons

Cnidarians have internal structures called cnidocytes which contain natural harpoons called nematocysts. See Figure 6.

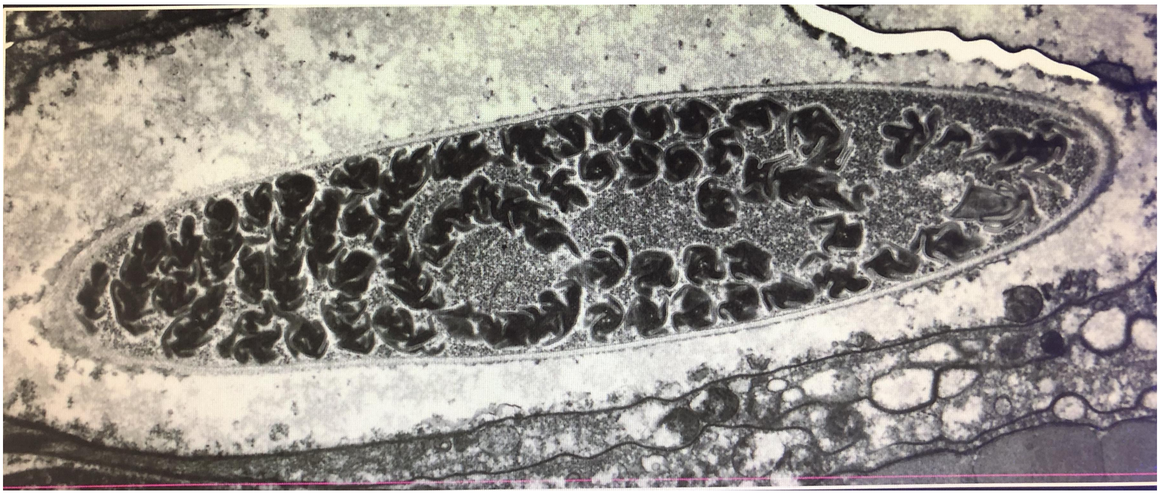

Figure 6. A cnidocyte – corals' structures for prey capture. Note the coiled nematocyst (a natural harpoon) within the organelle. A photomicrograph taken with an electron microscope at a power of 15,900x. Courtesy of Drs. Denny Aaron and Steven Poet, University of Georgia.

When a 'trigger' on a coral's surface is touched, a 'door' called an operculum springs open and the thread-like nematocyst is discharged. The nematocyst is loaded with venom that can immobilize relatively large prey. These toxic threads can also be used as defensive and offensive mechanisms. Nematocysts can also simply entangle and trap prey. See Figure 7.

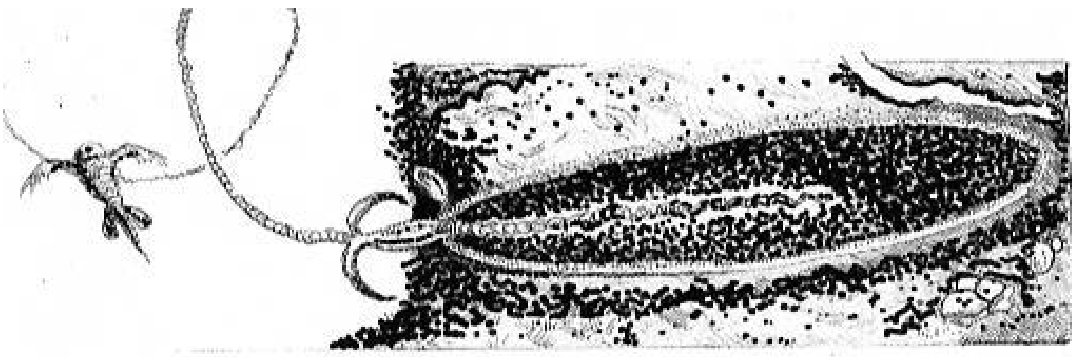

Figure 7. What the cnidocyte in Figure X might look like with its nematocyst discharged and entangling prey.

刺丝囊和刺细胞——大自然的鱼叉

刺胞动物的内部结构被称为刺细胞，其中含有被称为刺丝囊的天然鱼叉。参见图 6。

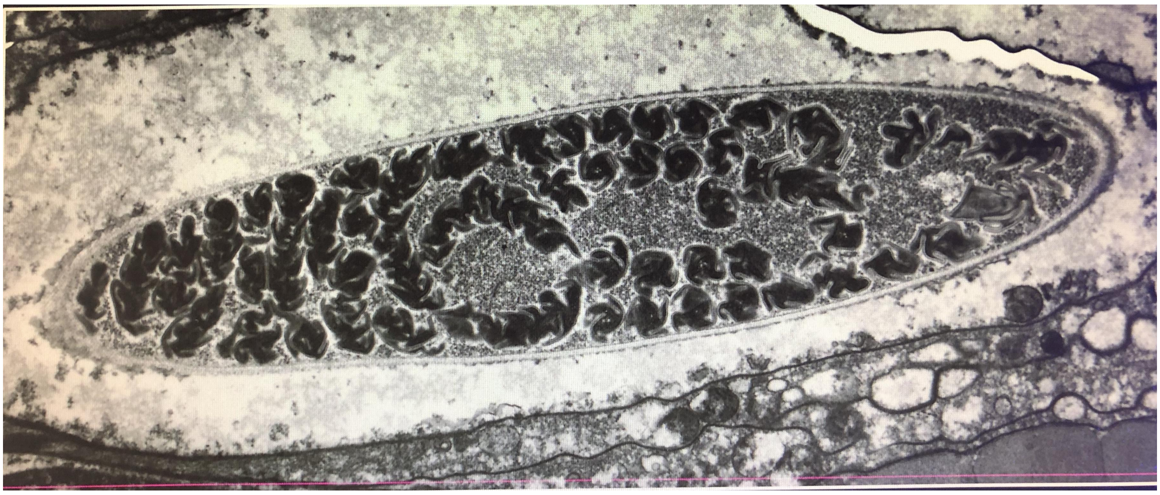

图 6 珊瑚捕捉猎物的结构。注意细胞器内盘绕的刺丝囊(一种天然鱼叉)。在电子显微镜下放大 15900 倍的拍摄的显微照片。佐治亚大学 Denny Aaron 博士和 Steven Poet 提供。

当猎物接触到珊瑚表面的“扳机”时，一个被称为盖子的“门”会弹开，丝状的刺丝囊被释放出来。其中充满了毒液，可以杀死相对较大的猎物。这些有毒的丝也可以用作防御和进攻。刺丝也可以简单地缠住和诱捕猎物。参见图 7。

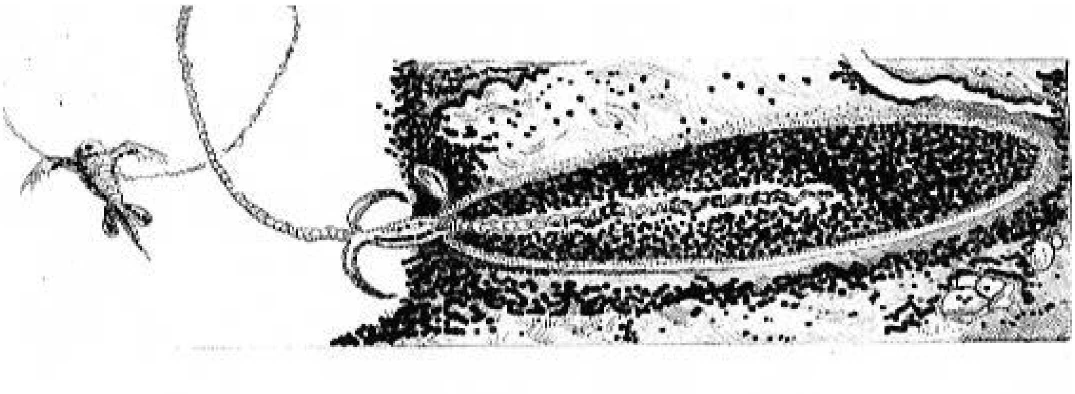

图 7　刺丝囊捕食的示意图

Bacteria

Bacteria (from the Greek word for 'staff cane' since the first discovered resembled rods) are a diverse group of prokaryotic micro-organisms and are thought to be the first organisms on earth. They usually range in size from 0.5 to 5 micrometers in length although a few are much larger and can be visible to the unaided human eye.

Nature is the great recycler of substances and bacteria make this possible. Aquarists are likely most aware of bacteria that cycle nitrogenous compounds (such as the conversion of ammonia to nitrite and nitrate), although those converting carbon, phosphorus, and others are also present.

Bacteria levels in an aquarium can be high or low depending upon water quality management techniques (Feldman et al., 2011.) It seems that tanks with 'aggressive' water management protocols have bacterial numbers less than seen in some marine environments, while passive maintenance (no skimmer, occassional water changes) results in higher bacteria counts.

