Sea-level Rise Impacts on Coastal Karst Aquifers

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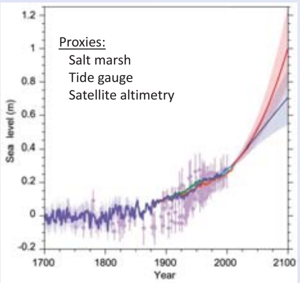


Figure 1. Proxy and direct records of average global sea-level elevations over the past three centuries. Sea-level rise was 1.7 mm/yr between 1901 and 2001 increasing to 3.2 mm/yr between 1993 and 2012. Sea level post-2010 based on models suggests rates are likely to increase through the 21[st] century. Figure from Church et al., 2013.

Introduction:

Fresh and salt water exchange could be extensive in karst aquifers because of their high hydraulic conductivity (Fleury et al., 2007) and thus be one of the first locations impacted by sea level rise, which is expected to accelerate in the future (Fig. 1). To evaluate potential impacts, we measured short-term variations in sea level change, salinity, pH, DO, and nutrient concentrations over two 2-wk periods at Pargos Spring, offshore of Quintana Roo, Mexico (Fig. 2). The spring is sourced from a conduit that has been explored ~15m (Fig. 3). During exploration, various sensors were installed along with sampling tubes. These data are evaluated here in light of expected changes resulting from sea-level rise.

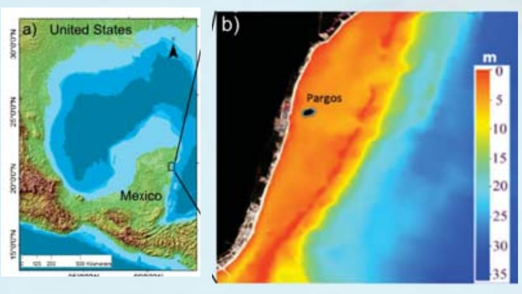


Figure 2. a)Location of sampled spring in Quintana Roo, Yucatan Peninsula, Mexico. b) Bathymetric map showing location of Pargos spring. The shallowest portion of the image represents the modern reef crest that encloses the lagoon. Pargos Spring is approximately 500 m offshore.

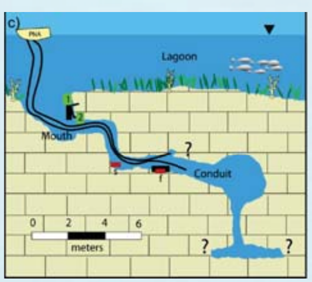


Figure 3. Explored extent of conduit and locations of sensors. Instrumentation: Black – coupled CTD and DO sensors, Red – YSI sensors, Green are velocimeters. Tubing was lead from a boat into two bifurcating conduits for grab sampling of water throughout tidal cycles.

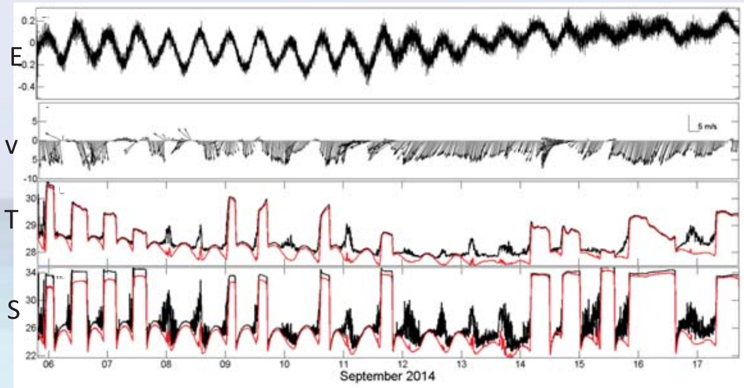


Figure 4. Time series of lagoon elevation, normalized to average elevation during observation period (E, top), wind velocity (v, middle top), and spring vent (black) and conduit temperature (red, T, middle bottom), and salinity (S, bottom) at Pargos spring in September 2014. Co-variations between E, T, and S show reversals of spring flow from discharge to intrusion when sea level is more than 0.08 m above average elevation. Local maxima during discharge periods potentially reflect entrainment of the lagoon water during times of lowest water elevations and maximum discharge flow rates.

