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Computer-driven image-based soil fauna taxonomy

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ABSTRACT

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The study of soil ecology has long been hampered by the diversity of species and functional groups of soil fauna. Many of these taxa are poorly studied and integrated taxonomic references are unavailable on a regional basis.

We used HyperCard, a hypermedia program for the Macintosh computer, to develop COMTESA (computer taxonomy and ecology of soil animals). COMTESA is an image-based, taxonomic key for soil fauna, which also acts as a data base to store ecological information about the organisms. Multilevel linking within COMTESA allows the user to peruse the module in a non-linear fashion so that learning can proceed at an individualized pace that is driven by curiosity. Its basic design can be useful to all levels of users from novice to experienced soil zoologist.

COMTESA is conceptually divided into two parts designed to deal with different scales of resolution. Part I distinguishes 150 different functional/taxonomic groups, has an ecological emphasis and should be useful throughout North America. Part II consists of modules that provide identification to the generic and species level and are specific to region/site/ecosystem.

Within the community of individuals involved in soil ecology research the demand is high for those with skills in identification of soil fauna. Since few individuals are knowledgeable in this area, the burden for identification of specimens falls either on inadequately trained ecologists or upon the limited resource of taxonomic specialists. COMTESA can offer a partial solution to this problem of "communication". Taxonomists can use COMTESA to produce user-friendly regional keys that can be rapidly updated and quickly distributed to users at a low cost. Ecologists would have better resolution in their results, and by high-grading their samples could provide material more likely of interest to the taxonomists. Successful integration would generate broader interest and support for the multidisciplinary basic research that needs to be done. A simplified version could be introduced to science classes in the secondary education system, to expose a new generation of potential taxonomists and soil ecologists to the world of soil biology.

INTRODUCTION

A wide variety of individuals not directly involved in soil fauna research are interested in the contribution fauna make to the soil processes they study.

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Interest often wanes once they are faced with the investment in time and effort required to obtain the taxonomic skills necessary to expand their research programs to include soil fauna. These individuals frequently view learning the taxonomy of soil fauna as an insurmountable task for various reasons which may include: (1) the information is not collated into a single source (the recent publication of Dindal (1990) should aid in this respect); (2) dichotomous keys are tedious and require detailed knowledge of body structures; (3) taxonomy is a visual skill but traditional keys are often limited to verbal descriptions. In North America, the problem of obtaining reliable taxonomic information is further exacerbated by the paucity of taxonomists with expertise in soil invertebrates (Stanton and Lattin, 1985).

Over the last few years hypermedia has been used successfully to educate students in topics with difficulties like those associated with soil fauna taxonomy and ecology. Hypermedia implies the ability to manage large collections of complex information, including images, and often connotes an interactive educational experience (Jaffe and Lynch, 1989). The user is able to peruse bodies of information in a non-linear fashion, so learning can be driven by curiosity rather than a teacher-designed direction and pace. Jaffe and Lynch (1989) state that biological topics are particularly suited to hypermedia and they have developed modules using HyperCard (a hypermedia program) on the Macintosh computer for comprehensive instruction in the taxonomy, anatomy and physiology of birds, whales and humans. Others have used HyperCard to develop a key for zooplankton (Estep et al., 1989).

HyperCard is a program that makes it possible to organize computer images and text in a manner analogous to a card file (referred to as a "stack" of "cards" in HyperCard lingo). The important advantage the computer-based "card file" offers is multilevel linking and searching capability. A Macintosh computer (plus, SE or II with at least 1 megabyte of memory) and the HyperCard program are required to use any HyperCard stack (Estep et al., 1989). The HyperCard program comes free with the purchase of a new Macintosh computer or can be purchased for about $39. Although it can be run from two 800K floppy drives, performance is sluggish, so a hard drive is recommended (Jaffe and Lynch, 1989). A digitizer such as Thunderscan, Apple Scanner or ScanJet Plus would be required to incorporate new images into a stack.

COMTESA

In light of the documented successes in the instruction of biological topics using HyperCard, we designed a module for instruction in the taxonomy and ecology of soil fauna (COMTESA – computer taxonomy and ecology of soil animals) of the Pacific Northwest. The intent of the design of COMTESA is that it be useful to all levels of users from novice to experienced soil zoologist.