Sorokin (1973) fed corals with bacterioplankton and found all small-polyp stony corals examined rates of ingestion and assimilation of bacteria. See Figure 8

细菌

细菌(源自希腊单词“手杖”,因为第一次发现的细菌形状是杆状)是一种多样的原核微生物，被认为是地球上的最早的生物之一。它们的长度通常在0.5到5微米的范围内，还有一些更大，并且可以被肉眼看到。

大自然是物质的伟大回收者，细菌使这成为可能。水族科学家很可能最了解参与氮循环的细菌(例如将氨转化为亚硝酸盐和硝酸盐)，剩下的就是那些转化碳、磷和其他物质的细菌。

取决于对水族箱的水质管理技术，水族馆中的细菌水平不尽相同(feldman等，2011年)。看起来，采用“激进”（所谓的设备控，药水控，哈哈）水管理方案的水族箱细菌数量（其实也可能是种类，比如zeo af 这些系统人为加入了一些菌种）少于某些海洋环境，而较少的维护(无蛋白质分离器，换水频率低)的水族箱中细菌数量将会增加。

sorokin (1973年)用浮游细菌喂养珊瑚，发现所有小水螅体石珊瑚（sps）都会摄入细菌（以细菌为食）。参见图8。

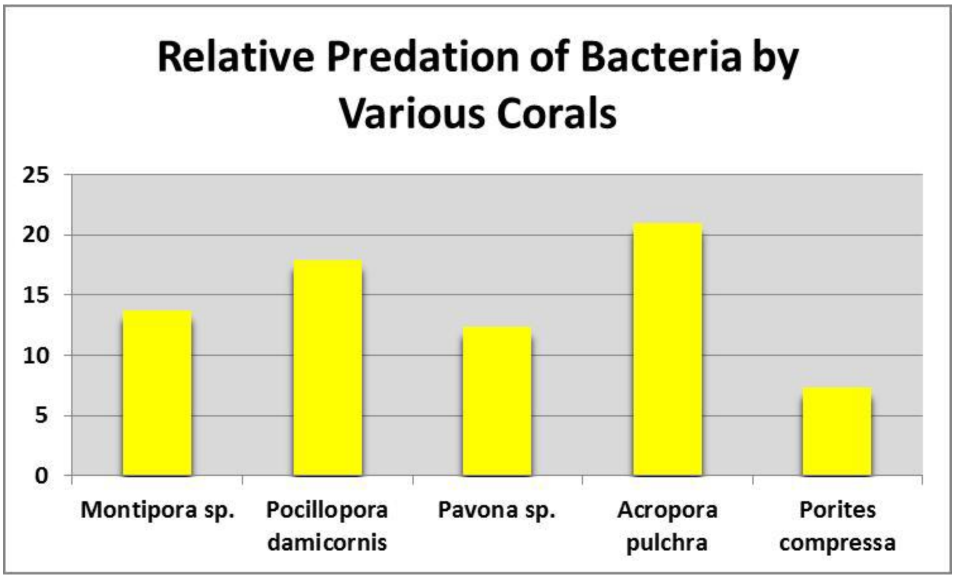

图 8 所有实验中的小水螅体石珊瑚（sps ，里面有我们熟悉的 m 属和 a 属哦）都以细菌为食。来自 sorokin，1973 年。

Predation of Green Algae by Corals

Many consider corals to be ravenous predators of zooplankton, but at least some corals ingest green algae as well. Sorokin (1973) showed that the green alga Platymonas was ingested by small-polyp corals,including Acropora, Montipora, Porites, Pocillopora and Pavona species. Platymonas is often (and easily) cultured by hobbyists as a food for rotifers (Brachionus spp.) and brine shrimp (Artemia spp.) Platymonas cells are approximately 15 micrometers in diameter. See Figures 9 and 10.

许多人认为珊瑚是浮游动物的掠食者，但至少部分珊瑚也同时

摄取绿藻（这个似乎是漂浮在水中的类似小球藻的那种绿藻）。sorokin (1973 年)的研究表明，漂浮在水中的绿藻被珊瑚虫摄入体内，包括 Acropora, Montipora, Porites, Pocillopora and Pavona（这些都是珊瑚的属，前两个就是 a 属和 m 属）都会摄取。水族爱好者经常(也很容易)培养绿球藻（扁形藻）作为轮虫(臂尾轮虫属)和卤虾(卤虫属)的食物。绿球藻（扁形藻）细胞直径约为 15 微米。参见图 9 和 10。

图 9　绿球藻（扁形藻）

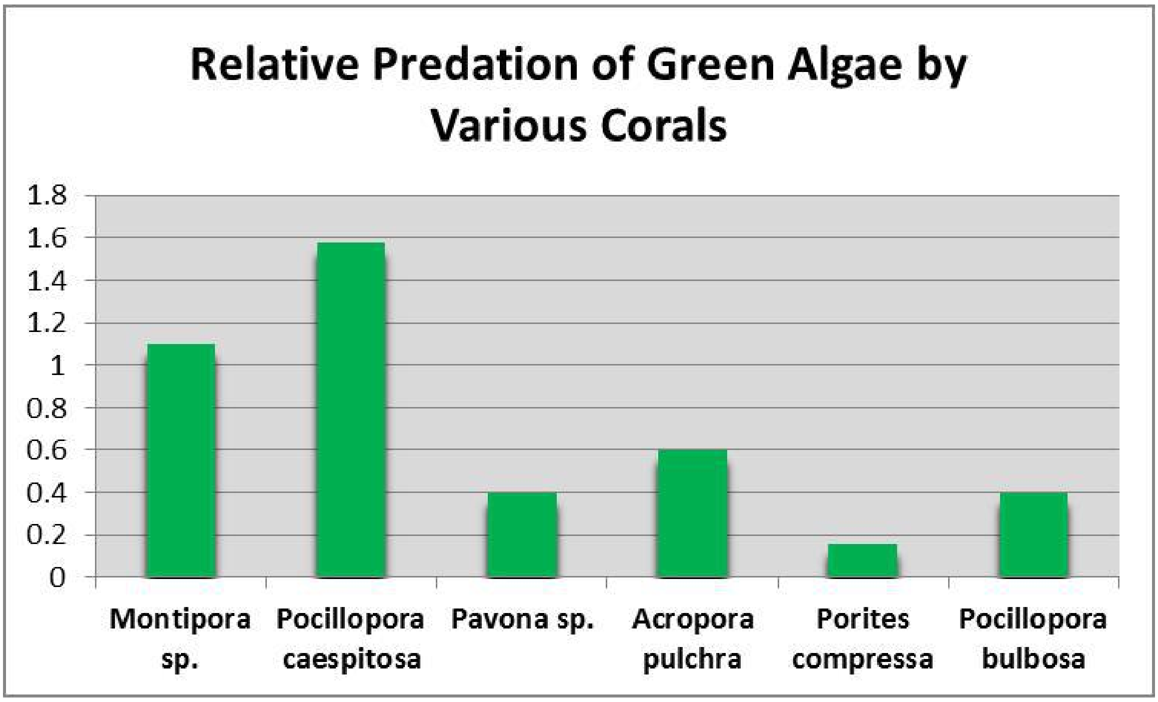

图 10。虽然许多研究人员在实验中使用了浮游动物，但 sorokin (1973)证明小水螅体石珊瑚（sps）也以绿藻(浮游植物)为食。

Predation of Dinoflagellates by Corals:*Amphidinium* and *Gymnodinium*

It is ironic that an animal (coral) dependent upon one dinoflagellate genus (Symbiodinium) would ingest and digest other types of dinoflagellates. Sorokin (1973) found that corals could eat the dinoflagellate genera Amphidinium and Gymnodinium. These dinoflagellates are about 35 – 60 micrometers in diameter.

(Symbiodinium are 6 to 13 micrometers in diameter, depending upon clade or species.) See Figures 11 and 12.

珊瑚对甲藻的捕食:前沟藻属和裸甲藻属

具有讽刺意味的是，依赖于一个甲藻属(共生藻)的动物(珊瑚)会摄取和消化其他类型的甲藻（和一种相依为命，但是吃另外的种）。sorokin (1973 年)发现，珊瑚可以吃前沟藻属和裸甲藻属的甲藻。这些甲藻的直径约为 35-60 微米。(共生甲藻的直径为 6-13 微米，取决于其种类。)参见图 11 和 12。

图 11.前沟藻

图 12 裸甲藻，也是很多珊瑚的食物

As Figure 13 shows, ingestion and digestion of dinoflagellates by corals appears to be species specific with a Pocillopora species ingesting most, while Porites compressa ate none.

如图 13 所示，珊瑚对甲藻的摄取和消化似乎是物种特异性的（不同珊瑚摄取差异很大），*Pocillopora* 属摄取最多，而 *Porites compressa* 属则几乎不摄取。

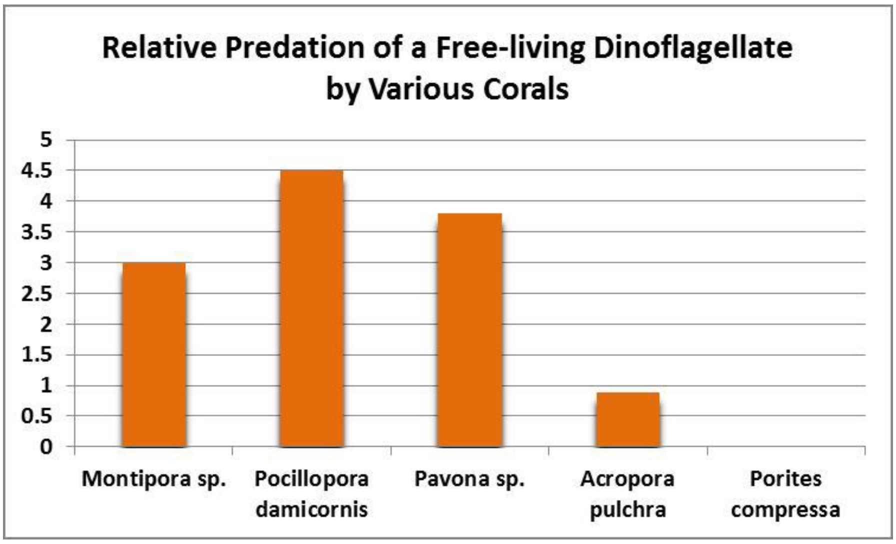

图 13 除 Porites compressa 属外，所有被测试的珊瑚都吃甲藻。来自 Sorokin，1973 年。（看起来 a 属的珊瑚摄取也不多啊）

Predation of Ciliates by Corals

Ciliates are a group of protozoans (from the Greek word ‘protozoon’ where protos = first and zoon = animal) characterized by hair-like structures called cilia. Sorokin (1973) found that corals will ingest the ciliate Euplotes (which are 80-200 micrometers in length.) This ciliate is photosynthetic and contains zoochlorellae (a symbiotic green algae.) See Figure 14.

珊瑚对纤毛虫的捕食

纤毛虫是一类原生动物(来自希腊语“proto zoon ”, proto s =第一， zoon = 动物， 第一种动物。。。),其特征是其体表有被称为纤毛的毛发状结构。sorokin (1973)发现珊瑚会摄取一种纤毛虫（Euplotes）(长度为 80-200 微米)。这种纤毛虫是可以光合作用的，因为其体内含有共生绿藻。参见图 14。

图 14 纤毛虫 （可以看到体内的绿藻）

Brine Shrimp (*Artemia* spp.)

