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Review

Solar ultraviolet radiation-induced DNA damage in aquatic organisms: potential environmental impact

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Abstract

Continuing depletion of stratospheric ozone and subsequent increases in deleterious ultraviolet (UV) radiation at the Earth's surface have fueled the interest in its ecological consequences for aquatic ecosystems. The DNA is certainly one of the key targets for UV-induced damage in a variety of aquatic organisms. UV radiation induces two of the most abundant mutagenic and cytotoxic DNA lesions, cyclobutane pyrimidine dimers (CPDs) and pyrimidine pyrimidone photoproducts (6-4PPs) and their Dewar valence isomers. However, aquatic organisms have developed a number of repair and tolerance mechanisms to counteract the damaging effects of UV on DNA. Photoreactivation with the help of the enzyme photolyase is one of the most important and frequently occurring repair mechanisms in a variety of organisms. Excision repair, which can be distinguished into base excision repair (BER) and nucleotide excision repair (NER), also play an important role in DNA repair in several organisms with the help of a number of glycosylases and polymerases, respectively. In addition, mechanisms such as mutagenic repair or dimer bypass, recombinational repair, cell-cycle checkpoints, apoptosis and certain alternative repair pathways are also operative in various organisms. This review deals with the UV-induced DNA damage and repair in a number of aquatic organisms as well as methods of detecting DNA damage.

Keywords: Cyclobutane pyrimidine dimers (CPDs); DNA damage in aquatic organisms; Photoreactivation; Photolyase; Pyrimidine pyrimidone photoproducts (6-4PPs); Solar ultraviolet radiation

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Contents

1. Introduction

During the last few decades, continuing decreases in stratospheric ozone over high- and mid-latitude areas with the regular occurrence of polar ozone holes both in the Antarctic and Arctic have been observed, which are attributed to catalytic ozone destruction by anthropogenically released gaseous pollutants such as chlorofluorocarbons (CFCs), chlorocarbons (CCs) and organo-bromides (OBs) [1–5]. The resulting increase in hazardous short-wavelength ultraviolet (UV-B; 280–315 nm) solar radiation has fueled concern about ecological consequences for aquatic ecosystems. By the year 2000, the Antarctic hole has expanded to a record size of approximately 28.3 million km^2, more than triple the size of the continental USA, which underpins the global scope of the problem [6]. Sabziparvar et al. [7] have devised the algorithms to model the global climatology of UV irradiation at the Earth's surface and to predict future UV trends on a global scale.

Surface solar UV radiation and the depth of penetration into the water column are the key factors controlling the potential for damage to aquatic organisms. Aquatic habitats differ enormously in their transparency [8]. Absorbing and scattering substances attenuate the incident radiation especially in eutrophic freshwater habitats and coastal areas of the oceans [9,10], while in clear oceanic waters UV penetrates to greater depths. Often pronounced variability and seasonal changes in the transparency are encountered [11,12]. Inorganic particulate matter, dissolved organic carbon (DOC) and particulate organic carbon (POC) as well as a variety of humic substances significantly attenuates short wavelength radiation [13]. DOC is fairly resistant to degradation in the water column but is readily broken down into smaller subunits by solar UV [14], which can easily be taken up by bacterioplankton. As a consequence, this process decreases the attenuation in the water column resulting in deeper penetration of solar UV [15].

Depth penetration of solar UV can be determined with various instruments including the Biospherical or the dive version of the ELDONET instruments [16]. The irradiance of biologically effective UV radiation can also be quantified using biochemical dosimeters based on the dimerization of adjacent cyclobutane nucleotides in isolated DNA or by analyzing the behavior of motile microorganisms [17,18].

Life is assumed to have evolved in the sea. Before the occurrence of atmospheric oxygen and stratospheric ozone, early prokaryotic organisms were exposed to hazardous solar UV-C radiation (<280 nm).