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Effects of the nuisance algae, *Cladophora*, on *Escherichia coli* at recreational beaches in Wisconsin

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ABSTRACT

Recreational beaches constitute a large part of the 12 billion dollar per year tourism industry in Wisconsin. Beach closures due to microbial contamination are costly in terms of lost tourism revenue and adverse publicity for an area. *Escherichia coli* (*E. coli*), is used as an indicator of microbial contamination, as high concentrations of this organism should indicate a recent fecal contamination event that may contain other, more pathogenic, bacteria. An additional problem at many beaches in the state is the nuisance algae, *Cladophora*. It has been hypothesized that mats of *Cladophora* may harbor high concentrations of *E. coli*. Three beaches in Door County, WI were selected for study, based on tourist activity and amounts of algae present. Concentrations of *E. coli* were higher within *Cladophora* mats than in surrounding water. Beaches displayed an *E. coli* concentration gradient in water extending away from the *Cladophora* mats, although this was not statistically significant. Likewise, the amount of *Cladophora* observed on a beach did not correlate with *E. coli* concentrations found in routine beach monitoring samples. More work is needed to determine the impact of mats of *Cladophora* on beach water quality, as well as likely sources of *E. coli* found within the mats.

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1. Introduction

During the summer months, swimmers gather at beaches across the country to escape the heat and enjoy local lakes and streams. In many areas, beaches serve as the basis for a significant source of tourism revenue (Rabinovici et al., 2004). In Wisconsin, tourism is a 12 billion dollar per year industry (Kleinheinz, 2003). Thus, beach closures or water quality advisories may have adverse affects on beach users and local businesses, alike.

During 2001 and 2002, three outbreaks of waterborne illness attributed to microorganisms were caused by exposure to recreational water in Wisconsin, including the 2002 outbreak in Door County that affected nearly 70 people (Kleinheinz et al., 2003). In addition, many cases of illness go unreported, further underestimating the number of infections contracted from recreational waters.

Those most at risk from using recreational water include children and groups that may have reduced immune function (Dufour, 1984; Dufour and Cabelli, 1986). Children are especially susceptible to disease not only because of reduced immune function, but because they are most likely to be fully submersed or to ingest swimming waters along with any pathogenic organisms that may be present (Dufour and Cabelli, 1986; Kleinheinz et al., 2006). Additionally, a recent study has shown that concentrations of *E. coli* are inversely related to water depth of recreational waters, suggesting children may play in areas of beaches with the greatest concentration of bacteria (Kleinheinz et al., 2006).

Fecal indicator organisms are measured to approximate the concentrations of pathogens associated with fecal contamination, and provide an estimation of the risk presented to swimmers using beaches (Anderson et al., 2005; Bower et al., 2005; Bushon and Koltun, 2003; Dufour, 1984; Dufour and

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Cabelli, 1986; Francy and Darner, 2003; Harwood et al., 2005; Toranzos et al., 2002; Wade et al., 2003, 2006; Whitman et al., 2004). The fecal indicator organism used as the standard for water quality assessments in many states, including Wisconsin, is *Escherichia coli* (*E. coli*), as it is considered to be indicative of recent fecal contamination (Dufour, 1984; Dufour and Cabelli, 1986; Francy and Darner, 2003; Jin et al., 2004; Kleinheinz and Englebert, 2005). Concentrations of *E. coli* found in beach water are used as the basis for management decisions to close or post swimming advisories, based on the assumption that elevated levels of this organism indicate a recent fecal contamination event, and thus an increased threat to public health from use of recreational waters. An indicator organism that persists for significantly longer periods than the associated pathogens, or is itself ubiquitous in the sampling environment is, however, of little use as an indicator of recent microbial contamination.

Large mats of the green alga, *Cladophora*, also can be found at many of the same beaches that experience fecal contaminations. This alga has made a resurgence in the recent past, since it thrives in eutrophic systems common along shorelines of the Great Lakes region, including Lake Michigan (Kleinheinz and Englebert, 2005). A variety of factors are responsible for this resurgence of *Cladophora*, but all likely can be attributed to human activity around the Great Lakes and all trace back to the introduction of the invasive species, *Dreissena polymorpha*, the zebra mussel (Barbiero et al., 2006; Bierman et al., 2005; Pillsbury et al., 2002; Fahnenstiel et al., 1995). Zebra mussels have resulted in greatly increased water clarity throughout the Great Lakes, and *Cladophora* can now be found growing attached to substrates meters deeper than in the past (Bootsma, 2007). Phosphorous accumulation and cycling through zebra mussels also appears to be a favored hypothesis to explain *Cladophora* resurgence (Bootsma, 2007).

