Chapter 21

Use of Algae in Ecological Assessments

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I INTRODUCTION

Algae have long been used to assess ecological conditions in aquatic habitats. During the early part of the twentieth century, algae were used as indicators of organic pollution in European streams and rivers (Kolkwitz and Marsson, 1908). Between 20 and 50 years ago, use of algal indicators of ecological conditions flourished based on changes in species composition with water quality and on the environmental sensitivities and tolerances of individual taxa (e.g., Butcher, 1947a,b; Fjerdingstad, 1950; Zelinka and Marvan, 1961; Sládecek, 1973; Lowe, 1974; Lange-Bertalot, 1979). Nutrient stimulation of algal growth made algae part of the problem in the eutrophication of lakes such that the trophic status of lakes was characterized by the amount of algae (Vollenweider, 1976; Carlson, 1977). In North America, Ruth Patrick and C. Mervin Palmer were pioneers in the development of large monitoring programs to assess the ecological health of rivers and nuisance algal growths (Patrick, 1949; Patrick et al., 1954; Palmer, 1969). More recently, the sensitivity of many algal taxa to pH, combined with preservation of certain algal cell wall components (e.g., diatom frustules and chrysophyte scales) in sediments, have been employed to assess problems with acid deposition and to determine if rates of lake acidification have been enhanced by human contributions to acid deposition (Smol, 1995; Battarbee et al., 2010). Government agencies throughout the world use algae to monitor and assess ecological conditions in many types of aquatic ecosystems (Weber, 1973; Watanabe et al., 1986; Biggs et al., 1998; Kelly et al., 1998, 2009; Stevenson and Bals, 1999; USEPA, 2009; Abdel Hameed and Stevenson, 2006; Chessman et al., 2007; Taylor et al., 2007; Coste et al., 2009; Potapova and Carlisle, 2011; Zhang et al., 2011; Kireta et al., 2012; Ni et al., 2012; Wu et al., 2012a,b; Brucet et al., 2013; Huo et al., 2013; Stevenson et al., 2013). Thus, characterization of algal assemblages has been important in environmental assessment both to indicate changes in environmental conditions that impair or threaten ecosystem health and to determine if algae themselves are causing problems.

Algae are particularly valuable in environmental assessments. Algae have long been recognized as the base of food chains, important in biogeochemical cycling, and the habitat for many organisms in aquatic ecosystems (e.g., Minshall, 1978; Wetzel, 2001; Carpenter and Kitchell, 1993; Stevenson et al., 1996; Wetzel and Likens, 2000; Dodds and Whiles, 2010). Thus a natural balance of species and assemblage functions are important for ecosystem health (Angermeier and Karr, 1994). Increases in algal biomass and shifts in species composition can cause problems with many ecosystem services.
by causing taste and odor problems in water supplies (Sigworth, 1957; Palmer, 1962; Arruda and Fromm, 1989; Watson, 2004), toxic algal blooms (Bowling and Baker, 1996; Burkholder and Glasgow, 1997; Heisler et al., 2008), and low dissolved oxygen (Wetzel, 2001; Stevenson et al., 2012).

In many aquatic habitats, algae are the most diverse assemblage of organisms that can be easily sampled and readily identified to species (particularly diatoms and desmids). The great species-specific sensitivity of algae to environmental conditions and their high diversity in habitats provide the potential for very precise and accurate assessments of the physical, chemical, and biological conditions that may be causing problems. Moreover, algae and paleolimnological techniques can be used to infer historical conditions in lakes, wetlands, and even reservoirs and rivers (Cohen, 2003; Smol, 2008; Smol and Stoermer, 2010). Algae occur in all aquatic habitats, so they could be very valuable for comparison across types of ecosystems with the same group of organisms. From a logistical perspective, algae are relatively easy to sample, and analysis is relatively inexpensive compared to bioassessment with other groups of organisms. In addition, many characteristics of algal assemblages can be measured and used as multiple lines of evidence for whether ecological integrity has been altered and the causes of those alterations. Algal bioassessment complements measurements of physical and chemical conditions by providing corroborative evidence for abiotic changes in environments.

