



## A Review on Advanced Studies of the Sulfur Biogeochemical Cycle in the Coastal Wetlands

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### Abstract

The biogeochemistry of sulfur is the most important mechanism in the earth science community due to its impact on many different biogeochemical processes such as, like carbon (C) Nitrogen (N) and heavy metals. The role of sulfur cycle at coastal wetlands and, role in complex network of transformation processes and the long-term stability of wetland systems are still not sufficiently understood. So in this review paper we are providing many of the advances in coastal wetland sulfur biogeochemical research of the last several years. This review paper includes (1) the sulfur mechanism and the action in coastal wetlands (2) Physico-chemical processes, such as., mineral precipitation and dissolution, biologically catalyzed redox reactions such as assimilatory and dissimilatory sulfate reduction, as well as oxidation/ reduction reactions (3) the interactions between sulfur transformations with other sediment minerals (4) Sulfur gas emissions to atmosphere from wetlands (5) microbial sulfur cycle (6) indicators for wetland biological assessment. Hence this review attempt has been to explain various aspects of the sulfur ecological mechanism in coastal wetlands.

**Keywords:** Coastal wetlands, Sulfur ecological mechanism, Assimilatory and dissimilatory sulfate reduction

### Introduction

Sulfur (S) is the tenth most common element by mass in the universe and the fifth most common on Earth. It has comprised many vitamins, proteins hormones and it has played critical roles in mankind's life, both climate and in the earth of various ecosystems. It is an essential component for making amino acids (cysteine, and methionine), thioesters and proteins. S is noted in the Bible as brimstone, which means burning stone (Greenwood and Earnshaw. 1997). After nitrogen (N), phosphorus (P) and carbon (C) elements S is the fourth important nutrient and it has been played an important role in the growth of plants; which is participate in the composition of protein aminophenol, photosynthesis and respiration, etc., (Verhoeven. 2009). And also S has been important for the functioning of proteins and

enzymes in plants and animals. Many plants are absorbing organic sulfur when it is dissolved in water (Hu. *et al.*, 2002). Animals consume these plants and take up enough sulfur to maintain their health. If the plant system lacks sulfur, it will decompensate, stunt and finally die. Coastal wetlands are varying extensively due to differences in soil texture, climate, landscape, hydrology, water quality, and flora and fauna from one region to the other region. The wetland is an important ecosystem; it has multiple various functional mechanisms that are main interest to study the contemporary ecology and S plays an important role in maintaining a healthy ecosystem (Yang. *et al.*, 2002). The biogeochemical sulfur cycle in the wetland ecosystem has attracted wide attention (Wu. *et al.*, 2013; Roberta. *et al.*, 2001).

Biogeochemical cycles are regulated by the oxidation and reduction reactions that occur within sediments (Pezeshki and DeLaune. 2012). The coastal biogeochemical cycles (N, P, C, and S) are dealing with the transformation of chemical speciation of elements and flow of materials between biotic and abiotic compartments of coastal and marine environments. Table 1 showing sulfur compounds at global emissions of biosphere, atmosphere, marine and anthropogenic sources. However, some researchers have examined the sulfur cycle in soil-plant systems of the wetlands in China. Zhang & his group reported the S accumulation and cycling in a mangrove ecosystem (Robert and

Andjean. 1988). The S exists from the wetland soils in a variety of oxidation states and present in gaseous, soluble, and solid forms. The sulfur biogeochemical interactions in wetland sediments are complex and have distinct consequences for the biota of the wetland and for the quality of the water flowing through it (Li. *et al.*, 2015, 2016 and 2017). In this review, 1) The sulfur mechanism and action in coastal wetlands, 2) Various levels at sulfur transformations in wetlands, 3) Sulfur Physico-chemical processes, 4) sulfur-reducing bacteria (SRB) investigation combined with the genetic level at coastal wetlands 5) SRB interaction within sulfur cycle at coastal wetlands.

