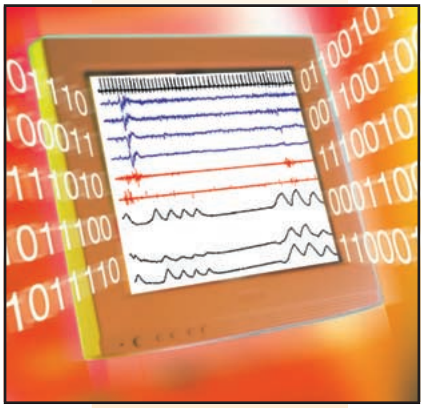

Database Design for an Archive of Animal Sounds

Elements of Building a Modern Database to Facilitate the Study and Use of Animal Sound Recordings

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Biological (natural history) museums are the repositories of scientific knowledge of the Earth's diversity of life. There are many such museums worldwide, some associated with universities, some privately owned, and others funded by various branches of government. While the public may be familiar with displays and dioramas depicting various plants and animals in life-like situations, the real "working" portion of a museum typically consists of steel cabinets housing seemingly endless numbers of prepared specimens: bird skins, pressed plants, pinned insects, fish skeletons, and the like. Associated with each specimen are a tag and a uniquely numbered catalog entry (today usually in the form of a computer database) that provides additional information about the specimen: collecting locality, date, sex, etc. With specimens in hand, taxonomists can compare their size, shape, color and myriad other phenotypic characters and test hypotheses concerning the evolutionary relationships of organisms. Large series of prepared specimens, which can be compared simultaneously, have produced key insights into geographic variation, the study of how populations of organisms vary in space. There is also unknown value to such specimens that can be reanalyzed with the emergence of new techniques and hypotheses.

In several animal groups, the production and reception of sound signals are other key aspects of their phenotype. The sounds produced by stridulating crickets, croaking frogs, singing birds, and roaring red deer are communication signals that in many cases serve to attract mates of the opposite sex and ward off competitors of the same sex. As such, they may play a key role as "reproductive isolating mechanisms" [1] that serve to demarcate species, the fundamental unit in the Linnaean hierarchy of biological nomenclature. In many cases, differences in animal sounds first led scientists to realize that apparently homogeneous populations were in fact composed of two or more distinct noninterbreeding species [2-4]. Some animal groups have exploited the acoustic communication channel because sound can travel over long distances, does not require line-of-sight for its detection, and is effective at night as well as during daylight hours. In some species, visual or chemical signals play a similar function in mate attraction, but until relatively recently, such signals were much more difficult to record permanently. Portable tape recorders have been available for over 50 years, and as a result, bioacousticians have extensively documented animal sounds.

Attached to several museums worldwide are sound archives, units dedicated to collecting, preserving, and making available to others recordings of animal sounds. In the case of the Borror Laboratory of Bioacoustics (BLB) at The Ohio State University, most recordings in the archive are the products of research by staff and students. The users of the collection include scientists, governmental agencies, and commercial enterprises. In this article we will describe our efforts to build a modern database that describes the sound recordings in our care at the BLB. The history of the BLB is described elsewhere [5].

Organization of the BLB Sound Archive

A sound archive consists of a series of "recordings" or "cuts," each of which is a record of an individual animal (or group of animals) at a single place and time. To understand how the individual recordings are organized in the BLB involves a bit of history and an appreciation that the col-

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lection had its beginning in the analog era and was started by a man trained in insect taxonomy, Donald J. Borror. Most of the recordings in the BLB are from animals in their natural habitats. Bird recordings comprise about 87% of the collection, with insects, frogs, and mammals making up the remainder. The first high-quality portable tape recorders capable of being used in the field used 6.35 cm open-reel tape. During a recording expedition, a field recordist might record several different individuals or even species on a single 6.35 mm reel of tape. Rather than deposit "raw" field recordings in the archive, Borror first spliced out, and later copied, selected cuts onto "species reels." A species reel holds a number of different cuts all of the same species. Some popular study species, such as the song sparrow, *Melospiza melodia,* occupy almost 200 species reels holding hundreds of cuts made at different times and places. Collecting all the cuts of one species together on a series of reels is analogous to the standard museum practice of collecting all the physical specimens of a given species together in one drawer in a collection cabinet. This species-level organization facilitates finding recordings among the thousands of reels of tape in the archive.