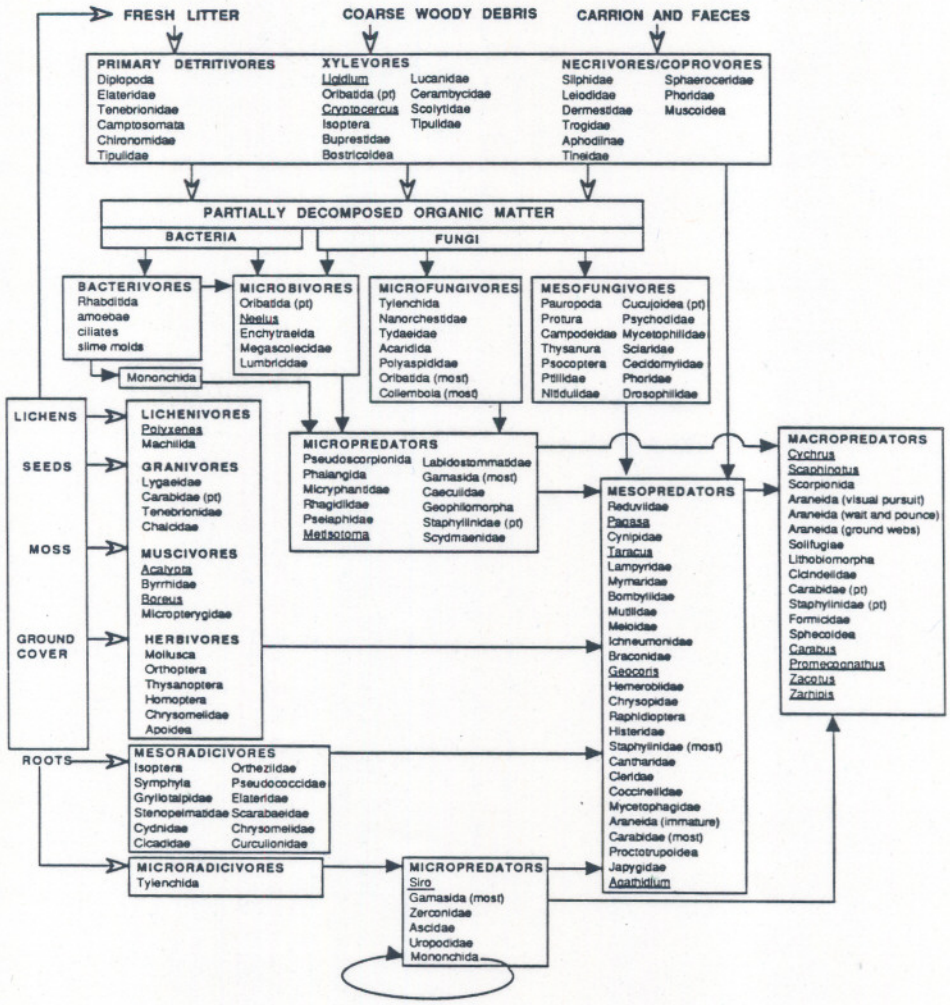

Fig. 1. Simplified food web of major functional groups in a Pacific Northwest conifer forest soils (corresponding to the endpoints of Part I of the COMTESA key). Empty arrowheads show flow of primary production while filled arrowheads show flow through decomposer food web. Specialized predator/prey relations are not indicated with separate arrows for ease of presentation but instances of known specialized trophic relations (e.g. the nabid bug *Pagasa* which feeds on the lygaeid granivore *Plinthisus*) are keyed independently in COMTESA. Though our knowledge of food web relationships is limited COMTESA can easily be modified and updated as information becomes available.

COMTESA can be used by the novice to differentiate basic functional groups with ease. Knowledgeable scientists and their research staff can use COMTESA to differentiate to the species and/or functional group levels, and can