Brine shrimp have been a staple of captive fish and invertebrate culture for decades. It is estimated that 2000 tons of brine shrimp cysts are marketed annually. Their ability to live in brine lakes allows them to grow in tremendous numbers without threat of being eaten by fishes. In addition, their egg cysts can be successfully stored dry for years. Freshly-hatched brine shrimp (nauplii) are ~400 µm in length and have been used in a number of coral feeding experiments. See Figure 15.

丰年虾

几十年来，丰年虾一直是人工饲养的鱼类和无脊椎动物的主食。据估计，每年市场上销售 2000 吨丰年虾。它们在盐水中大量繁殖的能力让他们的数量不会因为鱼类的摄食而受到威胁。此外，它们的卵囊可以干燥保存多年（也能孵化）。新孵化的丰年虾(无节幼体)长约 400 微米，已用于许多珊瑚饲养的实验。参见图 15。

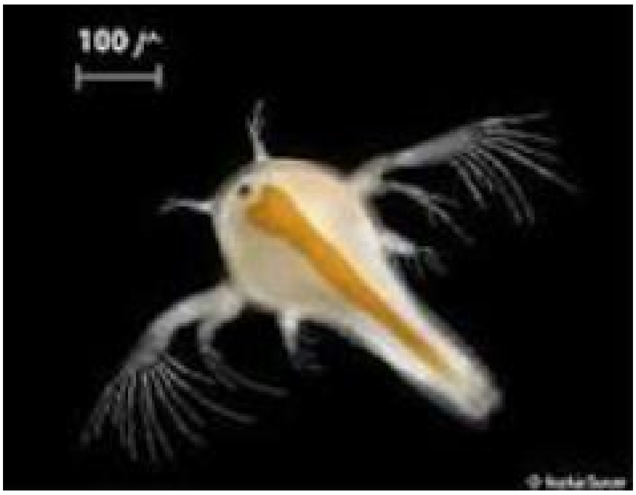

图 15 丰年虫无节幼体，经常用于珊瑚喂养实验。（上面有 100um 的标尺）

Coprophagy: The Scoop on Poop

Coprophagy, or eating of feces, is not a subject commonly discussed in polite company (or impolite company for that matter.) However, it is common in the bacterial world. It is also seen among some reef fish species. Feces can combine with other substances and form ‘marine snow.’

A concise investigation of nutritive value of fish poop was conducted for this article. Information on particle size, and nutrient content (total nitrogen and total phosphorus) will be shown below.

First and foremost, can the particle size be small enough for ingestion by small polyped corals? Samples of fish faeces (from Yellow Tangs (Zebrasoma flavescens) and a Chevron Tang (Ctenochaetus hawaiiensis) were drawn from an aquarium with no substrate ('bare bottom.') These were placed in a 1-liter bottle, capped, and shaken vigorously to simulate maceration by a pump impeller or propeller. The resulting suspension was sequentially filtered through filters with pore sizes of 1.5, 1.0, and 0.45 micrometers. Results are shown in Figure 16.

粪食：大便勺子（这或许是最不雅的小标题了，但是确实是这意思，我也无法把他翻译得更雅观。。。）

在人类世界里，吃粪绝对不是一个常见的话题（这 TM 的废话啊）。然而，它在细菌的世界中很常见，在一些珊瑚和鱼中也可以看到。海洋生物的粪便会与其他物质结合，形成“海洋雪”。（这个其实和我们玩家常见的 zeo 的 snow 不是一个东西，zeo snow 应该是碳酸钙成分居多，但是原理应该差不多，聚合形成珊瑚可捕食的东西。）

本文对鱼粪的营养价值进行了简要的调查。关于颗粒大小和养分含量(总氮和总磷)的信息如下所示。

首先也是最重要的一点是，颗粒大小是否小到足以被珊瑚虫摄取？鱼的粪便样本来自两种虾虎（*Zebrasoma flavescens*）和（*ctenochaetus* *hawaiiensis*）取自一个没有裸底的水族箱。将这些放入 1 升的瓶中，盖上盖子，剧烈摇动以模拟粪便被造浪搅碎的过程。所得悬浮液依次通过孔径为 1.5、1.0 和 0.45 微米的过滤器。结果如图 16 所示。

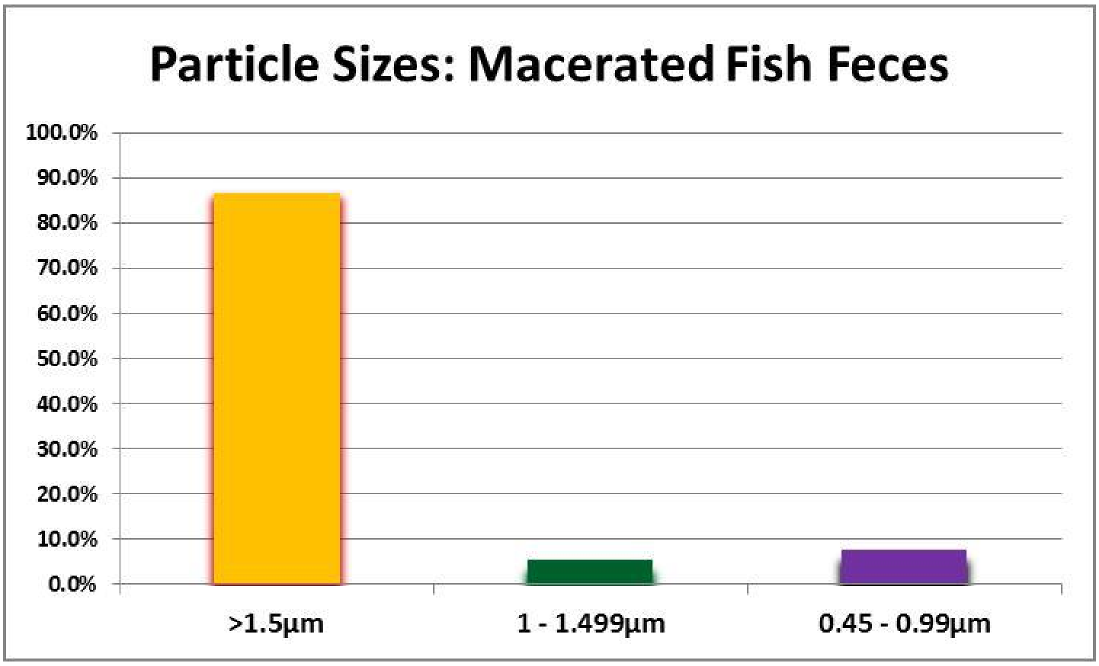

图 16 鱼粪的颗粒大小

As Figure 16 demonstrates, particle size can be small enough to feed any small-polyp stony coral. The second question asks about organic content. To this end, a suspension was filtered through a pre-combusted (and pre-weighed) glass fiber filter with a pore size of 1.5 micrometers. The filter, with captured solids, was dried at 103°C for one hour, cooled in a desiccator, and weighed with an analytical balance. Weight of the dry suspended material within the sample was determined using this formula:

[(a-c) / volume of sample (milliliters)] x 1,000

Once suspended solid content was determined, the filter (with retained material) was placed in a muffle furnace (temperature of 550°C) and volatized for 20 minutes. The volatile content (generally considered to be the organic portion) was determined with this formula:

[(a-b) / volume of sample (milliliters)] x 1,000

where a is filter and sample dry weight; b is weight of volatized filter and sample, and c is dry filter weight. See Figure 17.

如图 16 所示，颗粒大小可以小到足以喂养任何小水螅体石珊瑚（sps）。第二个问题是关于有机成分。为此，将通过孔径为 1.5 微米的悬浮液进行加热，带有过滤出来的固体的过滤器在 103℃中干燥 1 小时，在干燥器中冷却，用分析天平称重。使用以下公式确定样品中干悬浮物质的重量:

[(a-c) / volume of sample (milliliters)] x 1,000

确定悬浮固体含量后，将过滤器(带有剩下的固体)放入高温烘炉(温度为 550 ℃)中 20 分钟。挥发性物质含量(通常被认为是有机部分，也就是是 20 分钟后损失的部分)由以下公式确定：

[(a-b) / volume of sample (milliliters)] x 1,000

其中 a 是过滤器和样品干重；b 是挥发过滤器和样品的重量，c 是干燥过滤器的重量。参见图 17。

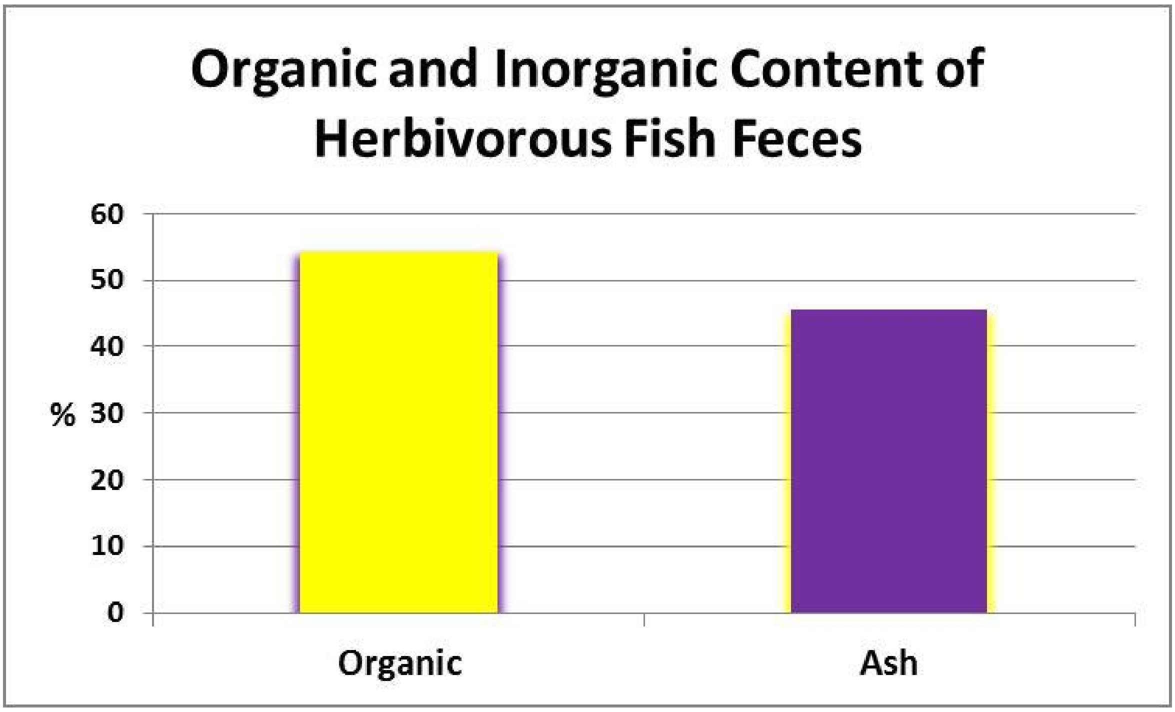

图 17　无机成分（也就是灰分 ASH）几乎占鱼粪便的一半重量

We have determined macerated fish waste is potentially of the correct size for ingestion by small polyp stony corals and that it has substantial organic content. The next examinations were for Total Nitrogen and Reactive, Condensed and Total Phosphorus.