Organization of the Database

As each recording or cut was added to a species reel, it was assigned a unique catalog number. The catalog number was written on a section of blank leader tape at the beginning of each cut, along with other basic identifying information (date, species name, recording location). A great deal of other information is associated with each recording to make it maximally useful to users. To store this information, and make it easily searchable, a computer database was developed. The first version of the BLB's computer database has already been described [6], but it was in dire need of improvement. It was begun when large hard drives were expensive. To save disk space, the program used extensive data coding and variable-length data fields, which, with extensive coding, could hold our (then) 22,000 records on 5.6 MB of hard disk with 5.3 MB in data records and 150 KB in cross-reference or secondary key files. Because nonprofessional programers and data entry personnel were used, we selected a commercial program requiring minimal postdevelopment programming. However, the data coding and small disk capacity produced unwieldy and complex relational data files that were difficult to use and maintain. Our first database has therefore been replaced in the past five years by a relational database written using commercially available software (Microsoft Access) that eliminated the codes and cumbersome file structures but was not difficult to maintain by a nonprofessional programmer. The information included in the database reflects standard museum practices and the particular needs of a sound archive. Currently there are 26,200 recordings occupying 35.5 MB of disk space in the database.

The database is operated from a system of menus, each performing a distinct function. The main menu controls access to the various functions (data entry, look-up table maintenance, data editing, etc.). We will describe the manual data entry interface in the most detail, because the information entered into the database and how it is organized serves to define the essential features of a database designed for a collection of animal sounds. Data can also be read in from a properly formatted ASCII file, but most data entry is done manually by the field recordist or BLB staff. Data entry is performed through a set of screens, which group together logically related information.

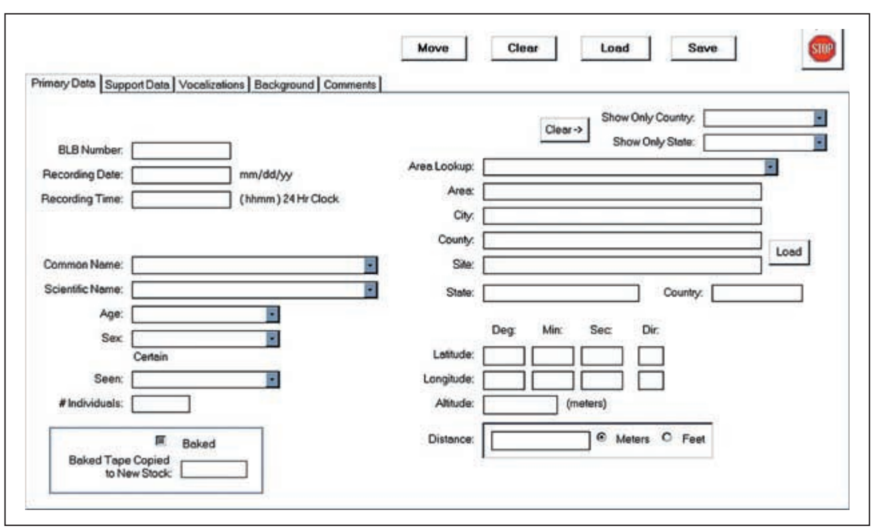
Primary Data

Some information entered into the primary data screen (Fig. 1) echoes that written on the leader associated with each cut in the collection (catalog number, date, species name, recording location). The time of day the recording was made is also recorded in the database. Many species vary their sound production on annual and diurnal cycles, so date and time information may be of interest to the user. Each species is also classified into the higher-level categories in the Linnaean hierarchy (Genus, Family, Order, and Class). The categories are hierarchically organized in the database, and an editing screen makes it easy to change the classification as systematists refine their hypotheses about evolutionary relationships. Age and sex are other standard data entered into the database, along with whether the animal was seen, how many individuals were recorded, and how far away they were. Distance to the subject has a large effect on a recording's quality (the closer the better), and a user may choose to eliminate some recordings from consideration if the animal was too far away when recorded.

Data on the recording location is stored in several fields: an area, and associated with each area, the city, county, state, country, latitude, longitude, and elevation. Frequently used areas are stored in a look-up table, organized within states, and can easily be entered from a drop-down list. This feature speeds data entry because many of the recordings in the BLB collection derive from research conducted in a limited number of areas. A researcher may make dozens or hundreds of recordings of different individuals within one study area. A site field contains more detailed information (often features of a location within 100 m of the event) about locations within a given area.

Support Data

The support data screen contains data about the recordist and the equipment used. We enter the name of the person who made



1. Primary data screen for entering data (see text for details).

To understand how the individual recordings are organized in the BLB involves a bit of history and an appreciation that the collection had its beginning in the analog era.

the recording for several reasons. Sometimes a question arises concerning the use of, or the sound on, a recording. If the recordist is available, they may be able to provide the needed information. Some recordists are renowned for making pristine, high-quality recordings, while others are rather loquacious and make more sound on tape than does the subject animal. BLB staff may be able to select recordings for users based on knowledge of such differences in recording "style."

