Carbon Dioxide, Coral Reefs, and Climate Change

The formation of coral reefs is influenced by the ocean's role in the global carbon cycle. In the ocean, carbon moves from the aquatic environment as carbon dioxide (CO_2), enters living organisms such as fish and algae, or binds with other elements to form solid particles, and eventually returns to the aquatic environment.

There are 2 different processes involved in carbon cycling: 1) carbon entering and leaving living organisms through **photosynthesis** and **respiration** (known as **organic carbon metabolism)**, and 2) carbon dissolving and settling from the water as calcium carbonate (known as **inorganic carbon metabolism).** The simplified chemical equations that illustrate these exchanges of CO2 are as follows:

Organic carbon metabolism

Photosynthesis

$$CO_2 + H_2O \rightarrow CH_2O + O_2 \qquad \text{Equation 1}$$

Plants and algae in the water **take in carbon dioxide** from the environment, and, using chlorophyll, convert this gas to sugar (CH_2O). Only photosynthetic organisms do this, such as plants and zooxanthellae (algae) that are found in the tissues of corals.

Respiration

$$CH_2O + O_2 \rightarrow CO_2 + H_2O \qquad \text{Equation 2}$$

Animals and plants **produce carbon dioxide** during cellular respiration, which happens in the mitochondria, the energy organelles found inside cells (cells other than bacteria).

Inorganic carbon metabolism

Calcification

$$2HCO_3^- + Ca^{2+} \rightarrow CaCO_3 + CO_2 + H_2O \qquad \text{Equation 3}$$

Bicarbonate (HCO_3^-) combines with calcium ions in the water to make calcium carbonate ($CaCO_3$, limestone). This process can occur both within organisms such as corals or as a simple chemical reaction in the water itself. In corals, calcium carbonate or limestone is the building block of coral reefs. As corals produce calcium carbonate they slowly add on to their existing reef structure allowing the reef to grow in size.

Dissolution of carbonate

$$CaCO_3 + CO_2 + H_2O \rightarrow 2HCO_3^- + Ca^{2+} \qquad \text{Equation 4}$$

Calcium carbonate can combine with carbon dioxide and water to make bicarbonate, a process that releases calcium ions (Ca^{2+}).

Equilibrium and inorganic carbon metabolism

Both calcification and dissolution of carbonate exist in **equilibrium**. This means that if there is an increase in *one* of the compounds on *one* side of an equation, *all* of the compounds on that side of the equation react to produce more of the compounds on the other side of the equation. Chemical equilibrium plays a large role in ocean chemistry and influences life in the ocean as follows.

Effects of a Greenhouse Gas – CO_2 – on Ocean Chemistry

Carbon dioxide (CO_2) concentrations, a greenhouse gas found in the Earth's atmosphere, have increased since pre-industrial times primarily due to the burning of fossil fuels. Based on realistic scenarios of future emissions this trend will continue and atmospheric CO_2 concentrations are expected to reach double pre-industrial levels by 2065 (Houghton et al. 1996). If the amount of CO_2 in the air increases, the amount of CO_2 in the ocean will also increase, because atmospheric CO_2 and seawater CO_2 are in equilibrium.

Based on equation 4 we now know that increases in CO_2 will cause a reaction where CO_2, H_2O, and $CaCO_3$ will all be consumed and HCO_3^- and Ca^{2+} will be produced. This is a concern to scientists because coral reef structures are made from $CaCO_3$. Increasing CO_2 has the net effect of causing the dissolution of $CaCO_3$. Coral reefs produce new $CaCO_3$ at a very slow rate, which is why it takes many years for large reefs to become established. Slight increases in the rate of $CaCO_3$ dissolution can cause the loss of total coral reef structure. When the reef structure fails, so to will the reef community including many species of fish that rely on the reef for life.