Effect of light quality on photosynthesis of the reef coral *Montipora verrucosa*

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Abstract

Pieces of the reef coral *Montipora verrucosa* (Lam.), collected from Kaneohe Bay, Oahu, Hawaii in 1982, were grown in four low-light treatments (11% sunlight): blue, green, red and the full spectrum of photosynthetically active radiation (PAR); and at high-intensity full PAR (90% sunlight). These acclimated corals were then tested for photosynthetic ability in blue, green, red, and white light. The photosynthetic parameters that were measured were: light-saturated photosynthetic rate, the initial slope of the photosynthesis/irradiance curve, the light intensity where these two lines crossed, and dark respiration. While acclimation intensity had a pronounced effect, the results also showed that the color of the acclimation treatment influenced the photosynthetic responses of the corals. The color of the light used in the measurements of photosynthesis had much less effect on the photosynthetic responses of the corals.

Introduction

The concept of complementary chromatic adaptation (CCA) resulted from the observation that certain divisions of seaweeds were characteristically found at distinct relative depths in the ocean. This observation, coupled with the knowledge of the differential spectral transmission of light in water, led to a theory of pigment adaptation (in an evolutionary sense) of algae to the spectral composition of daylight at the depth characteristic of each group (Engelmann, 1883). Engelmann's original statement was based on crude but ingeniously measured action spectra of green and red algae and diatoms (Ramus, 1982). Further work expanded the original phylogenetic formulation, as proposed by Engelmann, to include the possibility of physiological adaptation of algal pigment composition in response to altered light conditions. It is important to clearly differentiate between the original phylogenetic formulation of the theory and later physiological interpretations which focus on adaptation of existing pigment systems rather than pigment composition. In field studies, the correlation of spectral quality with light intensity confounds the interpretation of photoadaptation. A recent study of the theory of CCA using action spectra of several algae and published water-quality types (Dring, 1981), concluded that the changes seen in algal accessory pigments at increasing depths are best explained as responses to decreasing intensity and not to spectral quality of the light field.

Nevertheless, there has been a growing appreciation of the fact that the physiological responses of algae to light with experimentally altered spectral quality include not only changes in cell biochemistry (Wallen and Geen, 1971a, b; Kamiya and Miyachi, 1980; Jones and Galloway, 1979; Bird et al., 1981; Pickett, 1971), morphology and ultrastructure (Jeffrey and Vesk, 1977; Blatt and Briggs, 1978), and growth rate (Luning and Dring, 1975; Faust et al., 1982), but also the pigment composition, although not always in the direction predicted by the CCA model (Brody and Emerson, 1959; Hess and Tolbert, 1967; Jeffrey and Vesk, 1977; Kamiya and Miyachi, 1980). Ramus et al. (1976) found increases in accessory pigments relative to chlorophyll a in a green and two red seaweeds with increasing depth. This change was not seen in sun and shade plants grown in shallow water, suggesting a form of CCA. However, Ramus et al. (1977) found conflicting results when two brown seaweeds were tested under similar conditions. Later work by Ramus (1983) and Ramus and van der Meer (1983) using green and white light suggested that accessory pigments did not respond in the way predicted by the CCA model. Faust et al. (1982) grew the dinoflagellate *Prorocentrum mariae-lebouriae* in blue, green, red and white light, and found that the accessory pigments, chlorophyll c, peridinin and total carotenoids did respond to light quality and, as predicted by the theory of CCA, were highest in the green-light treatment.
Like seaweeds, corals, by virtue of their dinoflagellate endosymbionts (zooxanthellae), are benthic photosynthetic organisms. Many species of corals occur over a wide depth range, and so are subject to a wide range of light intensities along with the corresponding spectral alterations in ambient light. It has been generally accepted that a single symbiotic alga, Symbiodinium microadriaticum Freuden-thal, occurs in hermatypic corals throughout their depth range (Taylor, 1974). However, more recent work (Blank and Trench, 1985) suggests that the taxonomy of zooxanthellae may be more complex than originally thought. Nevertheless, one might hypothesize that algae from a single host-species would exhibit capabilities for photoadaptation that would enable it to exist throughout the host's depth range.

In a recent paper (Kinzie et al., 1984), it was shown that the coral/algal symbiotic system, as well the zooxanthellae in vitro responded differently under long-term culture in light of differing spectral composition. In particular, corals grown under blue or white light showed increased growth and had higher algal densities than corals grown in green or red light. It was suggested that the blue-light response represented a physiological adaptation to provide higher photosynthetic efficiency with increasing depth in the field. These results suggested that a measure of the photosynthetic ability of color-adapted corals would give a direct test of the CCA model. Two hypotheses were formulated that could be tested using this coral/algal system. The first, a statement directed at CCA, is that corals grown in a particular acclimation color would have higher photosynthetic capacity or efficiency when tested in light of that color than in light of other colors. This differs from Engelmann's theory in that it is a statement of adaptation in the physiological rather than the evolutionary time frame. The second hypothesis, a statement of adaptation in the physiological rather than light intensity may regulate the photic environment. It has been generally accepted that the photosynthetic rate of corals is light intensity may regulate the photic environment. It has been generally accepted that the photosynthetic rate of corals is low and high levels of white light. Direct comparison of the measured photosynthetic parameters provided a test of the first hypothesis. Comparison of the photosynthetic responses of corals in red and blue treatments with corals in the high- and low-level white-light treatments, respectively, provided a test of the second hypothesis. Additionally, data from this study provided an indication of how the use of light sources whose spectra differ from sunlight (a common problem in photobiological studies) might affect the results of studies of coral biology.

**Materials and methods**

**Culture methods**

A single plate-like colony of Montipora verrucosa (Lam.) was collected from a depth of approximately 3 m on the reef of Coconut Island, Kaneohe Bay, Oahu, Hawaii in 1982. The coral was returned to the laboratory in a seawater-filled container and divided into 15 approximately equal-sized pieces of about 20 cm² each. These fragments were placed in an outdoor tank furnished with running, unfiltered, Kaneohe Bay seawater and aeration. The tank was covered with shade cloth that transmitted approximately 20% incident solar radiation. The corals were allowed to acclimate for two weeks, during which time the broken edges healed. Most fragments were completely covered with living tissue by the end of this period. The coral fragments were then randomly assigned to five acclimation treatments and placed in five separate experimental tanks. These treatments were the same as described in Kinzie et al. (1984), consisting of blue, green, red and white treatments of equal photosynthetic photon-flux density, PPFD (Fig. 1). In addition a “full sunlight” treatment was used, which consisted of a clear Plexiglas cover (Rhom and Hass “clear”) which transmitted approximately 90% PAR (photosynthetically active radiation), compared with the 11% PAR transmitted by the colored and the “white” (=shade) filters. The Plexiglas covers transmitted little or no UV radiation (Jokiel and York 1984).

The corals were allow to acclimate for 35 d. During this time the average solar radiation (as measured with an Eppley pyrholiometer adjacent to the tanks) from sunrise to sunset was 388 g-cal m⁻² (=1.62×10⁵ W m⁻²).

**Selection of corals**

Coral fragments were chosen for testing using a cyclic scheme, so that the first replicate of each of the five...