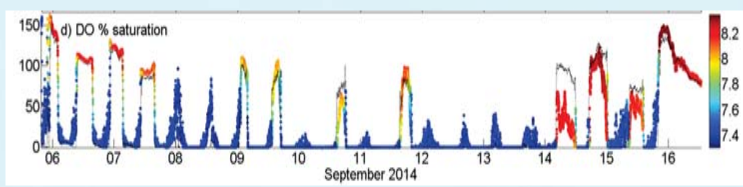
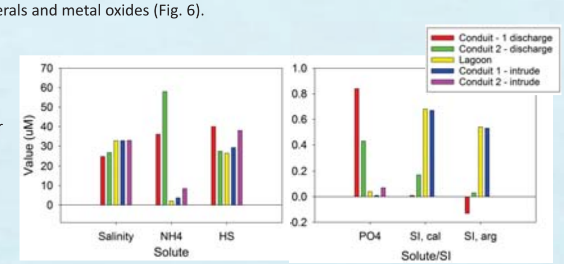


Figure 5. Time series data of the percentage saturation of dissolved oxygen (DO) saturation and pH (color coded) at Pargos spring for the September 2014 (black spring; color conduit). Spring reversals have elevated pH and DO saturation, reflecting primary productivity in the lagoon. DO saturation and pH drop during some recharge periods, suggesting oxygen is reduced during organic carbon remineralization and sulfide oxidation. These reactions produce carbonic and sulfuric acid, decreasing pH and decrease carbonate mineral saturation, produce NH_4 and P from organic carbon remineralization and P that co-precipitated with, carbonate minerals and metal oxides (Fig. 6).

Figure 6. Salinity, NH_4^+, HS^-, and PO_4^{3-} concentrations and calcite and aragonite saturation indices shown for discharge and intrusion conditions at Pargos Spring and for lagoon water. The spring water concentrations were collected from two separate conduits leading the main conduit (Fig. 3).



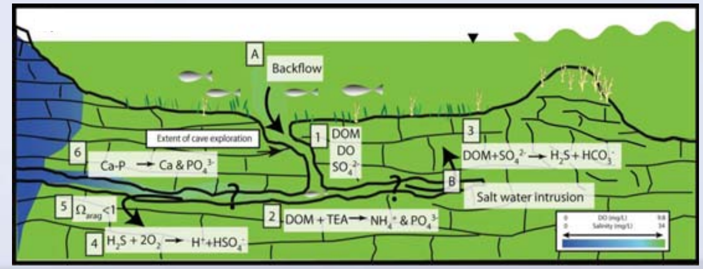


Figure 7. Conceptualization of coastal karst systems with elevated sea level. Once sea level passes a threshold in which the ocean head is greater than the aquifer head, springs reverse and allow water to flow to the conduit (A) and likely seep into the matrix (B). Chemical reactions include intrusion of organic matter, DO, and sulfate (1), remineralization of the organic matter and release of nutrients (2), sulfate reduction and sulfide generation (3), oxidation of sulfide and reduction of pH (4), generations of undersaturation with respect to carbonate minerals (5), and release of P during calcite dissolution (6).

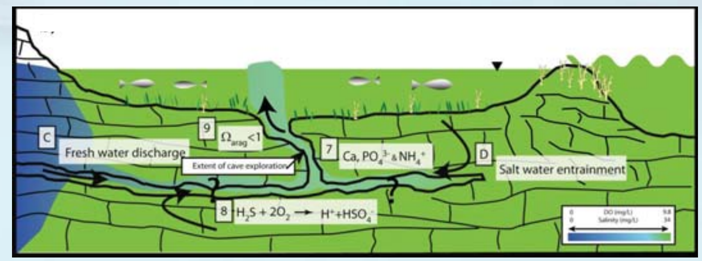


Figure 8. Conceptualization of hydrologic and chemical state of springs surrounding the Yucatan (and other coastal karst regions) during periods of low sea level. Fresh water discharges from the aquifer through the conduits (C) and can entrain salt water into the conduits from the matrix porosity and through fractures (D). Brackish water discharges from springs carrying with it solutes generated during periods of intrusion, including released P, Ca, and ammonium (7), sulfide from sulfate reduction (8), and low saturation state water (9) (Fig. 6).

Conclusions:

Sea level rise of as little as 0.08 m may alter the magnitudes of submarine ground water discharge and salt water intrusion at Pargos Spring; similar small shifts in sea level should also impact water exchange at other coastal springs. Persistent periods of backflow in the near future would limit the discharge of low pH water and increase DO input to the aquifer. Outlets for water with low pH values and elevated nutrient concentrations should move closer to the coast and away from the reef. This implies nutrient fluxes and locations of discharge will be altered, thereby affecting coastal ecosystems. Since nutrients are beneficial to coral growth these shifts should impact coastal ecosystem health as well as potable water resources.

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