A dearth of nitrogen can limit growth in any organism, hence the Total Nitrogen content of fish waste was determined. This procedure involves chemical oxidation of the sample with heat acting as a catalyst. Figure 18 shows the result.

我们已经确定浸软的鱼粪便的颗粒可能具有适合小水螅体石珊瑚摄取的大小，并且含有大量的有机成分。接下来的研究是总氮、总磷。

氮的缺乏会限制任何生物的生长，因此鱼粪便的总氮含量需要被测定。该测试程序涉及样品的化学氧化，以热量作为催化剂。图 18 显示了结果。

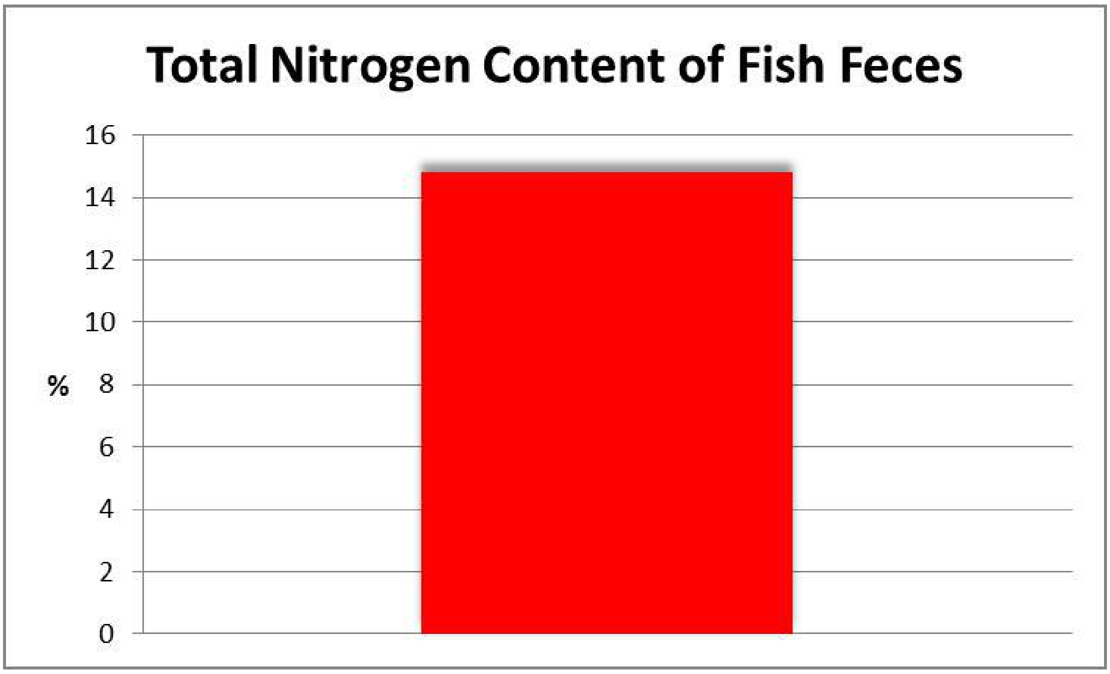

图 18 正如预期的那样，粪便样本中总氮含量约为 15%。

According to Liebig's Law of the Minimum, plant growth (including zooxanthellae) will be poor if one necessary nutrient is absent even if all others are in plentiful supply. Hence, Reactive phosphorus (orthophosphate) is often targeted for removal as it promotes algae growth and is easily removed chemically. It is possible to take orthophosphate to levels undetectable by sophisticated instrumens. However, particulates suspended in the water column can contain phosphorus. Total Phosphorus content was determined by oxidation with persulfate and applied heat. Acid Hydrolyzable Phosphorus was determined by conversion to orthophosphate through use of acid and heat. Orthophosphate was tested colorimetrically (the method used by most hobbyists. See further clarification of these types of phosphorus below.) The results are shown in Figure 19.

根据李比希最小养分定律，如果一种必需的营养缺乏，即使所有其他营养都充足，藻类生长(包括虫黄藻)也会很差。因此，磷(磷酸盐)通常是水族爱好者去除的目标，因为它促进藻类生长，并且易于采用化学方法去除。把磷酸盐降低到用精密仪器检测不到的水平是可能的。然而，悬浮在水体中的微粒可能含有磷。总磷含量通过用过硫酸盐氧化和加热来测定。通过使用酸和热转化成磷酸盐来测定可水解磷。而正磷酸盐（活性磷酸盐）的含量则用比色法来测定(大多数业余爱好者使用的方法，见下文对这

些类型磷的进一步说明。)（其实所谓的 hanna 蛋鸡也是比色法，只不过是机器比色而已）结果如图 19 所示。

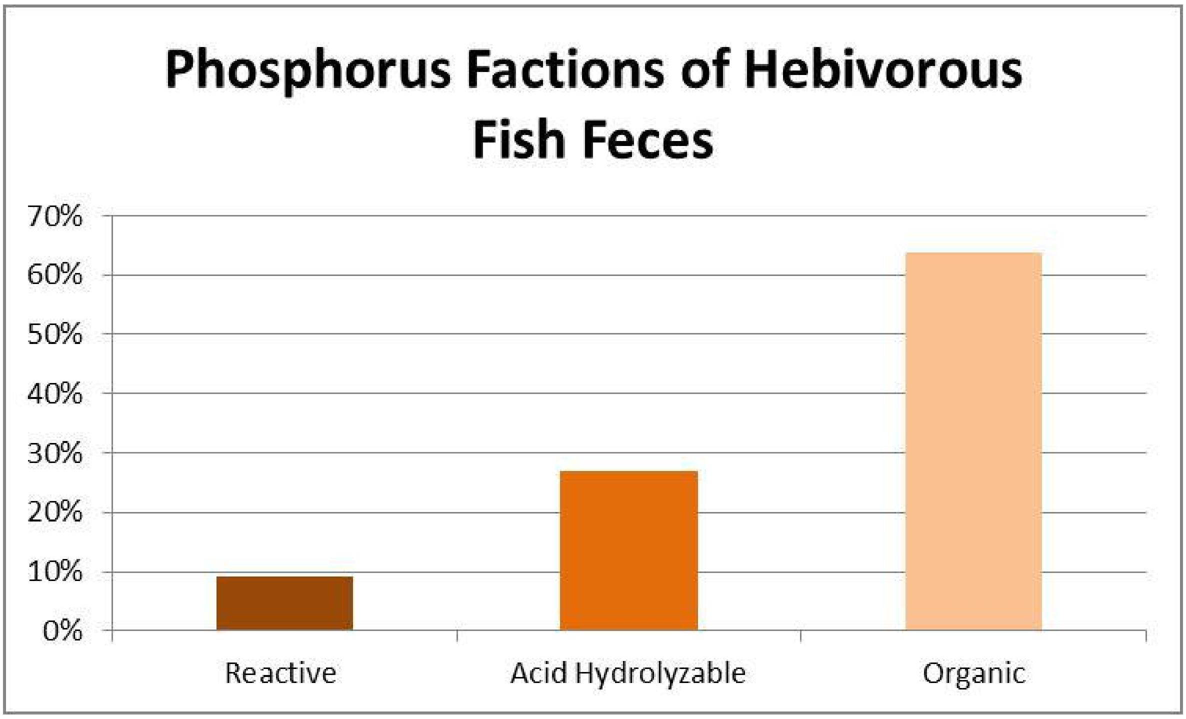

图 19 磷含量。有机磷约占 60%，聚合磷占不到 30%，而活性磷约占 10%。（我们水族中用比色法测量的磷指的是活性磷，也就是后面说的正磷酸盐）

1. ReactivePhosphateor orthophosphate: Reactive P (also called ortho-phosphate) is ‘bio-available’ for promotion of algae growth. Reactive P can be dissolved or suspended. Colorimetric tests forphosphates commonly available to hobbyists measure only orthophosphates although small amounts of easily hydrolysable inorganic and organic P might be included in the result. The most abundant forms of orthophosphates occurring between pH 5 to 9 in

aquatic environments are HPO4-2, H2PO4–, PO4-3, HPO4-2, and H2PO4(Stumm and Morgan, 1981).

2.Acid-hydrolyzable (A-H) Phosphate or CondensedPhosphate: Acid-hydrolyzable P can be found as dissolved or suspended forms. It may be in pyro-, meta-, tripoly-, and other forms of polyphosphates (such as hexametaphosphate). The term ‘acid-hydrolyzable’ is preferred over ‘condensed’. Phosphorus in the sample as measured by the sulfuric acid hydrolysis procedure, then pre-determined orthophosphates are subtracted (EPA, 1979). The acid-hydrolysis method reports dissolved and particulate condensedphosphatethat is converted to dissolved orthophosphate through acidification of the sample (APHA, 1998). It is referred to as Dissolved Hydrolyzable P or Total Hydrolyzable P, when filtered or unfiltered samples are tested respectively.

3.Total Phosphorus: The sum of organic and inorganic forms of phosphorus. As with reactive and condensed P, Total P can either dissolved or suspended. It is determined colorimetrically only after a severe oxidative digestion process where Total P is converted to orthophosphate.