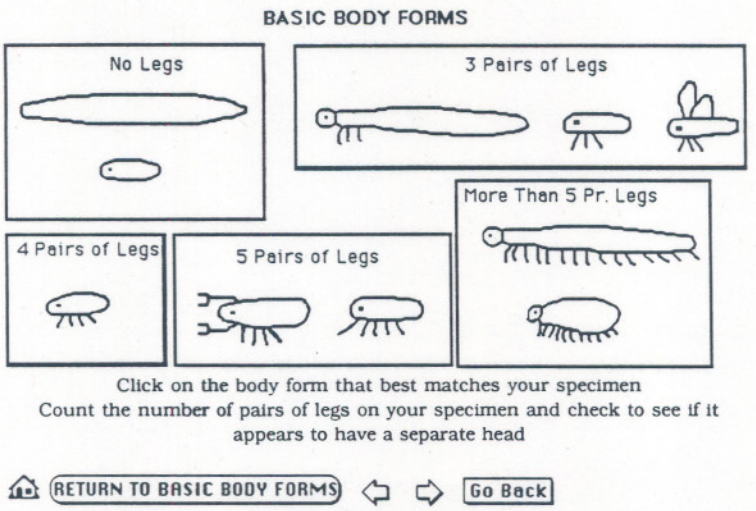

Fig. 2. Example of a "card" in the COMTESA image stack using simple images.

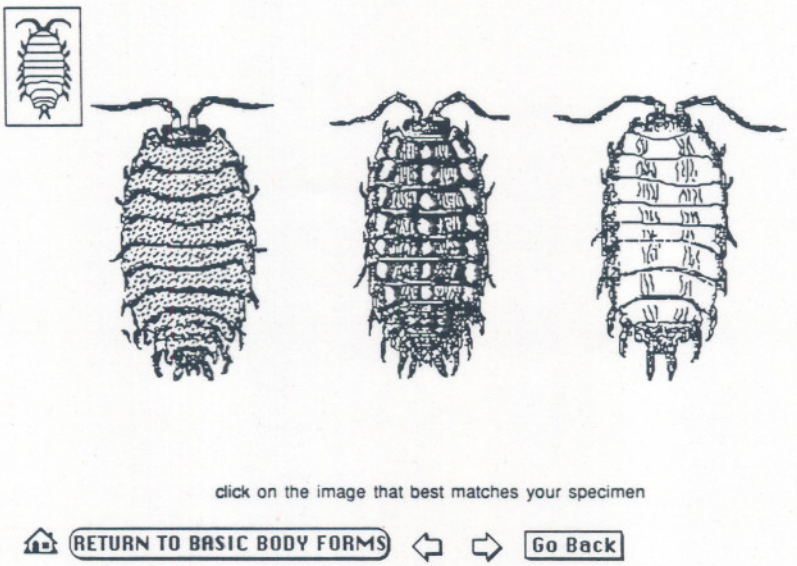

Fig. 3. Example of a "card" in the COMTESA image stack using detailed images.

use the module to store and retrieve information and scientific references about organisms at any level of organization (order, family, genus, species etc.).

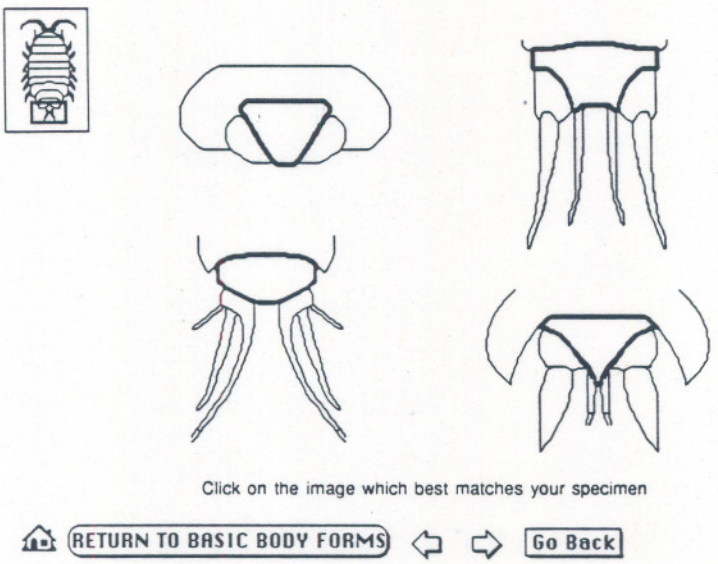

Fig. 4. Example of a "card" in the COMTESA image stack where the differentiating criteria are highlighted in bold.

