Modern knowledge about phosphate

Introduction: Scientific studies on the need for and effects of the nutrients: ammonium, nitrate and phosphate in corals, as well as numerous experiences of reef aquarists in recent years have shown that the corals' need for phosphate is higher than previously assumed (Wiedenmann et al. 2013, D'Angelo & Wiedenmann 2014, Morris et al. 2019). This overview article is intended to shed more light on recent knowledge and try to give the aquarist a newly discovered way of transporting phosphate in the aquarium to the coral.

New trends in rock and substrate: In addition to the traditional setup of a reef aquarium with coral sand or course coral gravel as the substrate, and wet transported, fresh live rock as the aquascaping material, alternative aquascaping forms and materials are being chosen more and more frequently.

Live rock has the multiple functions of bringing both bacteria and food for bacteria, and other nutrients such as phosphate and ammonium, into the aquarium from dying organisms and the rock itself. For reasons of biotope and nature conservation, and because of reduced availability, aquariums are increasingly being set up with dead rock or ceramic aquascaping materials. Unwanted passengers, who are often brought in with live rock, and more extensive design options also play a role in the use of dead rock and ceramics. However, these alternative materials do not, or only partially, fulfill the multiple functions of live rock.

In addition to the development of a movement toward dead rock and away from live rock, there is also a growing trend towards aquariums without a substrate. Classic substrates, such as coral sand and coral gravel, contain significant amounts of phosphate, which are gradually released into the reef aquarium water. In aquariums without a substrate (“bare bottom tanks”), the bottom is not used as a nutrient supplier and nutrient buffer. In traditionally set up aquariums, with live rock and coral sand substrate, the phosphate concentration cannot be regulated, and is sometimes a problem parameter with very low or even excess concentration. Consequently, heavy phosphate consumption by the introduction of corals, can lead to phosphate deficiency in a short period of time. However, if the phosphate concentration in the reef aquarium falls too low, this leads to reduced growth in corals and, especially in connection with an unbalanced high carbonate hardness, to tissue necrosis from the coral’s base. In bare bottom aquariums, with dead rock, the phosphate level can be controlled from the start.

Phosphate transport: According to recent scientific studies (Wiedenmann et al. 2013, D'Angelo & Wiedenmann 2014, Morris 2019), it is becoming increasingly clear that a phosphate limitation poses a greater risk to corals than an increased phosphate concentration. Adequate phosphate supply is necessary both for the functioning of the partnership between corals and the microalgae in their tissue (coral-zooxanthellae symbiosis) and for calcification and coral growth. These studies also show that the previously recommended low phosphate concentrations, in the aquarium, should be reconsidered. Optimum phosphate concentrations are seen today in the range between 0.05 mg/l and 0.15 mg/l. Even concentrations as high as 0.5 mg/l have proven to be unproblematic.

Corals benefit greatly from an energy transfer from their zooxanthellae to the coral polyps and coral microbiome. The microbiome, here, refers to the vital community of microorganisms within, and on the coral. During this energy transfer, the zooxanthellae deliver high-energy compounds (foods for bacteria) such as sugars and alcohols to the coral polyps, which then forwards them to the microbiome. This transfer can only be taken advantage of, if the corals are sufficiently supplied with phosphate, and there is a lack of nitrogen in the zooxanthellae. A significant part of this energy can only be transferred to the coral polyps and the coral microbiome if the zooxanthellae cannot fully convert the absorbed light energy into growth due to this lack of nitrogen. A stable coral microbiome is a key element in unlocking nutrients and fighting off harmful microbes and is therefore an important prerequisite for coral growth and well-being.

Difficulties in regulating the phosphate supply: A central complication with a targeted supply of dissolved phosphate for the corals, i.e. an increase in the phosphate concentration in the water column, is the substrate and rock. As previously described, these can leach their phosphate, but then also absorb and store it again. However, this process cannot be controlled. As a result, calcium carbonate and other aquascaping materials in the aquarium can adsorb much of the dissolved phosphate before the supplied phosphate is actually available to the corals in sufficient concentration. These mechanisms result in a phosphate intake that is difficult to control.

Current studies show that surface structures, especially in small-polyp stony corals, suffer from irregular calcification due to permanently increased phosphate concentrations (Van der Zande et al. 2021). Observations in aquariums confirm this response. The structures of the corals appear uneven and the regular structure of Acropora corals, for example, is lost. The structure of the coral is thin and fragile, the filigree structures of the polyp calyces seem to melt, and the colors appear flat and dull. The coral does not show its full beauty of the regular arrangement of the polyp calyces and its bright colors.

From soluble to particulate phosphate: Scientific studies in recent years have shown that fish excretions in the reef have positive effects on corals (Godinot & Chadwick 2009, Shantz 2016, Van der Zande et al. 2021). The fish excretion particle shape, the mobility of the fish (proximity to corals) and their excretion phases which cause briefly increased nutrient concentrations on the corals in the reef, are largely responsible for this beneficial contribution. These particulate excretions do not appear to cause adverse changes in coral skeletal architecture (as previously described). Fish excrete nitrogen compounds, especially ammonium, mainly in dissolved form through the gills, while phosphate is mainly excreted in particulate form with the feces, resulting in "pulsing" nutrient concentrations (Ballester-Moltó et al. 2017, Rempel et al. 2022). Investigations and observations in our laboratory lead to the conclusion that particulate phosphate, similar to that which is excreted by fish, is visibly superior to a liquid dose of phosphate. Insoluble, particulate phosphates in combination with organic components as required by corals can thus be used for an optimized pulsing coral nutrient supply. This change, away from liquid phosphate dosing to particulate phosphate dosing, could be game changing development in reef keeping.

Summary: Phosphate is an important engine for coral growth and an essential part of coral metabolism. Contrary to older assumptions, recent studies and observations indicate that phosphate limitation poses a greater threat to corals than previously known. Sufficient phosphate concentrations and low nitrogen concentrations in the coral ensure the required energy transfer (bacterial foods) inside and outside the coral. This energy transfer reinforces the constant growth and beauty of the coral. Interactions between or the structure of these organic components (e.g. zooxanthellae, microbiome) are the focus of much current research (Maire et al. 2021). Such studies also confirm that particulate phosphate, i.e. insoluble phosphate, in contrast to dissolved phosphate, ensures optimum coral growth resulting from pulsing nutrient concentrations. These observations are important in consideration of the optimum phosphate supply and overall organic and inorganic nutrient supply in the reef aquarium.

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