1.活性磷酸盐或正磷酸盐:活性磷(也称为正磷酸盐)是促进藻类生长的“生物可利用的磷”。活性磷可以溶解或在水体中悬浮。业余爱好者通常可使用的磷酸盐比色试验仪测量活性磷，尽管结果中可能包含少量易水解的无机和有机磷。在水生环境中，ph 值为 5 至 9 的时候，活性磷最丰富的形式是 hpo_4^{-2}、$h_2po_4^{-}$、po_4^{-3}、hpo_4^{-2} 和 h_2po_4(stum 和 morgan，1981 年)。

2.可酸水解的(A-H)磷酸盐或聚合磷酸盐:可酸水解的 p 可以溶解或悬浮的形式存在。它可以是焦磷酸盐、偏磷酸盐、三聚磷酸盐和其他形式的聚磷酸盐(如六偏磷酸盐)。把其称为“酸可水解的”比“聚合的”更为贴切。通过硫酸水解程序测量样品中的磷，然后减去事先测定的正磷酸盐(EPA，1979)。酸水解法报告称，通过样品酸化，溶解的和微粒状的聚合磷酸盐转化为溶解的正磷酸盐(apha，1998 年)(也就是前文所说的一般水族爱好者用比色法测量的活性磷酸盐）。当分别测试过滤的和未过滤的样品时，它被称为溶解的可水解磷和总的可水解磷。

3.总磷:有机和无机磷的总和。与活性磷和聚合磷一样，总磷可以溶解或悬浮。只有在剧烈的反应过程后，总磷转化为正磷酸盐（活性磷），才能用比色法测定。

（这一段关于磷的有些晦涩，大致的意思是我们平时用比色法测定的磷---有机磷应该只是缸里磷元素的一小部分，也是这一小部分磷对水族箱生物的影响比较大，但是其他部分的磷在一定条件下是会转化成这类磷的。书到用时方恨少，这段翻译得非

常艰难，水平感觉也很拉胯。。）

Size of Particulates in Aquarium Water

Water clarity is an important aesthetic issue in an aquarium; hence mechanical filtration is often employed to this end. Hobbyists might be surprised to learn that, even with mechanical (micron cartridges, filter socks) there is still a considerable amount of material suspended in the aquarium water.

Testing of water from a biologically under loaded aquarium showed the water contained over 3 mg/L of particles with a diameter of at least 1.5 µm (slightly less than half of this material was organic in nature.) A filter with a pore size of 0.45 µm retained 1.5 mg/L suspended solids. This aquarium utilizes a filter sock with a pore size of 200 micrometers for mechanical filtration. See Figure 20.

水族箱水中微粒的大小

在水族箱中，为了美观，透明度是爱好者关注的一个问题，为此通常采用机械过滤。但爱好者可能会惊讶地发现，即使使用了机械设备(滤筒、过滤袋)，水族箱的水中仍然悬浮着大量的物

质。

对一个生物量较低的水族箱的水进行的测试表明，水中含有超过 3 毫克/升的直径至少为 1.5 微米的颗粒(这种物质中有不到一半是有机的)。孔径为 0.45 微米的过滤器过滤了 1.5 毫克/升的悬浮固体（也就是说大于 0.45 微米的悬浮固体密度大约为 1.5 毫克/升）。这个水族箱用孔径为 200 微米的过滤袋进行机械过滤（也就是说这个水族箱 200 微米以上的悬浮固体应该是比较少的）。参见图 20。

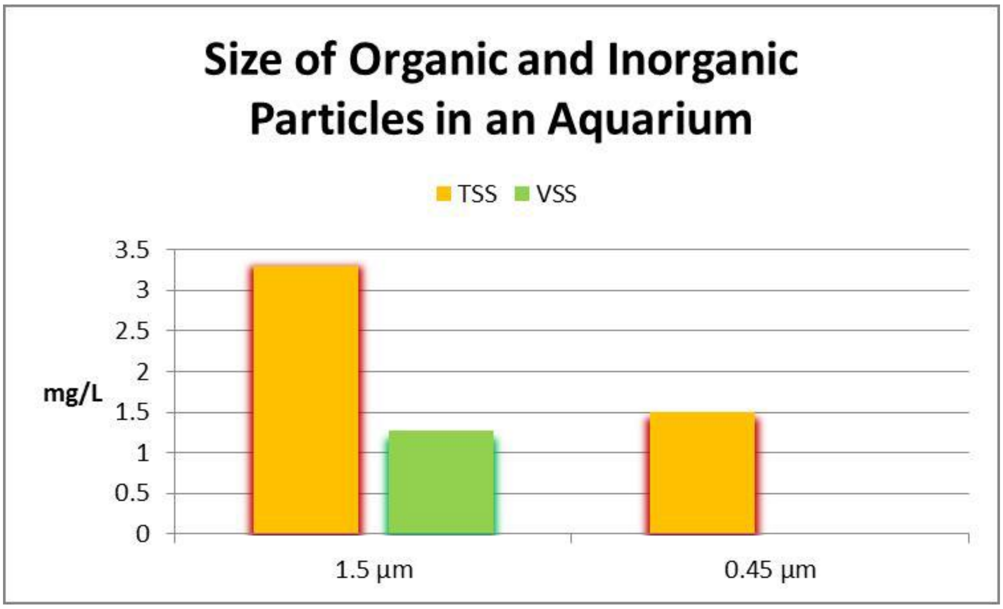

图 20。水族馆水中的微粒物质。这个水族箱含有约 1.3 毫克/升的有机物质，其颗粒大小至少为 1.5 微米。由于用于确定较小颗粒物质的过滤器是由纤维素（本身就是有机质）制成的，因此不能确定更小的颗粒物是有机还是无机。

Marine Snow

Marine Snow is a term for conglomerations of suspended organic matter. On coral reefs, marine snow can be composed of remains of dead organisms including animals, plants and algae, coral mucus (which harbors bacteria), fecal matter, and other material.

海洋雪

海洋雪是悬浮有机物聚集物的统称。在珊瑚礁，海洋雪可以由死亡生物的遗骸组成（在我们的鱼缸中，海洋雪可以是 ZEO 的 snow 加珊瑚粮，哈哈。。再次说明了这个海洋雪和我们的水族箱产品是不一样的，但原理有点类似。。），包括动物、植物和藻类、珊瑚粘液(含有细菌)、粪便和其他物质。

Dissolved Food Sources

To begin our discussion of dissolved substances, we should define the word 'dissolved.' Generally, a substance deemed to be dissolved is one that will pass through a filter with a very small pore size (often 0.2 – 0.45 micrometer in diameter.)

There are many categories of dissolved food sources. Some contain carbon, while others contain nitrogen or phosphorus, combinations of these, or any of many others.

An examination of metal uptake for use in skeleton formation will be the subject of a separate article.

溶解的食物来源（水中的溶解物作为珊瑚的食物来源）

开始讨论溶解物质时，我们首先对“溶解”一词进行定义。一般来说，被认为是溶解的物质是通过孔径非常小(通常直径为 0.2-0.45 微米)的过滤器的物质（也就是说小于 0.2 微米或者至少小于 0.45 微米的物质就被称为是溶解于水中，区别于前面一段的在水中悬浮的物质）。

溶解食物的来源种类繁多。一些含有碳，而另一些含有氮或磷，又或者是这几种的组合或者其他。

对用于珊瑚骨骼形成的金属元素的吸收的将于单独的文章进行讨论。（这篇只讨论食物。。。）

Absorption

From the Latin word absorbere, meaning ‘to suck in, swallow,’ absorption of dissolved substances is an important process in coral nutrition. Water motion must be sufficient to minimize the momentum boundary layer (or MBL – a ‘coating’ of stagnant water that surrounds the coral, or any other aquatic animal for that matter.)

If water velocity does not minimize the MBL, concentration gradients may exist and these could potentially rob the animal/symbionts of necessary nutriment.

吸收

来源于拉丁语 *absorbere*，意思是“吸入，吞咽”，吸收溶解的物质是珊瑚获得营养的一个重要过程。水的运动必须足以最小化动量边界层(或 MBL——围绕珊瑚或任何其他水生动物的一层水的“涂层”)如果水流速度不能使 MBL 最小化，则可能存在浓度梯度(外界高,接近珊瑚浓度却变低,让珊瑚得不到足够的营养)，这可能会让珊瑚或它的共生藻不能获得所需的营养。（又一次提到这个动量边界层，所以我一直是强水流的拥趸，sps 珊瑚的进食绝不仅仅是触手捕捉，还有更多的玄机）

Dissolved Organic Material (DOM)

Dissolved Organic Material (DOM) is a broad classification of mainly carbon-based compounds found in water. Coastal seawater contains 3-6 mg/l organic carbon (Chailow, 1971.) Coral researchers have used various compounds in DOM-uptake experiments including algal extracts, dissolved amino acids, and sugars.

Sorokin (1973) examined the uptake of DOM by various corals. This particular compound was hydrolyzate of algal protein (various amino acids produced by ‘splitting’ algal proteins with an acid, followed by neutralization of acidic pH. Hence, this DOM contains carbon, nitrogen, and relatively minor amounts of phosphate and others.)

Dissolved Organic Carbon (DOC)

Dissolved Organic Carbon is a broad category of organic substances found in aquatic environments. DOC usually is a result of decaying animal or plant matter, although it can be the result of materials leached by marine plants and algae. Some DOC compounds (sugars, for example) are said to be labile, meaning they are easily consumed by bacteria. Others are refractory and are not easily used by bacteria.

Dissolved Inorganic Carbon (DIC) can exist in the forms of carbon dioxide, carbonic acid, carbonates and bicarbonates.

Total Organic Carbon

Total Organic Carbon (TOC) is the sum of particulate and dissolved organic carbon. Aquarium water contains up to 1.5 mg/L TOC (Feldman et al., 2009) if protein skimming is used. It presumably could be higher if no aggressive means of water quality management are used.