The goal of a sound recordist is to acquire a noise-free record of the animal's sound that is unaltered by the recording equipment. This, of course, is never possible, and because the type of equipment used influences the quality of the recording [7], detailed information on the recording equipment is recorded in the database. Perhaps the most critical component is the microphone. Information about the type and manufacturer are recorded in the database because this tells the recording's user something about the potential quality of the recording. Certain manufacturers make very high quality microphones that are capable of recording over a wide frequency range with high and stable sensitivity. The directional pattern (omnidirectional, cardiod, "shotgun") describes spatial and frequency variation in the microphone's sensitivity. Some recordists use a parabola to record distant subjects. Parabolas produce frequency-dependent amplification of the sound and are also frequency-dependent in their directionality. It is essential for the user to know this information when judging the suitability of a sound recording.

All of the recordings in the BLB were recorded originally on either analog, or more recently, digital (R-DAT) tape recorders. High-quality analog recorders using open-reel tape running at 38.1 cm per second produce recordings that rival the specifications produced by a digital tape recorder. Analog cassette recorders are perhaps the most common recorders used today because of their lightweight and convenience. As long as their limitations are recognized, they can make excellent recordings of many species. Information describing the recorder, tape, and tape speed are recorded in the database, as these data may influence the choice of a recording by the end user.

In addition to information about the equipment used to make the recording, the support data screen stores descriptions of the tape recorder used to copy the recording into the collection, and the identity of, and location on, the original field tape from which the recording was derived. Rarely, a recording in the collection is lost or damaged. Saving information about the original field tape speeds recovery of the recording. Also recorded on the data support screen is the number of the CD holding the digital copy of the recording. We will describe this further below. Finally, fields are provided for entering data on the weather and temperature. These are essential for interpreting the sounds of insects and frogs. In these groups, the body temperature of an individual usually closely follows that of the environment (they are "poikilothermic"). Because muscular activity is temperature dependent, important temporal aspects of the sounds produced by poikilotherms vary with the ambient temperature [8, 9].

Vocalization Screen

The vocalization screen stores data describing the sounds on the recording. The term "vocalization" reflects the bird bias in the BLB collection. Many animals, birds included, make sounds that are not produced by a vocal apparatus (the syrinx in birds, larynx in mammals) and thus are not true vocalizations. All sounds, regardless of the mode of production, are described here. The type of sound recorded (song, call, mobbing, drumming, etc.) can be selected from a drop-down list. The duration of the recording, along with the recordist's subjective assessment of the recording quality (poor to very good) are stored here, along with a count of the number of sounds produced by the subject. Most animals produce fairly discrete songs or calls that are separated from one another by a silent interval. Counting them is fairly straightforward. Other animals produce sound continuously, and this can be noted in a "Comments" field. The Comments field is typically used to store data describing the sound or the subject, such as the type of song sung or the bird's color-band markings. If the tape recorder was stopped and restarted during the recording, these times can be entered here. Finally, a check box can be selected if the level of background noise, described on the next screen, is high.

Background Screen

The human brain has a remarkable ability to focus attention on the subject animal, and to "filter out" other sounds in the background. Microphones do not have this ability and are unselective in what they record (within their frequency and spatial sensitivity ranges). The novice recordist is often amazed at all the "other" sounds that appear on his/her recordings. The background screen allows one to register the various other sounds that almost inevitably appear on a recording. Other animal species that appear on the recording can be entered from a drop-down list. A second table contains common sounds that appear in the background (traffic, narration, wind, surf, aircraft, motors, etc.). The listing of background sounds may be very important to some users in deciding whether a recording suits their purposes. For example, an airplane in the background would not prevent a scientist from identifying the dialect sung by the subject bird, but it would probably prevent the recording from being included in a commercial audio field guide to bird sounds. The final screen used in data entry, the comments screen, allows the recordist to enter miscellaneous details in a text box.

Other Database Functions

The information stored in a database is useful only to the extent that it is accurate. The main menu contains several options that allow the user to examine and edit data.

Before a record (all the data associated with a single catalog number) is added to the database, it is held in a temporary file. Each record in the temporary file can be examined in a condensed format either on a computer monitor or hardcopy and corrections can be made. After a record has been proofread, a hardcopy "long-data form" is printed and filed. In the event of catastrophic loss of the hard drive and tape backup of the database, the data could be restored manually from the long-data forms. After a record has been edited, it is moved to the permanent database using a separate menu accessible from the main menu. "Short-data forms" can also be printed from the main menu. A short-data form contains summary statistics on the recordings of a given species (number of recordings, locations by state, total duration, etc.). An example of our long-data form can be examined on our website (http://blb.biosci.ohio-state.edu/ editing.htm).