**Table 1:** Global emissions of sulfur compounds natural, marine and anthropogenic sources

Sl No	Sources	Intensity (kg/year)	Reference
1	Hydrosphere - Sea - Freshwater	1.3 × 10 <sup>18</sup> kg 3.0 × 10 <sup>12</sup> kg	Savoie. 1984; Hu. <i>et al.</i> , 2018
2	Atmosphere	4.8 × 10 <sup>9</sup> kg	Wu. <i>et al.</i> , 2013
3	Pedosphere -Soil -Soil organic matter	2.6 × 10 <sup>14</sup> kg 0.1 × 10 <sup>14</sup> kg	Chou. 2012; Zopfi. <i>et al.</i> , 2008
4	Biosphere	8.0 × 10 <sup>12</sup> kg	Zopfi. <i>et al.</i> , 2004

### The Sulfur Mechanism and Action in Coastal Wetlands

The coastal ocean is a crucial link among land, the ocean and the atmosphere. Coastal wetlands played an important role and responsibility for a series of important processes in the wetland ecosystem, such as carbon mineralization, water acidification, pyrite formation, tantalum cycling, etc., (Thamdrup. *et al.*, 1994; Mandernack. *et al.*, 2000; Wen. *et al.*, 2019). Some researchers (Thomas. *et al.* 2009, Stebbins. *et al.*, 2018) are identified anaerobic [carbon mineralization](#) in the deep ocean as a significant biological alkalinity source. Sulfate (SO<sub>4</sub><sup>2-</sup>) and nitrate (NO<sub>3</sub><sup>-</sup>) compounds serve as electron acceptors for anaerobic [respiration](#) in the deep ocean. The majority of S is present as reduced inorganic sulfur minerals (pyrite, iron monosulphides and S<sup>0</sup>), organic forms, or SO<sub>4</sub><sup>2-</sup>. The majority of the Earth's S is stored underground in rocks and minerals including

as SO<sub>4</sub><sup>2-</sup> salts buried deep within ocean sediments. The coastal wetland ecosystems are exposed to very high SO<sub>4</sub><sup>2-</sup> concentrations of up to the 2,700 ppm found in seawater (Schlesinger. 1991), and consequently sulfide (S<sup>2-</sup>) helps plant structure community in various systems (Chambers. *et al.*, 1998, Koch. *et al.*, 2007). In contrast, S supply to freshwater ecosystems is more heterogeneous. Usually the S cycle starts with in both atmospheric and terrestrial portion of the environment. The terrestrial portion, the cycle begins with the weathering of rocks and releasing the stored S to the water (H<sub>2</sub>O) through the soil later this S comes into contact with air where it is converted into SO<sub>4</sub><sup>2-</sup>. This SO<sub>4</sub><sup>2-</sup> is taken up by plants and microorganisms (*Desulfovibrio*), and converted into organic forms. Animals consume these organic forms through foods, thereby moving the S through the food chain. Because of this organic S, organisms die decompose and some of the S is

again released as  $\text{SO}_4^{2-}$  and enters the cells of microorganisms. The S cycle of marine sediments is primarily driven by the dissimilatory  $\text{SO}_4^{2-}$ -sulfate reduction (DSR) to  $\text{S}^{2-}$  by anaerobic microorganisms (Jorgensen and Kasten. 2006; Jorgensen. *et al.*, 2019) (Fig 1). This process links with the food web complex of organic matter degradation to the terminal organic carbon oxidation to  $\text{CO}_2$ . Most of the  $\text{S}^{2-}$  is ultimately reoxidized back to  $\text{SO}_4^{2-}$  via diverse S intermediates by geochemical or microbial reactions that involve  $\text{O}_2$ , nitrate, manganese [Mn(IV)], iron [Fe(III)], and other potential oxidants (Rickard., 2012). A fraction of the  $\text{S}^{2-}$  precipitates with iron and other metals react with organic matter and are buried deeply into the seabed. The microbial S transformations affect the isotopic composition of  $\text{SO}_4^{2-}$  and  $\text{S}^{2-}$  and the resulting isotope fractionation is thereby diagnostic for both process rates and pathways of the S cycle (Canfield., 2001). Different natural sources emit S compounds directly into the atmosphere, including volcanic eruptions, the breakdown of organic matter in swamps and tidal flats, and the evaporation of water (Andreae. *et al.*, 1992). (Li. *et al.* 2016) reported the  $\text{SO}_4^{2-}$  applications had a significant influence on the geochemical cycling of Fe and P in the coastal sediments. In the wetland bed, the spatial and temporal micro-scale gradients of oxygen ( $\text{O}_2$ ) concentrations and redox states established close to root surfaces enable the development of microbial biofilms of functionally different microorganisms. Those microorganisms can simultaneously mediate processes such as nitrification, denitrification, and mineralization of organic carbon, methanogenesis,  $\text{SO}_4^{2-}$  reduction, and  $\text{S}^{2-}$  oxidation on a small spatial scale (Lee. *et al.*, 1999; Holmer and Storkholm. 2001).

