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Benchmark Database for Fine-Grained Image Classification of Benthic Macroinvertebrates

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Abstract

Managing the water quality of freshwaters is a crucial task worldwide. One of the most used methods to biomonitor water quality is to sample benthic macroinvertebrate communities, in particular to examine the presence and proportion of certain species. This paper presents a benchmark database for automatic visual classification methods to evaluate their ability for distinguishing visually similar categories of aquatic macroinvertebrate taxa. We make publicly available a new database, containing 64 types of freshwater macroinvertebrates, ranging in number of images per category from 7 to 577. The database is divided into three datasets, varying in number of categories (64, 29, and 9 categories). Furthermore, in order to accomplish a baseline evaluation performance, we present the classification results of Convolutional Neural Networks (CNNs) that are widely used for deep learning tasks in large databases. Besides CNNs, we experimented with several other well-known classification methods using deep features extracted from the data.

Keywords: Biomonitoring, Fine-grained Classification, Benthic Macroinvertebrates, Deep Learning, Convolutional Neural Networks

1. Introduction

All ecosystems and ultimately human societies depend on biodiversity and ecosystem functioning [18]. Freshwater ecosystems are among the most threatened ecosystems worldwide (see, e.g., [39, 13]) as the loss of aquatic biodiversity and associated ecosystem services is estimated to surpass the loss of biodiversity in rainforests (e.g., [37, 48]). The importance of monitoring aquatic ecosystems and biodiversity is acknowledged in environmental legislation, such as the EU Water Framework Directive (WFD) [1], the EU Marine Strategy Framework Directive [2], and the US Clean Water Act [3]. The EU WFD legislation requires monitoring of several biological indicator groups for freshwater ecological status assessment. Knowledge obtained from these biomonitoring programs is used to assess the status of ecosystems, preserve and assure good future water quality. Even for the species living in species poor freshwaters of northern Europe, this legal requirement brings about a need to track hundreds of macroinvertebrate and thousands of microscopic periphyton and phytoplankton taxa.

Taxonomic identification of biomonitoring samples involving microscopy is cost intensive, as the identification of indicator species is usually done by human experts. While there are also DNA-based methods of identification, they currently do not cope well with the WFD requirements for information on indicator taxa abundance. Furthermore, genetic methods are still at least as cost intensive as traditional ones, although the price of these methods is decreasing quickly [14]. A recent study showed that manual identification of freshwater macroinvertebrate taxa done by human experts is more prone to errors (i.e., 30%) than previously assumed [16], and this may extend to other microscopic indicator groups as well [11, 12]. Thus, human-made taxonomic identification errors can affect the results and reliability of ecological aquatic research and managerial decisions regarding ecosystems services and resources. Put into a management context and recalling that the number of highly trained taxonomic experts is decreasing, this suggests that large amounts of resources may be ineffectively allocated in restoration efforts [16].

In this paper, we focus on automatic methods of identification of benthic macroinvertebrates and present a benchmark database to evaluate and test automatic identification methods. Alongside aquatic macrophytes, which generally do not require microscopic identification, benthic macroinvertebrates are the most commonly used biological indicators in the WFD implementation [7]. In Finland, 280 taxa are currently used as indicators for WFD index calculations. In official Finnish aquatic monitoring, four to six samples, each containing ca. 50-1000 benthic macroinvertebrates belonging to 2-70 taxa, are taken from each