溶解的有机物质（DOM）

溶解的有机物质(dom)范围广泛，主要是指在水中发现的碳基化合物。沿海海水含有 3-6 毫克/升的有机碳(chailow，1971 年。)珊瑚研究人员在溶解有机物（dom）摄取实验中则使用了各种化合物，包括藻类提取物、溶解的氨基酸和糖（也就是说这些都可被称为溶解有机物）。

sorokin (1973)研究了各种珊瑚对 dom 的吸收。用于研究的这种特殊的化合物是藻类蛋白质的水解产物(各种氨基酸，这些氨基酸是通过用酸“裂解”藻类蛋白质，然后再予以中和其酸性的 ph 值而产生的。因此，这种 dom 含有碳、氮和相对少量的磷酸盐及其他物质）。

溶解有机碳(doc)

溶解有机碳是在水生环境中发现的一大类有机物质。doc 通常是腐烂的动物或植物形成的，尽管它也可能是海洋植物和某些藻类分泌的一些物质形成的。一些 doc 化合物(例如糖)据说是不稳定的，这意味着它们容易被细菌消耗。其他的是较为稳定的，不容易被细菌利用。

而另一方面，溶解的无机碳(dic)可以以二氧化碳、碳酸、碳酸盐和碳酸氢盐的形式存在。

总有机碳(TOC)

总有机碳(toc)是颗粒和溶解有机碳的总和。如果使用了蛋白质分离器，水族箱中的总有机碳含量高达 1.5 毫克/升(feldman 等人，2009 年)（当然这个只是针对这个实验，每个水族箱的情况可能不一样，仅供参考）。如果不使用积极的水质管理手段，这个数字可能会更高。

Primary Production

'Primary production' refers to the manufacture of organic compounds by plants and algae.

As Figure 21 shows, dissolved organic carbon in the form of sugars is by far the major sort of organic matter released, followed by dissolved combined amino acids.

These are some of the sugars produced and released to the surrounding water:

Glucose ($C_6H_{12}O_6$) is a simple sugar and an important product of photosynthesis. Glucose is used by cells as an energy source and is also a precursor to amino acids and fatty acids.

Galactose ($C_6H_{12}O_6$) : From the Greek word galakt or milk, it is a simple sugar and is an epimer of glucose (that is, the chemical formula of galactose is the same as that as glucose, but its structure is slightly different.)

Mannose ($C_6H_{12}O_6$) is also an epimer of glucose.

Xylose ($C_5H_{10}O_5$): First isolated from wood, xylose's name originates from the Greek word xylon, or wood.

Arabinose ($C_5H_{10}O_5$) found in pectin (from cell walls in terrestrial plants and often used as a gelling agent) and hemicellulose (also found in plant cell walls.)

Rhamnose ($C_6H_{12}O_5$)

Fucose ($C_6H_{12}O_5$)

Sucrose ($C_5H_{10}O_5$) an epimer of arabinose

Ribose ($C_5H_{10}O_5$)

初级生产力

“初级产品”指水生植物和藻类制造的有机化合物。

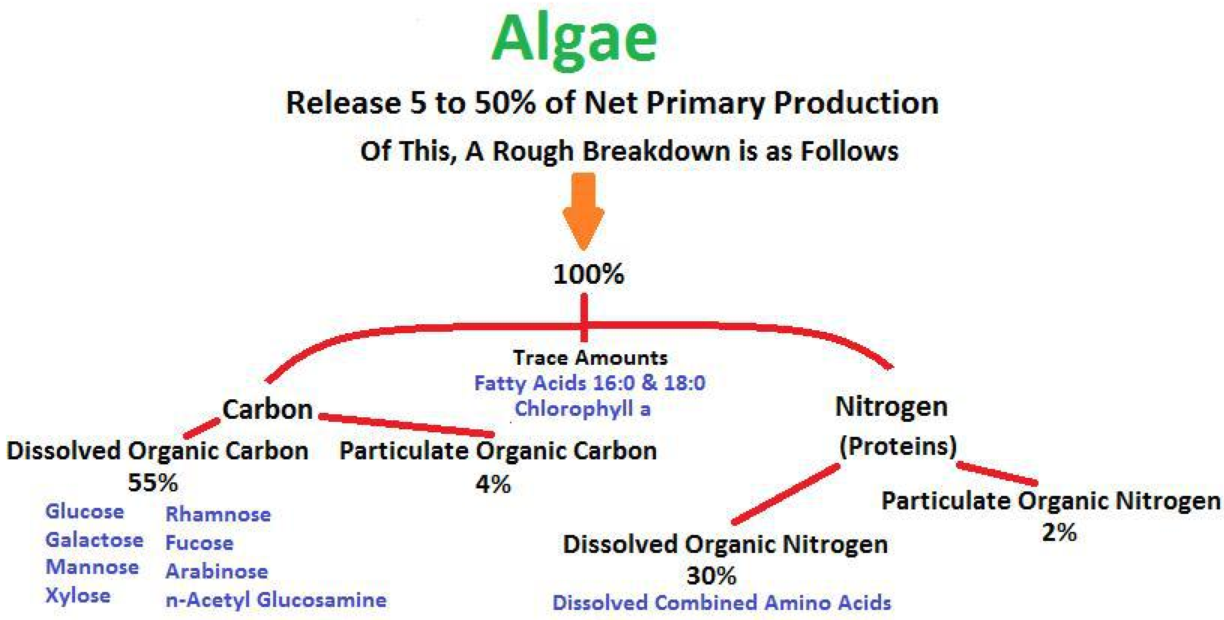

图 21 *Caulerpa* 和 *Halimeda*（这是两种海洋藻类）可以释放一些珊瑚可以用作食物的化合物。

如图 21 所示，以糖形式存在的溶解有机碳是目前释放的主要有机物，其次是溶解的复合氨基酸。

这些是初级生产者生产并释放到周围水中的一些糖：

. 葡萄糖($C_6H_{12}O_6$)是一种简单的糖，也是光合作用的重要产物。葡萄糖为细胞提供能量，也是氨基酸和脂肪酸的前体。

. 半乳糖($C_6H_{12}O_6$)：名字来源于希腊语单词 galakt 或 milk（奶），它也是一种简单的糖，是葡萄糖的差向异构体(也就是说，半乳糖的化学式与葡萄糖相同，但其结构略有不同）。

. 甘露糖($C_6H_{12}O_6$)：同上，也是葡萄糖的差向异构体。

. 木糖 ($C_5H_{10}O_5$)：木糖最初是从木头中分离出来的，它的名字来源于希腊语单词木糖，或木头。

. 阿拉伯糖($C_5H_{10}O_5$)：存在于果胶（阿拉伯糖本来也叫果胶糖）

(来自陆生植物的细胞壁，通常用作胶凝剂)和半纤维素(也存在于植物细胞壁中）中。

. 鼠李糖 ($C_6H_{12}O_5$)。（这个好像是一种甜味剂）

. 海藻糖($C_6H_{12}O_5$)。

.蔗糖($C_5H_{10}O_5$)。

.核糖($C_5H_{10}O_5$)。

Release of Organic Carbon by Marine Algae

It is well known that zooxanthellae within coral tissues are ‘leaky’ and provide some of their photosynthetic products. The same applies to micro- and macro-algae growing within the aquarium.

Carbohydrates Released by *Caulerpa* and *Halimeda* Algae

Figures 21 and 22 examine the release of organic material (in the form of carbohydrates) by algae commonly maintained in aquaria – Caulerpa and the calcifying Halimeda.

As Figure 22 demonstrates, algae commonly found in marine aquaria can release a number of sugars, so it would seem there would be a steady supply of carbohydrates. Or is there? Stephens (1962) examined sugar uptake by the solitary stony coral Fungia scutaria and found, at least for this coral, that glucose is the most preferred compound. See Figure 23.

海藻释放有机碳（这里指非共生的微型和大型藻）

众所周知，珊瑚组织中的虫黄藻是“渗漏的”（其实就是说虫黄藻会释放一些东西，漏勺。。），会释放出一些光合产物。水族馆内生长的微型和大型藻类也同样如此。

Caulerpa 和 *Halimeda* （两种海洋藻类）释放的碳水化合物

图 21 和 22 显示了水族箱中常见藻类释放有机物质(以碳水化合物的形式，就是前面列的各种糖)，Caulerpa 和 the calcifying Halimeda.（两种海洋藻类名字）

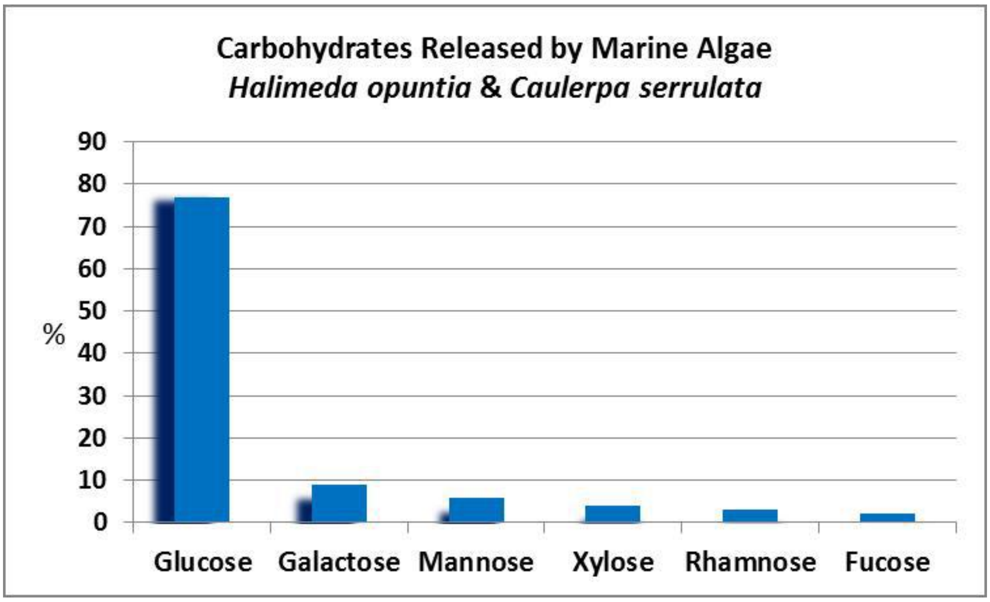

图 22 碳水化合物-糖-由水族馆中常见的藻类释放。

如图 22 所示，在海洋水族箱中发现的藻类可以释放出大量

的糖，所以看起来碳水化合物的供应应该（珊瑚需要的）是稳定的。是这样的吗？stephens (1962)研究了 Fungia scutaria（一种珊瑚，查阅资料应该是类似飞盘珊瑚的品种）对糖的吸收，发现至少对这种珊瑚来说，葡萄糖是最优选的化合物。参见图 23。