### Plants

Coastal wetlands are identified some of the following plant species are present in the marsh land area, i.e., *Spartina alterniflora*, *Juncus roemerianus*, *Salicornia* spp, *Distichlis spicata*, *Limonium* spp., *Scirpus* spp., *Cladium jamaicens*, *Typha* spp., *Spartina patens* and *Spartina cynosuroides*. Oceans are the major

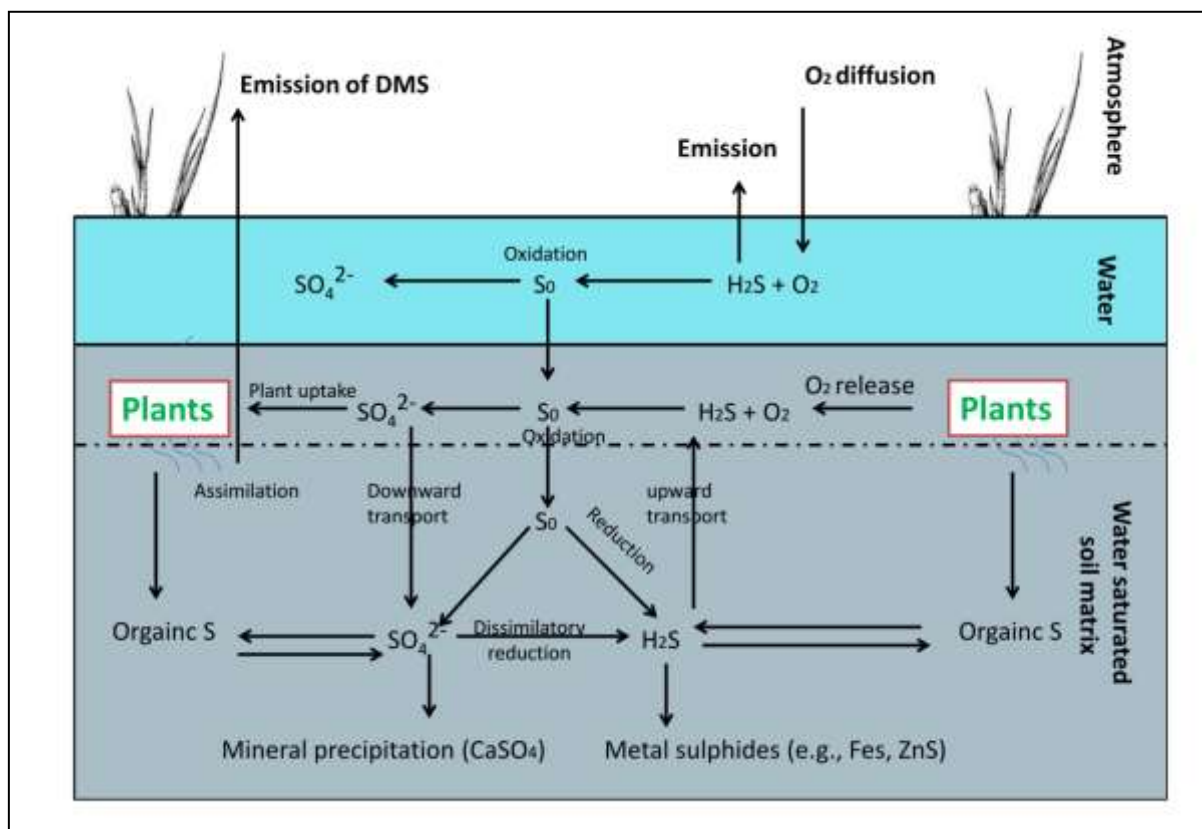
natural source of S in the troposphere and these are having nine trees, six shrubs, fourteen grasses, and one vine species, it has been listed as invasive species in the coastal area (Rejmanek and Richardson. 2013).  $\text{SO}_4^{2-}$ -ubiquitous trace elements in the oceanic atmosphere and derived from sea spray. An extensive survey on  $\text{SO}_4^{2-}$  concentrations from non-marine origins over 25 regions of the world ocean concluded the average S concentration is about  $0.7 \mu\text{g}/\text{m}^3$  (Savoie., 1984). Wetlands are important because it protects and improve water quality, provide fish and wildlife habitats, store floodwaters and maintain surface water flow during dry periods. Coastal wetland plants require S as a constituent of some amino acids which are essential to protein synthesis and it is also necessary for the formation of chlorophyll (Chl), vitamins, enzymes, and aromatic oils (Korb. *et al.*, 2002) and also S is important in the bread making quality of wheat and the protein and sugar contents of forages and grains, and it increases digestibility of grasses and legumes (Wang. *et al.*, 2002). Some researchers reported estuarine plants (salt marsh plants and mangrove swamps) detoxify the environmental  $\text{S}^{2-}$  via sulfide oxidation (Lee. *et al.*, 2009). Coastal wetland is used broadly to identify areas where wetland plants inhabit the coastal zone, in either freshwater or saltwater environments of the coastal zone. In the coastal zones are having vegetated environments such as salt marshes, fresh marshes, bottomland hardwood swamps, and mangrove swamps. The starting point in the marine atmosphere is S cycle is the air sea exchange of dimethylsulphide (DMS) which is a function of the gas transfer velocity and surface seawater DMS concentration (Liss and Merlivat. 1986; Wanninkhof. *et al.*, 2009).