Both structural and functional characteristics of algae can be used to assess environmental conditions in aquatic habitats. Algal biomass (measured as chlorophyll $a$, cell numbers, and/or algal biovolume [Stevenson, 1996]) can be used to indicate the presence of toxic pollutants as well as trophic status and nuisance algal growths (Carlson, 1977; Dodds et al., 1998). Taxonomic composition and diversity of algal assemblages are used to assess the ecological health of habitats and to infer probable environmental causes of ecological impairment (e.g., Patrick et al., 1954; Smol, 2008, 2010; Stevenson et al., 2010). Ratios of chemicals in algal samples can be used to indicate algal health (phaeophytin:chlorophyll $a$) and nutrient limitation (N:P) (Weber, 1973; Hecky and Kilham, 1988; Biggs, 1995; Borger et al., 2013). Photosynthesis, respiration, and phosphatase activity are examples of algal metabolism that can be used to assess the amount of algae in habitats, physiological impairment, and phosphorus limitation (Blanck, 1985; Hill et al., 1997; Newman et al., 1994).

In this chapter, the abundant and diverse methods of using algae to assess environmental conditions in all aquatic habitats are organized in an ecological assessment framework (U.S. Environmental Protection Agency, 1992, 1996, 1998; Stevenson et al., 2004a,b). Many reviews of algal methods for ecological assessment have been published in the last 30 years (Stevenson and Lowe, 1986; Round, 1991; Coste et al., 1991; Smol, 1992; Whittton and Kelly, 1995; Rosen, 1995; Reid et al., 1995; Lowe and Pan, 1996; Stevenson, 1998; McCormick and Stevenson, 1998; Wehr and Descy, 1998; Kelly and Whittton, 1998; Kelly et al., 1998; Ibelings et al., 1998; Prygiel et al., 1999a; Stevenson and Bahls, 1999; Whittton et al., 1991; Whittton and Rott, 1996; Prygiel et al., 1999b; Bellinger and Sigee, 2010; Smol and Stormer, 2010; Stevenson et al., 2010; Stevenson, 2014). We take this abundance and persistence of reviews as an indication of the ongoing and growing importance of algae in ecological assessment. In our chapter, we emphasize understanding the goals of environmental programs, developing and testing hypotheses that address program goals, and selecting the simplest and most direct methods for achieving program goals. We present the characteristics of algae that can be used in environmental assessments and then elaborate on how these characteristics can be related by using them in different steps of ecological assessment. Although algae have been used for such assessments in habitats throughout the world, great potential exists for developing indices that more directly meet the needs of specific environmental assessment programs. Thus, in this chapter, we present the many approaches for developing algal methods for environmental assessment and then we describe the application of algal methods for assessment.

II A FRAMEWORK FOR ECOLOGICAL ASSESSMENT

The goals of environmental assessment programs can be established by legislation, by government officials and policy makers, by scientists, or by the general public. In most cases, scientists play an important role in translating the official goals of an environmental program into hypotheses that can be tested and in developing a practical study plan that can be implemented within the budget allocated for the project. The overall goals of environmental assessment, with algae or other organisms, are to characterize the effects or potential effects of human activities and to implement management strategies that reduce the risk of ecological problems or restore valued ecological conditions. In addition to the actual state of the ecosystem, factors such as economic, social, and legal issues may affect decisions on how to protect or restore valued ecological attributes. Because of the complexity of many environmental issues, clearly stated goals and a well-organized process for gathering information and making decisions facilitates effective environmental management.

A framework for ecological assessment and management (EAM) helps to organize the process of designing assessments, characterizing ecological conditions, diagnosing causes of existing or potential problems, and selecting management options for protecting valued ecological attributes. Many frameworks have been developed for EAM that have a foundation in