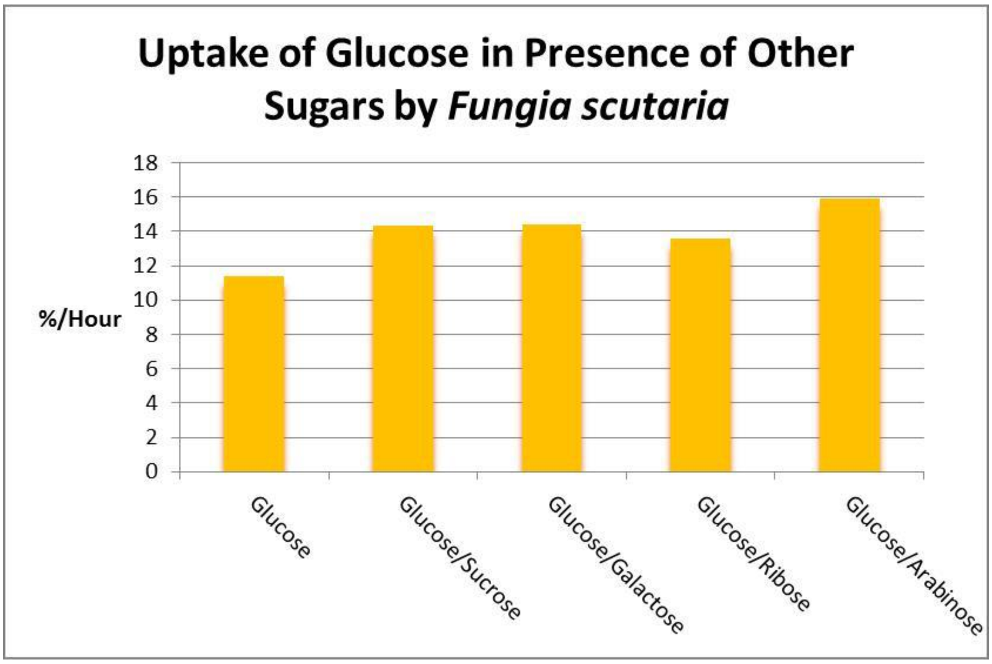

图 23。Fungia scutaria 珊瑚对糖的吸收，葡萄糖吸收量很高。Stephens，1962 年。

Dissolved Inorganic Nitrogen

Dissolved Inorganic Nitrogen is defined as the sum of ammonia/ammonium, nitrite, nitrate, and nitrogen gas.

Since nitrogen gas composes ~79% of earth's atmosphere, it is only natural that seawater contains dissolved nitrogen gas. Nitrogen gas is not readily bio-available to organisms except for a group of bacteria that possess the ability to 'fix' this gas. These bacteria generally have a symbiotic relationship with a number of plants (such as peanut plants, alfalfa, and others.) When these cyanobacteria die (or are eaten) the nitrogen within their tissues is available as fertilizer.

Lesser et al. (2004) found symbiotic nitrogen-fixing cyanobacteria in the Caribbean stony coral Montastrea cavernosa. Interestingly, the reddish-orange color of the coral is due to the presence of phycoerythrin within the bacteria. When the bacteria die and decompose within the tissues of the coral, they potentially provide a source of nitrogen. I have some reason to believe these cyanobacteria also exist in some (not all) orange Montipora digitata specimens. As discussed earlier in this article, Jeong et al. (2012) found Symbiodinium acquired from the stony coral Alveopora japonica can feed on Synechococcusspp., cyanobacteria thought to fix nitrogen gas. It is an interesting thought that some corals could host a symbiont capable of supplying organic nitrogen manufactured from dissolved nitrogen gas.

Uptake of Inorganic Nitrogen: Ammonia and Nitrates

As organic nitrogen compounds degrade, they become ammonia and eventually nitrates through actions of aerobic bacteria. Ammonia and nitrate can be absorbed by at least some corals. See Figure 24 (which demonstrates that ammonia/ammonium is the preferred source of inorganic nitrogen.)

Tests have shown that ammonia spikes occur just after feeding fishes in an aquarium.

溶解无机氮

氨/铵、亚硝酸盐、硝酸盐和氮气的总和定义为溶解的无机氮。

由于氮气占地球大气的79%,海水中含有溶解的氮气是很自然的事情。

除了通过一群具有“固定”这种气体能力的细菌之外,生物不容易靠自身获得氮气。这些细菌通常与许多植物有共生关系(如花生植物、苜蓿等)。当这些细菌死亡(或被吃掉)时,它们组织中的氮可以作为肥料被植物所利用。

lesser 等人(2004 年)在加勒比石珊瑚中（Caribbean stony coral *Montastrea cavernosa*）发现共生固氮蓝细菌。有趣的是，这种珊瑚的橙红色是由于蓝细菌中存在的藻红蛋白。当细菌死亡并在珊瑚组织内分解时，它们就有可能成为氮源。我有理由相信这些蓝细菌也存在于一些(不是全部)橙色的 digi Tata montipora 珊瑚（m 属珊瑚，DIG MONTI ，但是其实好像橙色的 m 属不多啊）中。正如本文前面所讨论的，jeong 等人(2012 年)发现从 *Alveopora japonica* （某一种石珊瑚）中获得的共生藻可以蓝细菌为食（这种蓝细菌可以固定氮气）。一个有趣的想法是，一些珊瑚可能拥有能够供应由溶解的氮气制造的有机氮的共生体（藻）。（这段扯来扯去就是固氮细菌提供氮源，然后细菌是生活在珊瑚体内的或

者共生藻体内的，珊瑚通过消化死亡的细菌或通过共生藻来获得氮源）

无机氮的吸收:氨和硝酸盐

随着有机氮化合物的降解，它们通过需氧细菌的作用变成氨并最终变成硝酸盐（有机氮到无机氮）。氨和硝酸盐可以被一些珊瑚吸收。见图 24(显示氨/铵是无机氮的优选来源。）

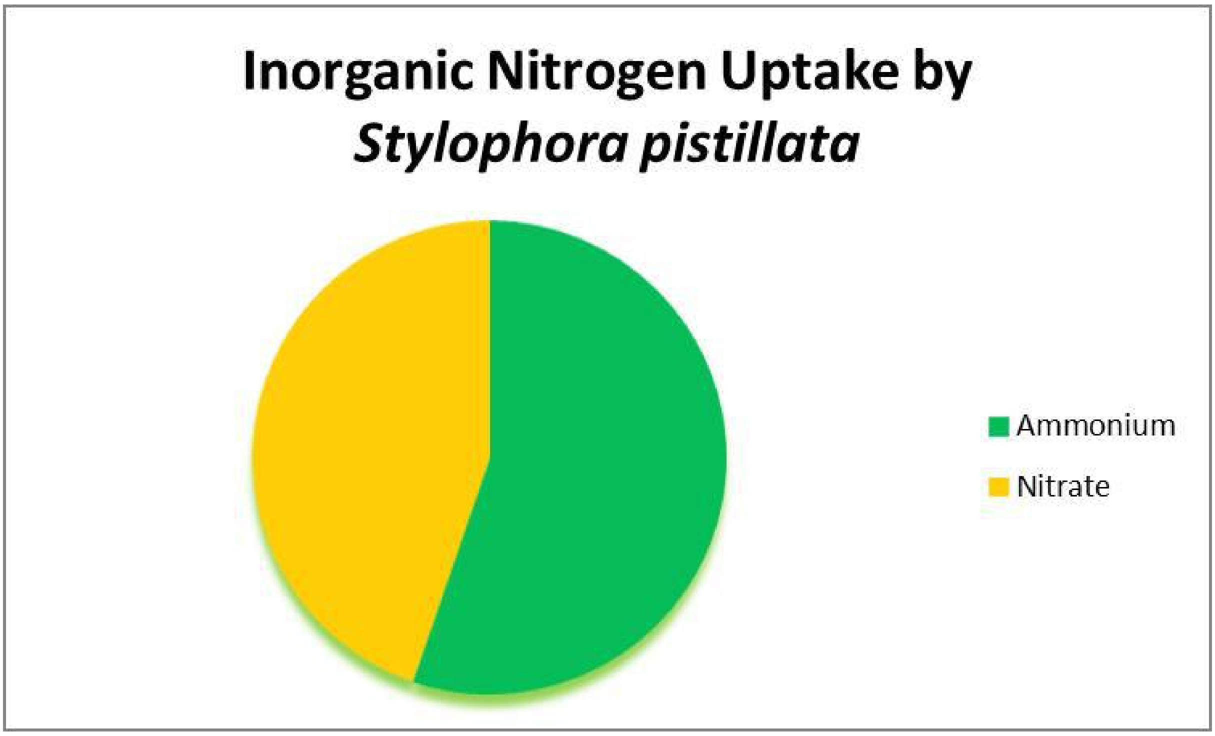

图 24.铵是这种石质珊瑚的首选氮源，即使只是少量的。

测试表明，氨峰值发生在水族箱喂鱼之后。

Dissolved Organic Nitrogen

Dissolved Organic Nitrogen can exist in many forms – as urea, dissolved free amino acids, combined amino acids, and so on.

Urea

Produced by mammals and some marine fishes, urea (CH_4N_2O)

is a major end product of nitrogen metabolism. The stony coralStylophora pistillata can absorb urea and other organic nitrogen sources. See Figure 25.

Urea eventually degrades to ammonia and becomes a source of inorganic nitrogen.

This researcher also found that the stony coral Stylophora pistillata can absorb dissolved free amino acids. Note: A future article will be devoted to the importance of amino acids in coral nutrition.