### Sediment and Mineral Precipitation

Depending on the natural conditions, S compounds in the environment may play the role of electron acceptor or donor in the redox processes. S containing proteins are degraded into their constituent amino acids by the action of a variety of soil organisms (bacteria and algae). The soil has formed though, big

rocks break down into smaller rocks by continuous action of wind and rain. This process takes many years for these rocks to break down into smaller particles. The S of the amino acids is converted to hydrogen sulfide ( $\text{H}_2\text{S}$ ) by another series of soil microbes. In the

presence of  $\text{O}_2$ ,  $\text{H}_2\text{S}$  is converted to S and then to  $\text{SO}_4^{2-}$  by SRB. Eventually the  $\text{SO}_4^{2-}$  becomes  $\text{H}_2\text{S}$ . These  $\text{H}_2\text{S}$  compounds rapidly oxidize to gases that dissolve in water to form sulphurous and sulphuric acids ( $\text{H}_2\text{SO}_4$ ) (Sheoran and Sheoran. 2006).



**Fig 1:** Sulfur cycling in coastal wetlands

These compounds contribute in large part to the acid rain this can kill sensitive aquatic organisms and damage marble monuments and stone buildings.  $\text{H}_2\text{S}$  is a common metabolic poison that is abundant in marine-reducing environments (Sheoran and Sheoran. 2006). Some researchers are reported, most marine sediment concentrations ( $\text{SO}_3^{2-}$ , and  $\text{S}_2\text{O}_3^{2-}$ , and  $\text{S}_4\text{O}_6^{2-}$ ) are in values not exceeding micromoles ( $\mu\text{M}$ ) per liter (L) and also also reported elemental sulfur ( $\text{S}^0$ ) is the most abundant S intermediate in coastal marine sediments in Black Sea, Germany (Zopfi. et al., 2004). Mineral components can dissolve in the weathering and erosion process, it can precipitate when environmental conditions are good. As minerals break down, compounds are separated into their ion and cat-ion components as it dissolves in water.

