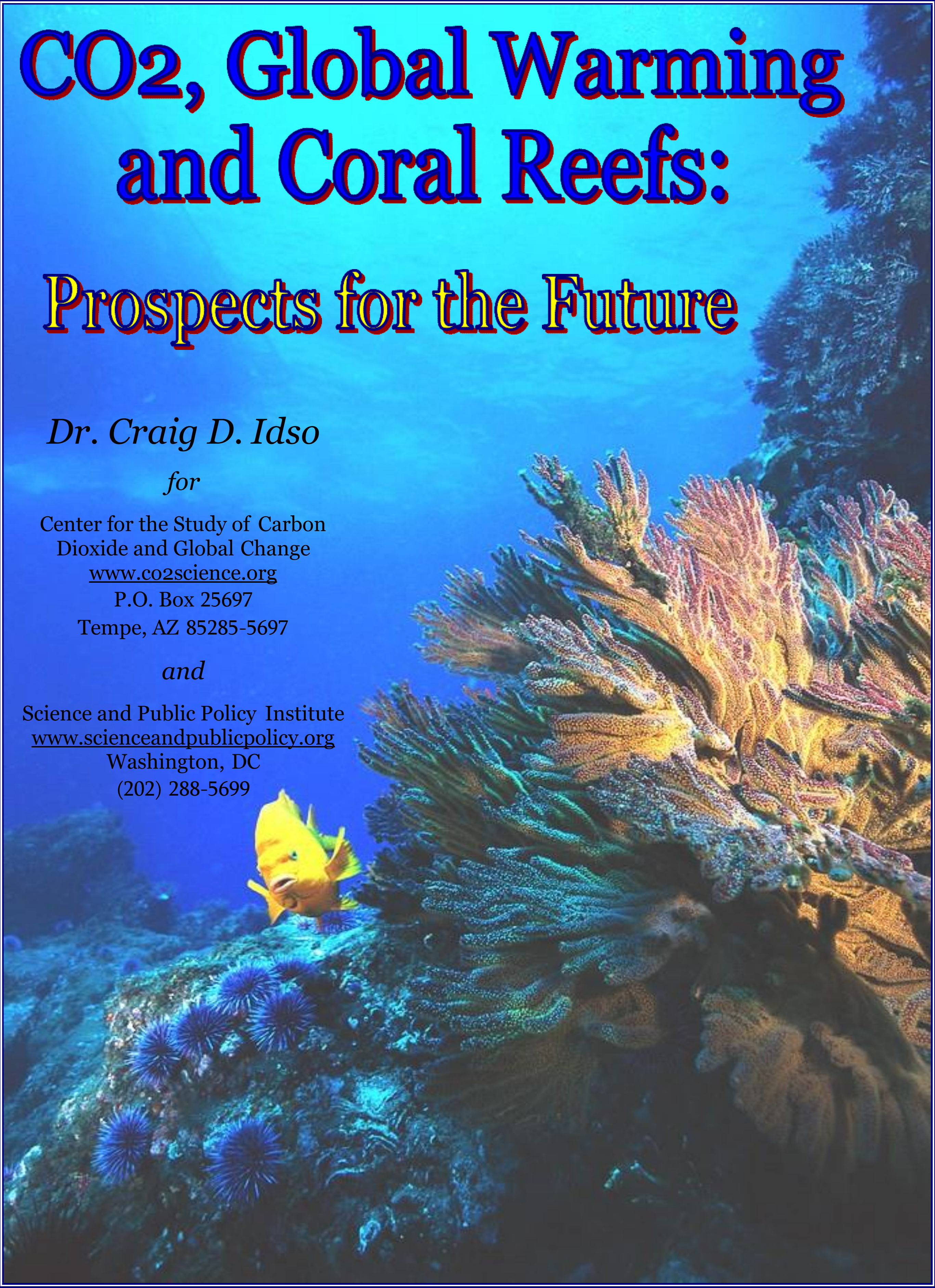
CO2, Global Warming and Coral Reefs:

Prospects for the Future



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Part II: Direct Threats

In addition to the CO_2-induced indirect threats postulated to harm the world's coral reefs, as discussed in Part 1 of this document, the global increase in the atmosphere's CO_2 content has been hypothesized to possess the potential to harm coral reefs *directly*. By inducing changes in ocean water chemistry that can lead to reductions in the calcium carbonate saturationstate of seawater, it has been predicted that elevated levels of atmospheric CO_2 may reduce rates of coral calcification, possibly leading to *slower-growing* – and, therefore, *weaker* – coralskeletons, and in some cases even death.