溶解有机氮

溶解的有机氮可以以多种形式存在——如尿素、溶解的游离氨基酸、混合氨基酸等。

尿素

尿素(CH_4N_2O)由哺乳动物和一些海洋鱼类产生，是氮代谢的主要终产物。*Stylophora pistillata*（一种硬骨珊瑚）可以吸收尿素和其他有机氮源。参见图25。

尿素最终降解成氨，成为无机氮的来源。

该研究人员还发现，*Stylophora pistillata*（一种硬骨珊瑚）可以吸收溶解的游离氨基酸。注:未来的文章(就在这6篇文章中，有一篇专门讨论氨基酸）将讨论氨基酸在珊瑚营养中的重要性。

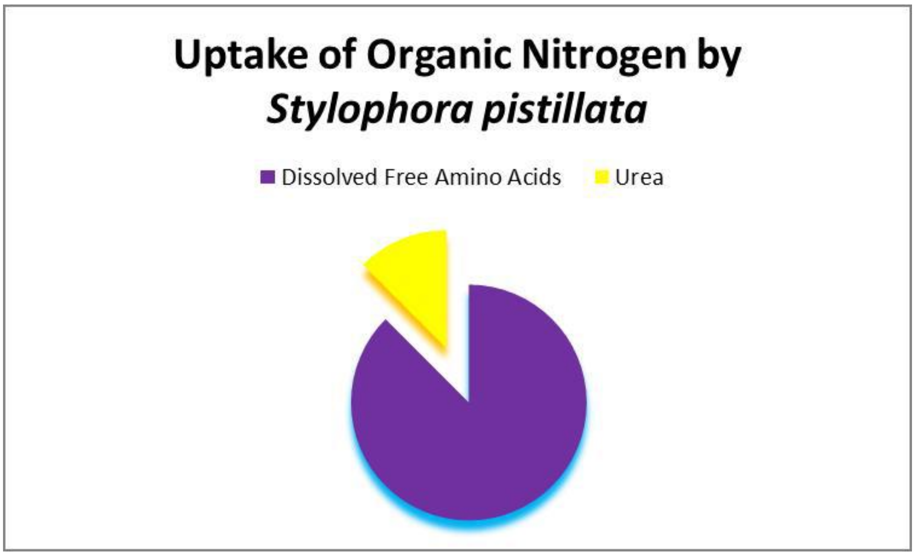

图 25.溶解的有机氮包括尿素、游离氨基酸和结合氨基酸等。grover 等人，2008 年

Dissolved Inorganic Phosphorus (DIP)

Dissolved inorganic phosphorus generally refers to ortho-phosphate (or reactive phosphate.) Ortho-phosphate is the sort of nutrient that stimulates plant and/or algal growths. While it is tempting to think that ortho-phosphate could be a primary source of phosphorus in nutrient-scarce waters, it is not. Sorokin (1973) found that many corals popular in the aquarium trade (Acropora,Montipora, Pocillopora, etc.) actually obtain more phosphorus by ingesting bacteria that have organic phosphorus bound in their cellular walls.

溶解无机磷

溶解的无机磷通常指正磷酸盐(或活性磷酸盐)。正磷酸盐是一种刺激植物和/或藻类生长的营养物质。（这就是我们用蛋机或者莎利法这种机器或者肉眼比色法测出来的所谓磷酸盐）尽管人们很容易认为正磷酸盐可能是缺乏营养的水体中磷的主要来源，但事实并非如此。sorokin (1973)发现，许多在水族贸易中很受欢迎的珊瑚(acropora、montipora、pocillopora 等)（鹿角、瓦片和 p 属，哈哈），实际上通过摄取细胞壁中结合有机磷的细菌来获得更多的磷。(所以说蛋机测零有问题吗，无问题。。)

In Closing

We have examined corals' uptake of various dissolved substances (carbohydrates, inorganic and organic phosphorus, as well as inorganic and organic forms of nitrogen.)

.At least some Symbiodinium species can ingest and assimilate bacteria, cyanobacteria, and algae.

.Corals can capture particulate food particles by use of stinging cells or mucus net.

.Prey capture can be a function of concentration and water movement.

.Small polyp stony corals can ingest particles ranging in size from 0.45 µm to ~400 µm and perhaps larger (see Figure 26.)

最后（结论）

我们研究了珊瑚对各种溶解物质(碳水化合物、无机和有机磷，以及无机和有机形式的氮)的吸收。

.至少一些珊瑚的共生体物种可以摄取和吸收细菌、蓝细菌和藻类。（这句我始终没有很理解，是共生藻吗，还是珊瑚自身？）

.珊瑚可以利用螯刺细胞或粘液网来捕捉食物微粒.

.珊瑚对猎物的捕捉和猎物浓度和水流速度有关。（这点很重要，文中已经写了，对于实际操作就是珊瑚粮的喂食和造浪水流的大小）

.石珊瑚可以摄取 0.45 微米至 400 微米甚至更大的颗粒(见图 26).

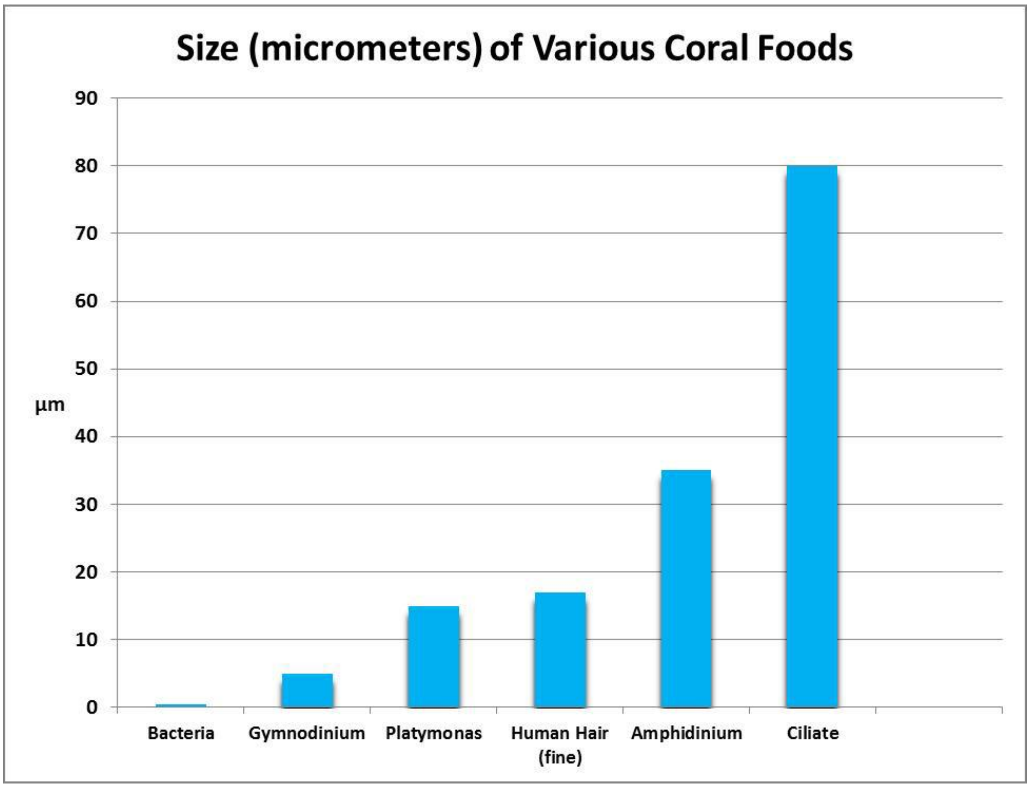

图 26.珊瑚猎物的相对大小

. SPS corals can ingest and assimilate bacteria, green algae, dinoflagellates, ciliates, and larger zooplankton.

. Organic phosphorus (bound in bacteria tissue) is the preferred phosphate source (as opposed to dissolved reactive phosphate.)

. Some algae often grown in aquaria (Halimeda and Caulerpa) release carbohydrates (sugar) that be absorbed by corals. Glucose is the preferred sugar of some Fungia specimens.

. Ammonium is preferentially absorbed by corals. Nitrate is also absorbed.

.Fish poop is a potential source of nitrogen and phosphorus.

.Urea (from fishes, and a source of nitrogen) can be absorbed.

.Even well-maintained aquaria (protein skimmers, filter socks) can contain suspended organic matter.

.Some corals are host to nitrogen-fixing bacteria. These are a source of nutriment when they die (or are consumed.)

.Amino acids (either combined or free) can be a nitrogen source.

. sps 珊瑚可以摄取和吸收细菌、绿藻、甲藻、纤毛虫和较大的浮游动物.(珊瑚的食物来源除了共生藻提供的以外其实真的很丰富了。。。)

.有机磷(结合在细菌组织中)是优选的磷酸盐源(与溶解的活性磷酸盐相反)(再强调一次，溶解的活性磷酸盐，也就是前面写到的正磷酸盐，是我们蛋机和莎利法测出来的磷酸盐，并不是珊瑚的优选的食物，所以，一个稳定的系统只要有细菌提供的有机磷和其他食物来源，哈纳测试磷酸盐一直为零也没有什么问题，这个已经在我现在的鱼缸上验证了,何况按照一般的说法这种消费级测试产品是有比较高的检测下限的,就这样活性磷酸盐也不会为零。。。)

. 一些在水族箱中常见的藻类(如 halimeda 和 caulerpa)释放的碳水化合物(糖),会被珊瑚吸收利用。葡萄糖是一些珊瑚最喜欢的糖。

. 铵优先被珊瑚吸收,硝酸盐也会被珊瑚吸收。(我记不起来还在其他哪个地方看到过了,铵是珊瑚很重要的氮来源之一,不是氨,注意。。)

. 鱼粪是氮和磷的潜在来源。

. 尿素(来自鱼类的一种氮源)可以被珊瑚吸收。

. 即使设备非常良好的水族馆(蛋白质分离器、过滤袋)也可能含有悬浮有机物。

. 一些珊瑚是固氮细菌的宿主。当它们死亡时(或被珊瑚捕食时),都会作为珊瑚所需氮的来源。

. 氨基酸(结合的或游离的)可以是珊瑚的氮源。

Amino Acids

Production of amino acids by zooxanthellae and corals as well as absorption of free amino acids and ingestion of nitrogen-containing compounds is a complex subject and deserves separate examination. Hence, our discussion for this time concludes. Next time we'll discuss amino acids. I'll also present some rather interesting results of tests on a commercially available amino acid supplement.

氨基酸(下一篇的提要)

虫黄藻和珊瑚产生氨基酸以及吸收游离氨基酸和摄取含氮化合物是一个复杂的课题，值得单独研究。因此，我们这次的讨论到此结束。下次我们将讨论氨基酸，我还将介绍一些关于市售氨基酸补充剂的有趣测试结果（会有广告吗，还是黑，哈哈）。

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（参考文献的名字和作者就不再翻译了，呼呼。。。。）