Changes in physical and chemical conditions (such as changes in temperature, pressure, or addition or removal of dissolved compounds like carbon dioxide ( $\text{CO}_2$ ) and biological activity) cause minerals to precipitate. In desert environments,  $\text{H}_2\text{O}$  evaporates causing salts to precipitate on the surface of dry lake beds. The cementation is what hardens sediments into sedimentary rocks, there are common mineral cements include silica (quartz), calcite, limonite, hematite, and clay minerals (Zheng and Hoefs. 1993). Among soil microbial community, soil reducing bacteria are considered to be one of the richest and the most important groups of microbes, which play pivotal roles in participating soil organic matter (SOM) decomposition, and regulating soil C and N cycling (Jurburg. et al., 2018).



## Atmosphere

The S found in the atmosphere and enters into the atmosphere through both natural and human sources. Natural recourses occur ; instance of volcanic eruptions, bacterial processes, evaporation from water, or decaying organisms. When S enters the atmosphere through human activity, this is mainly a consequence of industrial processes where sulfur dioxide (SO<sub>2</sub>) and H<sub>2</sub>S gases are emitted on a wide scale. When SO<sub>2</sub> enters the atmosphere it will react with O<sub>2</sub> to produce sulfur trioxide gas (SO<sub>3</sub>), or with other chemicals in the atmosphere, to produce S salts. SO<sub>2</sub> may also react with water to produce H<sub>2</sub>SO<sub>4</sub>. This H<sub>2</sub>SO<sub>4</sub> may also be produced from DMS, which is emitted to the atmosphere by plankton species (Andreae. *et al.*, 1992; Larry. *et al.*, 2014). The S gases are both foul smelling and noxious. Researchers examined various studies, wetlands emit the range of S gases and they vary according to factors such as salinity, wetting drying regime, soil type and diurnal cycles. Three main types of S gases can be emitted by wetlands; which are., H<sub>2</sub>S, volatile organic sulfur compounds (VOSC) and SO<sub>2</sub>. These S compounds are differing in the way these are produced and their odour characteristics smell threshold and toxicity. The human nose can detect some of these compounds at very low concentrations and also other various types of S compounds, H<sub>2</sub>S, Carbonyl sulfide (COS), Carbon disulfide (CS<sub>2</sub>), Methanethiol (MT) (CH<sub>3</sub>SH), DMS ((CH<sub>3</sub>)<sub>2</sub>S), Dimethyl disulfide (DMDS) ((CH<sub>3</sub>)<sub>2</sub>S<sub>2</sub>), SO<sub>2</sub>. All these particles are settled back onto earth, or react with rain and fall back onto earth as acid deposition. The particles are absorbed by plants again and are released back into the atmosphere, so that the sulfur cycle will start over again (Amend. *et al.*, 2004).

## Sulfur Physico-Chemical Processes

### Sulfur Oxidation and Desulfonylation

Sulfur oxidation involves the oxidation of reduced S compounds such as H<sub>2</sub>S, inorganic sulfur (S<sub>0</sub>) and thiosulfate (S<sub>2</sub>O<sub>3</sub><sup>2-</sup>) to form H<sub>2</sub>SO<sub>4</sub>, an example of a sulfur oxidizing bacterium is *Paracoccus*. Generally, the oxidation of sulfide occurs in various