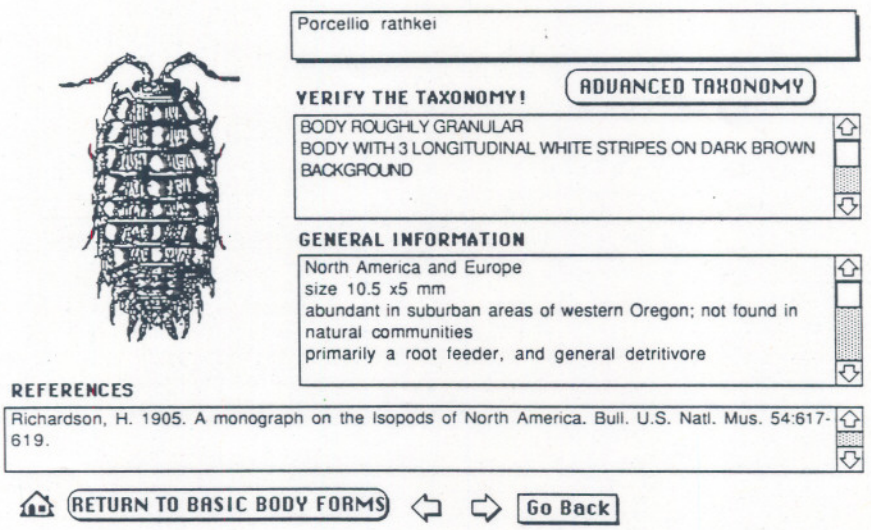

Fig. 5. Example of a "card" in the COMTESA information stack providing detailed descriptive information about the organism at a level commensurate with the identification.

Print-based keys currently available for identification of arthropods are often designed to cover wide geographic regions, such that their level of resolution is poor for the scale at which most ecological studies are conducted. The modular approach of COMTESA copes with this problem since it is conceptually divided into two parts designed to deal with the different scales of resolution. Part I distinguishes 150 different functional/taxonomic groups and has an ecological emphasis (Fig. 1). For instance, the xylevorous and microphytophagous species of oribatid mites are distinguished from one another while predaceous spiders are divided into component hunting guilds. This part of the key should be useful across North America with minor alterations to meet local needs. Part II consists of modules that provide identification to the generic and species level and are specific to region/site/ecosystem. Currently, the key has one such module for the coniferous biome of the Pacific Northwest and as such is identified as CONIFOR-COMTESA. The level of resolution of such a module is limited by the degree of taxonomic expertise available for any specific group. Modules for other ecosystems will be developed through collaboration and will be readily identified by different prefixes.

Functionally, COMTESA is comprised of two stacks with multiple links between them. Initially the users work their way through the image-based key (identification stack) by "clicking on" the one image on each screen which best matches the specimen to be identified. Any choice on an image screen that leads to a final identification sends the user directly to the appropriate card in the second stack (information stack) which is comprised of cards that provide detailed information about the organism, or group of organisms, that was identified.

The image-based taxonomic key takes full advantage of unique Macintosh and HyperCard features. Identification is fairly rapid and easy, since multiple choices are offered on each screen and the user is not required to know (but can learn) the names of a wide variety of body parts. Initially, the images are simple line drawings (Fig. 2) and they become more detailed as one proceeds through the key (Fig. 3). The use of explanatory text is kept at a minimum so that the user concentrates on the images and learns to differentiate on the basis of visual characteristics. For example, one of the first choices to be made in order to identify genera and then species of isopods is the shape of the telson and uropodites. The user is presented with the range of forms for the uropodites and telson (Fig. 4) and makes a choice of the form which best matches the specimen under consideration. In many cases the organism is drawn in faint lines with the key portions highlighted (Fig. 4) in bold or indicated with arrows, to avoid those characteristics which may be confusing or diversionary. A miniature generic organism for the group under consideration appears in the upper left hand corner of every card with a box indicating

the region of the organism the user should concentrate on to make a selection from the choices on the screen (Fig. 4).

Considerable redundancy is built into the key in order to delineate groups of organisms with easily confused forms or where immature forms are dissimilar from the adult. For example, the first time one discovers abundant immature *Neelus* (a nearly jumpless, blind, minute, transparent glob) it is unlikely to be keyed to "fungus-feeding springtail". Its antennae would likely be mistaken for a fourth pair of legs, and one would end up unsatisfactorily amongst the prostigmatid mites. We have foreseen that possibility, and correct identification is made possible by including *Neelus* with the group of prostigmatid mites it could be confused with. Once the identification has been made through the incorrect route the user learns that *Neelus* is a springtail and can check for the antennae they had mistaken for legs. The next time through the key, the user might remember about the antennae and will also reach the correct identification through an alternate (correct) path.