We begin this part of our review by discussing the important role biology plays in driving the physical-chemical process of coral calcification, followed by a discussion of several real-world observations that depict *increasing* rates of coral calcification in the face of rising temperatures and atmospheric CO_2 concentrations. Indeed, as ever more pertinentevidence accumulates, the *true* story appears tobe just the *opposite* of what the ocean acidification hypothesis promotes.

1. Ocean Acidification

The rate of deposition of calcium carbonate on coral reefs, or *coral calcification rate*, is controlled at the cellular level by the saturation state of calcium carbonatein seawater; and oceanic surface waters have likely been saturated or supersaturated in this regard – providing a good environment for coral reef growth – since early Precambrian times (Holland, 1984). Currently, however, as the air's CO_2 content rises in response to ever-increasing anthropogenic CO_2 emissions, and as more and more carbon dioxide therefore dissolves in the surface waters of the world'soceans, pH values of the planet's oceanic waters are, or should be, gradually dropping,leading to a reduction in the calcium carbonate saturation state of seawater.

This phenomenon has been theorized to be leading to a corresponding reduction in coral calcification rates (Smith and Buddemeier, 1992; Buddemeier, 1994; Buddemeier and Fautin, 1996a,b; Holligan and Robertson, 1996; Gattuso *et al*., 1998; Buddemeier and Smith, 1999; IPCC, 2007a,b; De'ath *et al*., 2009), which reduction has been hypothesized to be rendering corals more susceptible to a number of other environmental stresses, including "sea-level rise, extreme temperatures, human damage (from mining, dredging, fishing and tourism), and changes in salinity andpollutant concentrations (nutrients, pesticides, herbicides and particulates), and inocean currents, ENSO, and storm damage" (Pittock, 1999). Kleypas *et al*. (1999), forexample, have calculated that calcification rates of tropical corals should already havedeclined by 6 to 11% or more since 1880, as a result of the concomitant increase inatmospheric CO_2 concentration; and they predict that the reductions could reach 17 to35% by 2100, as a result of expected increases in the air's CO_2 content over the comingcentury. Likewise, Langdon *et al*. (2000) calculated a decrease in coral calcification rateof up to 40% between 1880 and 2065.

The ocean chemistry aspect of this theory is rather straightforward; but it certainly is not as solid as acidification alarmists make it out to be. In evaluating global seawater impacts of (1) model-predicted global warming and (2) direct seawater chemical consequences of a doubling of the air's CO_2 content, Loaiciga (2006), for example, used a mass-balance approach to (1) "estimate the change in average seawater salinitycaused by the melting of terrestrial ice and permanent snow in a warming earth," and he (1) applied "a chemical equilibrium model for the concentration of carbonate species in seawater open to the atmosphere" in order to "estimate the effect of changes in atmospheric CO_2 on the acidity of seawater." Assuming that the rise in the planet's mean surface air temperature continues unabated, and that it eventually causes the melting of all terrestrial ice and permanent snow, Loaiciga calculated that "the average seawater salinity would be lowered not more than 0.61‰ from its current 35‰." He also reports that across the range of seawater temperature considered (0 to 30°C), "a doubling of CO_2 from 380 ppm to 760 ppm increases the seawater acidity [lowers its pH] approximately 0.19 pH units." He thus concludes that "on a global scale and over the time scales considered (hundreds of years), there would not be accentuated changes in either seawater salinity or acidity from the risingconcentration of atmospheric CO_2."

> The rising CO_2 content of earth's atmosphere may well be a *positive* phenomenon, enhancing the growth rates of coral reefs and helping them to better withstand the many environmental stresses that truly are inimical to their well-being.

Furthermore, with more CO_2 in the air, additional weathering of terrestrial carbonates islikely to occur, which would increase delivery ofCa^{2+} to the oceans and partly compensate for the CO_2-induced decrease in oceanic calcium carbonate saturation state (Riding, 1996). Andas with all phenomena involving living organisms, the introduction of *life* into the ocean acidification picture greatly complicates things. Considerations of a suite of interrelated biological phenomena, for example, also make it much more difficult to draw suchsweeping negative conclusions as are currently being discussed. Indeed, as shown inthe next section, they even suggest that the rising CO_2 content of earth's atmospheremay well be a *positive* phenomenon, enhancing the growth rates of coral reefs and helping them to better withstand the many environmental stresses that truly are inimical to their well-being.

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