stages, with inorganic S being stored either inside or outside of the cell until needed. The two step process occurs because S<sup>2-</sup> is a better electron donor than inorganic sulfur or S<sub>2</sub>O<sub>3</sub><sup>2-</sup>; this allows a greater number of protons to be translocated across the membrane. Sulfur oxidizing microorganisms generate reducing power for CO<sub>2</sub> fixation via the calvin cycle using reverse electron flow an energy requiring process that pushes the electrons against their thermodynamic gradient to produce Nicotinamide adenine dinucleotide (NADH). Biochemically reduced S compounds are converted to sulfite (SO<sub>3</sub><sup>2-</sup>) and, subsequently, SO<sub>4</sub><sup>2-</sup> by the enzyme sulfite oxidase. Some organisms, however, accomplish the same oxidation using a reversal of the APS reductase system used by SRB. In photosynthetic reactions, the energy liberated is transferred to the electron transport chain for ATP and NADH production. In addition to aerobic S oxidation, some organisms (*Thiobacillus denitrificans*) use nitrate (NO<sub>3</sub><sup>-</sup>) as a terminal electron acceptor and grow anaerobically. S<sup>2-</sup> is a product of bacterial DSR by using organic compounds as electron donors. Elemental sulfur is a product of S<sup>2-</sup> oxidation, which may be performed by abiotic oxidation and/or biological oxidation by using different electron acceptors, such as oxygen, nitrite and nitrate (Zheng., 2007; Zheng and Cai., 2007) (Fig 2). There are several chemical reactions leading to the removal of a sulfonyl group from organic compounds i.e. desulfonylation reactions. As the sulfonyl functional group is electron-withdrawing, methods for cleaving the S-carbon bonds of sulfones are typically reductive in nature. Olefination or replacement with hydrogen may be accomplished using reductive desulfonylation methods (Alonso and Ájera., 2009). The wetland system can influence the sulfur cycling by the releasing of organic carbon compounds and/or oxygen from the plant roots to enhance the sulfate reduction or re-oxidation of the reduced sulfur compounds. Moreover, the processes of sulfur transformations, such as SO<sub>4</sub><sup>2-</sup> reduction can also influence the conditions for the biochemical processes (Leon. *et al.*, 2002;

Geurts. *et al.*, 2009). Oceanic DMS emissions to the atmosphere are potentially important to the Earth's radioactive balance. Since these emissions are driven by the surface seawater

concentration of DMS, it is important to understand the processes controlling the cycling of sulfur in surface seawater (Bates. *et al.*, 1994).



**Fig 2:** Oxidation and Reduction reactions

### Assimilatory and Dissimilatory Sulfate Reduction

Assimilatory sulfate reduction (ASR) is a pathway used by prokaryotes, fungi and photosynthetic organisms to convert inorganic  $\text{SO}_4^{2-}$  to  $\text{S}^{2-}$ , which is further incorporated into carbon skeletons of amino acids to form cysteine (Cys) or homo-Cys. In this pathway,  $\text{SO}_4^{2-}$  is first activated by (adenosine triphosphate) ATP sulfurylase (ATPS) forming adenosine 5-phosphosulfate (APS). In higher plants, APS is reduced by APS reductase (APR) to sulfite, which is further reduced to the level of  $\text{S}^{2-}$  by sulfite reductase (Suter. *et al.*, 2000). APS can also be phosphorylated by APS kinase to phosphoadenosine 5-phosphosulfate, which is utilized for synthesis of a wide range of sulphated compounds in reactions catalyzed by a variety of sulfo transferases. DSR is a form of anaerobic respiration that uses  $\text{SO}_4^{2-}$  as the terminal electron acceptor. This metabolism is found in some types of bacteria and archaea which are often termed sulfur reducing microorganism (SRM). DSR occurs in three steps (a) Conversion (activation) of sulfate to Adenosine 5-phosphosulfate (APS), (b) reduction of APS to sulfite (c) reduction of sulfite to  $\text{S}^{2-}$ . This process requires the consumption of a single ATP molecule and the input of 8 electrons ( $e^-$ ) (Larry. *et al.*, 2014; Grein. *et al.*, 2013). The protein complexes are responsible for these chemical conversions (-Sat, Apr and Dsr-) are found in all currently known organisms that perform dissimilatory sulfate reduction (Pereira. *et al.*, 2011). Energetically  $\text{SO}_4^{2-}$  is a poor electron acceptor for microorganisms as the sulfate-sulfite redox couple is  $E^0$  -516 mV, which is too negative to allow reduction by NADH or ferredoxin that are the primary intracellular electron mediators (Muyzer and