Recent research suggests that these algal mats may play a role in beach water quality advisories by harbor the microbial water quality indicator, *E. coli* (Byappanahalli et al., 2003; Whitman et al., 2004). The mats may provide a favorable environment in which certain bacteria, including human pathogens (Ishii et al., 2006), are able to persist for longer periods of time than is possible in an aquatic system lacking *Cladophora* mats (Byappanahalli et al., 2003; Kleinheinz and Englebert, 2005; Whitman et al., 2003). *Cladophora* mats may allow for longer survival of fecal coliform bacteria, after discharge into recreational waters, by reducing or eliminating many of the common environmental stresses bacteria are faced with upon deposition to the secondary (aquatic) environment, as well as by providing a more stable habitat in which to exist (Byappanahalli et al., 2003; Oragui and Mara, 1983; Whitman et al., 2003). In addition, *Cladophora* provides potential sites for bacterial adherence, a factor leading to increased survival in the secondary environment (Brettar and Höfle, 1992; Davies et al., 1995; John and Rose, 2005; Weinbauer and Höfle, 1998). Likewise, mats of *Cladophora* may provide a steady supply of nutrients to resident bacteria, more so than found in the surrounding waters. Thus, the combination of all of these factors may result in conditions that are more favorable for fecal indicator bacteria than those found in the receiving waters they are released into.

If increased persistence of these organisms is possible, mats of *Cladophora* may be able to act as reservoirs, supplying the surrounding waters with elevated fecal coliform bacteria, even in the absence of a recent fecal contamination event, thus challenging the conventional use of indicator organisms. This could happen when wave action at affected beaches serves to wash elevated amounts of bacteria from the mats (Whitman et al., 2003). Thus, the highest concentrations of indicator organisms would be within the mats, with reduction in the amount of bacteria with increasing distance from the *Cladophora* mats. This could greatly affect the management of beaches with recurring persistent mats of *Cladophora*, possibly preventing the detection of an actual fecal contamination event or misrepresenting the risk posed to swimmers using the beach. On the other hand, if mats of *Cladophora* are able to provide conditions suitable for the increased survival of *E. coli*, it is possible that pathogens associated with the presence of *E. coli* are able to persist for longer periods as well, posing an increased risk to swimmers in affected areas.

The objective of this study was to investigate the effects the presence of mats of *Cladophora* have on concentrations of *E. coli* at recreational beaches in Wisconsin. Specifically, correlations between concentrations of *E. coli* collected in beach water and amounts of *Cladophora* observed at beaches were investigated. Additionally, the potential for a spatial distribution of *E. coli* concentrations surrounding mats of *Cladophora* was investigated.

2. Methods

2.1. Routine beach water sampling

Water samples were collected from 27 beaches in Door County, WI two–four times per week, depending on location, throughout the course of the 2005 & 2006 summers to determine the *E. coli* concentrations in the water for use in posting beach advisories or closures, and for comparison of concentrations where mats of *Cladophora* were present or absent. Samples were collected in a water depth of 60 cm using sterile 100 mL polystyrene sample bottles (IDEXX Inc. Westbrook, ME) following Wisconsin Department of Natural Resources established beach sampling protocols (Wisconsin Department of Natural Resources, 2005). Samples were taken from the center of the beach area, or the center of the most used portion of the beach. Samples were maintained at 4 °C until later processing. All samples were processed within 2 h of collection in the University of Wisconsin Oshkosh's State of Wisconsin DATCP certified laboratory in Sturgeon Bay, WI (certification #105–453).

2.2. Spatial sampling of beach water

Observational data on amount of *Cladophora* present at 27 Door County beaches was collected during summers 2005 and 2006. Observational data on *Cladophora* and routine beach sampling data were collected at the same time of day (between 8 AM and noon) and on the same days at each location. To determine what impact, if any, *Cladophora* had on *E. coli* concentrations in the surrounding water, three beaches in Door County, WI (Anclam Park, Murphy Park, and Whitefish Dunes State Park) with high amounts of near shore or