Building the Digital Extended Specimen: A case study of invasive European frog-bit (*Hydrocharis morsus-ranae* L.)

Sara Hansen[‡], Jutta Buschbom[§], Talia Karim[|], Anna Monfils[‡]

‡ Central Michigan University, Mount Pleasant, United States of America
§ Statistical Genetics, Ahrensburg, Germany
| University of Colorado, Boulder, United States of America

Corresponding author: Sara Hansen (hanse2s@cmich.edu)

Abstract

The Extended Specimen was first described by Webster (2017). He defined a "constellation of specimen preparations and data types," centered around an occurrence of an organism, which captures the breadth of empirical facts about an organism's phenotype, genotype, and ecology in space and time. The Extended Specimen Network was embraced by the collections community in the Biodiversity Collections Network Extended Specimen Report (Lendemer et al. 2020) and the National Academies of Science, Engineering, and Medicine *Future of Collections* report (Lendemer et al. 2020, National Academies of Science, Engineering, and Medicine 2020). Several global discussions are underway to build a common definition of the Digital Extended Specimen (DES) and elucidate next steps in building the infrastructure to support Digital Extended Specimens and their network of associated data (including efforts among Distributed System of Scientific Collections (DiSSCo), Biodiversity Collections Network (BCoN), GBIF's Alliance for Biodiversity Knowledge, TDWG's Task Group on Minimum Information about a Digital Specimen (MIDS), and others.) At the foundation of the DES is the occurrence of an organism in time and space, which is represented by physical specimens or observations serving as tokens of reality. Tokens are translated to digital records, which can be extended through a network of linkages between them and with derived and associated data, e.g. project methodologies, environmental conditions, habitat characteristics, and associated taxa. For digital records to be integrated with the larger network of Digital Extended Specimens, they must become FAIR digital objects that are Findable, Accessible, Interoperable, and Reusable (Wilkinson et al. 2016). By translating the Digital Extended Specimen concept to the local project scale, we provide opportunities to move beyond a theoretical understanding of the DES and towards a practical framework for its implementation.

Here we present and discuss the power, limits, and questions in the implementation of the Digital Extended Specimen framework by applying it to the case study of an invasive

aquatic plant in the Laurentian Great Lakes region. European frog-bit (*Hydrocharis morsus-ranae* L.; EFB) is native to western and northern Eurasia and invasive in North America and India. Dense mats of EFB may hinder commercial and recreational use of waterways and decrease light, dissolved oxygen, and native species diversity. We describe a multi-taxonomic study that examined EFB along with associated plant species, animal species, and environmental characteristics (Monfils et al. 2021). The integration of such diverse types of empirical data is a necessary prerequisite for determining the factors associated with EFB establishment, the impacts of EFB on native coastal wetland ecosystems, and the development of suitable management regimes for the conservation of native biodiversity. Data gathered from this study are housed in a local database. In our database, we consider both physical specimens and recorded observations as tokens of concrete occurrences of EFB, which define the base units. These tokens are linked to their collection events, which provide environmental and sampling context, as well as co-occurrences of other taxa including plants, invertebrates, fish, anurans, reptiles, and birds. Digitally linked, these extensions of each digital representation of a collected token provide not only empirical evidence of an EFB occurrence, but also directly connect it with all additionally sampled, derived, and associated information. Through this network of extensions we gain a more holistic understanding of EFB's species associations, habitats, and ecosystem impacts at the level of populations and communities. The application of the Digital Extended Specimen framework at the project level illustrates how the DES can be used in a real-world context and highlights challenges in translating the concept from a theoretical to a practical perspective.

Keywords

digital data, invasive plants, specimens, observations

Presenting author

Sara Hansen

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