Stams., 2008). To overcome this issue,  $\text{SO}_4^{2-}$  is first converted into APS catalysed by the enzyme ATP sulfurylase (Sat), utilized a single ATP molecule. The APS sulfite redox couple has a  $E^0$  of -60 mV, which allows APS to be reduced by either NADH or reduced ferredoxin using the enzyme adenylyl-sulfate reductase (Apr), which requires the input of 2 electrons (Muyzer and Stams., 2008). In the final step, sulfite is reduced by the dissimilatory sulfite reductase (Dsr) to form  $\text{S}^{2-}$ , requiring the input of 6 electrons (Grein. *et al.*, 2013). Thus, APR is a key step in sulfate assimilation and as such, the enzyme is highly regulated, e.g. by light, S and nitrogen supply, heavy metals, or chilling (Koprivova. *et al.*, 2000).

### Sulfur Reducing Microorganisms

SRB are anaerobic microorganisms that use  $\text{SO}_4^{2-}$  as a terminal electron acceptor, for example, the degradation of organic compounds. These organisms are ubiquitous in anoxic habitats, where they have an important role in both the S and carbon (C) cycles. SRB can cause a serious problem for industries, such as the offshore oil industry, because of the production of  $\text{S}^{2-}$ , which is highly reactive, corrosive and toxic. A classic example of a sulfur-oxidizing bacterium (SOB) is *Beggiatoa* grows chemoorganotrophically by oxidizing organic compounds to  $\text{CO}_2$  in the presence of  $\text{O}_2$ , though high concentrations of oxygen can be a limiting factor (Pester. *et al.*, 2012). Organic compounds are also having carbon source for biosynthesis of this organism. Some species may oxidize  $\text{H}_2\text{S}$  to  $\text{S}^0$  as a supplemental source of energy, this S is stored intracellularly. Some species have the ability of chemolithoautotrophic growth, using sulfide oxidation for energy and  $\text{CO}_2$  as a

source of carbon for biosynthesis (Ng. et al., 2010). In this metabolic process, internal stored nitrate is the electron acceptor and reduced to ammonia (NH<sub>3</sub>). Marine autotrophic *Beggiatoa* species are able to oxidize intracellular S to sulfate. The reduction of S<sup>0</sup> frequently occurs when O<sub>2</sub> is lacking. S is reduced to sulfide at the cost of stored carbon or by added hydrogen gas. This may be a survival strategy to bridge periods without O<sub>2</sub>. This reaction process follows as below.

Sulfide oxidation:  $2\text{H}_2\text{S} + \text{O}_2 \rightarrow 2\text{S} + 2\text{H}_2\text{O}$

However, these organisms can also be beneficial by removing SO<sub>4</sub><sup>2-</sup> and heavy metals from waste water streams. In addition, SRB have been studied for new molecular biological and genomic techniques (Hu. et al., 2018). Various SRB's (like *Desulfovibrio*, *Desulfotomaculum* and *Desulfomonas*) are used in reduction and oxidation reactions.

### ***Desulfovibrio***

*Desulfovibrio* is a genus of gram negative sulfur reducing bacteria and this species has commonly consists in aquatic environments with high levels of organic material, as well as in water logged soils. Like other SRB, *Desulfovibrio* was long considered to be obligately anaerobic. *Desulfovibrio* strains have been found in a variety of habitats, including soil, the intestines and feces of animals, and both salinic and fresh water (Tarasov. et al., 2015). *Desulfovibrio vulgaris Hildenborough* is a model organism for studying the energy metabolism of SRB and for understanding the economic impacts of SRB, including biocorrosion of metal infrastructure and bioremediation of toxic metal ions (Heidelberg. et al., 2004). These types of bacteria are known as aerotolerant. Some *Desulfovibrio* species have in recent years been shown to have bioremediation potential for toxic radionuclides such as uranium and iron by a reductive bioaccumulation process. Because of *Desulfovibrio*'s historical importance, two strains have already been genomically sequenced and one is currently in progress.