Special features of HyperCard and the COMTESA module allow the user to move quickly and efficiently throughout the key. For example, if at any time the user wishes to start over from the beginning, he simply clicks on the RETURN TO BASIC BODY FORMS button (Fig. 4). If he has, for example, worked his way partially through the isopod genus/species portion of the key and wishes to start over again at the beginning of isopods, the user simply clicks on the miniature generic image in the upper left hand corner of the screen (Fig. 4). If an advanced user already knows she has an isopod and wishes to determine the genus or species, she simply has to pull down "Messages" from under "Go" on the menubar and type in "go to card isopods", and will immediately be sent to the beginning of the isopod key. Similarly if the user knows the genus of the isopod is *Porcellio* and wants to determine the species he simply types in "go to card Porcellio" and is taken directly to the appropriate card in the key to begin keying out the species. At any time the user may pull down "Recent" from the menubar, and the screen will be filled with miniature versions of the last 30 cards the user passed through. Clicking on any one of the miniatures returns the user to that card in the key.

When an identification is made in the image stack the user is sent directly to a card in the information stack (Fig. 5). Information cards are introduced at several different levels of identification. For example, after determining the specimen of interest is an isopod the user will be sent to an information card containing information commensurate with that level of identification. The information card provides a written description providing details to VERIFY THE TAXONOMY (Fig. 5). If the written description does not fit the specimen one simply clicks on GO BACK to return to the same card in the image stack the user came from, so he can make a different choice. If the identification is correct the user can proceed to learn more about the organism (or group of organisms) by studying the information card. The scien-

tific name and common name(s) (if appropriate) are provided in the upper right hand corner. General information and suitable references from the scientific literature are provided in scroll boxes so the user can add more (with almost no limit) to these boxes as the information becomes available (Fig. 5). By clicking on the OTHER LIFE STAGES button one is sent to other information cards to view alternate forms in which the species may occur. If one desires to identify the isopod (or other organism) to the family, genus or species level one simply clicks on the ADVANCED TAXONOMY button and returns to the image key at the appropriate card to carry on. Once the next level of identification is successfully completed the user will be sent to a different information card which contains information specific to the family level identification, and so on.

In the cases where novel species or forms are found through intensive sampling, their images can be rapidly added to the key and recorded as unknown species "X". Once the necessary consultation with taxonomic experts is complete, the species "X" can be replaced with a proper name.

DISCUSSION

Within the community of individuals directly or indirectly involved in soil ecology research the demand is high for those with skills in identification of soil fauna. Yet, a recent study sponsored by the National Science Foundation noted the paucity of taxonomists with expertise in soil invertebrates in North America (Stanton and Lattin, 1985).

Education in taxonomy and/or technical training in identification frequently requires a tutorial style of teaching, one on one between teacher and student, or through a workshop to educate a larger group of people. These traditional means of passing on taxonomic knowledge place heavy demands on the few experts for teaching, and the need for tutorial-style training means that they are only able to train the few individuals who have some way of directly accessing the expert. Since few individuals are trained, taxonomists frequently are pressured into assisting with the tedious sorting of extensive ecological samples, severely limiting their ability to conduct critically limiting systematic studies. COMTESA does not remove the need for experts to study high-graded synoptic materials, but it allows the technician to sort samples with high efficiency and allows the taxonomist to deal with only the material of greatest potential utility to him or herself. The ecologist gets meaningful identifications and avoids "black-boxing apples and oranges".

The ultimate benefit for such a system lies in integrating taxonomic and ecological research, removing the mutual impedance which frequently develops and stimulating research interests in correlative fields. Further, a simplified version of COMTESA could be introduced to science classes in the secondary education system, to expose a new generation of potential taxonomists

(for which a need has been identified) and soil ecologists to the intriguing complexity of the world of soil biology, through a medium which more accurately than the printed page stimulates learning driven by curiosity; the same curiosity that drives scientific and therefore taxonomic and soil ecological research.

Part I of COMTESA may be acquired through a request in writing to the corresponding author. A nominal fee of $25 is charged to cover the cost of discs and shipping.

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