These strains include *Desulfovibrio desulfuricans* G20 (completed), *Desulfovibrio vulgaris* subsp. *vulgaris* str. *Hildenborough* (completed), and *Desulfovibrio magneticus* (in progress), which were sequenced by DOE Joint Genome Institute, TIGR, and NITE, respectively. Both of the completely sequenced genomes showed *Desulfovibrio* to have one chromosome and measure over 3 Mbp in length. Both sequencings also found the number of proteins to be above 3000 (Heidelberg. et al., 2004). *D. vulgaris Hildenborough* is a model organism for studying energy metabolism of SRB and for understanding the economic impacts of SRB, including biocorrosion of metal infrastructure and bioremediation of toxic metal ions.

### **Indicators for Wetland Assessment**

Wetland assessment has been a popular field and however, various indicators have been used in wetland assessment for different purposes and backgrounds (Reddy and Ronald., 2009). Wetlands are receiving millions of sewage and pollutants from industrial and agricultural effluents producing by harmful algal blooms (HABs) and which is caused human diseases & destroy aquatic systems (Van Dohla, 2000). The development of wetland monitoring and assessment strategies is necessary to explain the impact on human activities on wetland health and improve wetland management and protection. Various wetland assessment indicators have been developed and employed to measure the changes in ecological condition. There are primarily three types of indicators based on physical (water depth, open water area, and land uses), chemical (total P and N, sediment chemistry) and biological (plant species, composition and abundance of macroinvertebrates, algae, etc.) characteristics (Asmus. et al., 2009; Yagow. et al., 2006). Bioindication uses higher plants, animals, and microbial species to predict or indicate wetland water quality and health conditions (Liu and Sun., 2010; Sims. et al., 2013).



### Concluding Remarks and Perspective

Several groups of microbes are responsible for carrying out processes involved in the **S cycle**. Anoxygenic photosynthetic bacteria as well as chemoautotrophic archaea and bacteria use  $\text{H}_2\text{S}$  as an **electron donor**, oxidizing it first to  $\text{S}^0$ , then to  $\text{SO}_4^{2-}$ . This leads to stratification of  $\text{H}_2\text{S}$  in soil, with levels increasing at deeper, more anaerobic depths. Many bacteria and plants can use  $\text{SO}_4^{2-}$  as a S source. Coastal biogeochemical cycle's exhibit interlinks of different mechanisms that regulate the transfer of chemical elements in the marine ecosystem and encompass rapid and complicated processes that bridge the material transport between the various compartments of the Earth system, land, ocean, and atmosphere as well as human society. The external forcing factors on coastal biogeochemical cycles can be either natural or anthropogenic, as well as the combination of these two. Biogeochemistry in the coastal ocean is composed of cycles of macronutrients and trace elements between biotic and abiotic compartments driven by formation of organic matter fuelled by solar energy and the metabolisms (i.e., anabolic and catabolic processes) based on the chemical energy stored in the organisms. Since the late 1970s, it has been recognized that the microbial loop can be an important component of biogeochemical cycles in the ocean, which is an integral part of the entire food web and affects considerably the pathways of biogeochemical cycles in the coastal ocean. It is known that coastal biogeochemical cycles, such as sulfur cycle have strong feedbacks to the atmosphere (e.g., emission of greenhouse gases) as well as the open ocean through change in material fluxes. This review expended the biogeochemical role of S in marine sediments, such as sulfate reduction, pyrite and organic S formation and metal cycling, is an area of intense research. Sulfate reduction and burial of S in the form of pyrite and organic S have previously been observed in mangrove sediments. Little is known, however, about the actual mechanisms and control of specific processes involved in mangrove S cycling. Although S compounds generally are important for energy transfer

and element cycling in tidal sediments, pyrite formation and oxidation.

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