Several other housekeeping functions are accessed from the main menu. All of the look-up tables that relate to individual records in the database (recordist identity, area, taxonomy, microphone type, etc.) can be edited. A listing of all records in the database in taxonomic order can be produced in the form of a catalog. The catalog is produced annually and is sent out in hardcopy form and is also available on our website (http://blb.biosci.ohio-state.edu/ blbcatalog.htm). The catalog's function has been augmented in recent years with the advent of web-based searches of the database (see below).

The Digital Project

The BLB is currently involved in copying the entire analog collection onto CD-Rs. Copying the archive onto a digital format was prompted by several considerations. Some of the first recordings in the collection are over 50 years old, which is the proven life expectancy of analog tape stock. These recordings need to be copied to new media before they are lost. Other recordings were made on tape stock reformulated in the 1970s that had the undesirable property of absorbing atmospheric humidity. These tapes need to be baked at a low temperature before they can be played on a tape recorder and the recordings recovered (baking a recording is noted in the database). In addition to providing a means to preserve our analog recordings, the CD-R medium holds several advantages over analog media. The optical read device does not wear the disk with each use, whereas analog (or digital) tape suffers some loss of magnetic particles each time it is used. Digital disks are also random access, which speeds access to recordings.

The BLB's current database was planned and built with the knowledge that the collection of analog tape recordings would be copied onto digital CD-R media. Several functions in the database were designed to accommodate this step. The analog recordings are being digitized one-at-a-time at a sampling rate of 50 kHz with 16-bit precision and stored as individual data files. Each data file has a header containing some of the information that was written onto the tape leader associated with each recording in the analog collection. The database generates this information, which is then added to the header using a custom program. The server hosting our database is networked with the digitizing computers, so that information can be easily passed back and forth. We decided not to include the species name from the header because there would be no way to change it in the future short of "reburning" the entire disk. In the analog archive, the pencilled-in species name on the leader can be easily changed to reflect taxonomic changes.

Database verification is time consuming and therefore costly. As discussed above, a first-order verification is achieved in the BLB by comparing the original hardcopy long-data form with the data entered. The digital project has facilitated further verification at three levels.

- 1) Each data record must have a matching specimen. Because each specimen must be physically examined during digitization and each data record must be updated with the information from the digital process, data record and specimen matching is achieved.
- 2) The transfer of data between our old and new database is verified when a hardcopy of each specimen's data record is produced for the digitizing technician. Before producing this copy a database manager compares the record in the current database with the old database for completeness and accuracy of transfer.
- 3) Completeness of data is further verified when the technician compares the data record with the specimen tag (leader) and with the audio output (vocal type, vocal number, source of background sounds, etc.).

As each CD-R is produced, it is given a unique number. Each of the records in the database associated with a given CD-R is then updated with information generated by the digitizing process (e.g., CD number, digitization date, occurrence of "clipping" during digitizing). We also maintain a separate database of the CD-Rs produced. Each CD-R is tested when first written for several kinds of physical errors. Samples of CD-Rs are tested quarterly to monitor these same error statistics. These data are stored in the CD-R database and can be examined to see if the CD-Rs deteriorate with age or usage. Should this occur, we could move the collection onto a different storage medium. For safekeeping, the analog recordings are being preserved in the Ohio State University Library Archives.

The information entered into the database and how it is organized serves to define the essential features of a database designed for a collection of animal sounds.

The Internet Interface

The rapid growth of the Internet in recent years has led many museum curators to make their collections' databases available online, thereby enabling remote users to search the database. The BLB has begun this process and intends to expand online search capabilities in the future.

Currently, the BLB database can only be searched by common species name, although expanded search criteria including the scientific name and geographical location are planned. Selection of a common name, "song sparrow" for example, from

The BLB's current database was planned and built with the knowledge that the collection of analog tape recordings would be copied onto digital CD-R media.

a drop-down list yields a version of the short-data form that includes the catalog number, duration, location, data and content [vocalization type(s), number(s) and brief comment(s)] for all the recordings of that species. The catalog numbers are active links, which when selected produce a version of the long-data form that provides more extensive information on the selected recording. These web pages are dynamically generated using Microsoft's Active Server Pages (ASP). These ASP pages allow the BLB's web server to query the Access database and return information to the user's Internet browser in standard HTML format.

In the future, we hope to make it possible for users to order recordings online after they have browsed the database and determined which recordings suit their purposes. BLB staff could then return a price quote based on the intended use of the recordings (research, commercial). Due to current bandwidth limitations, it is not possible to actually deliver recordings themselves over the Internet. It takes too long to transmit an average-length recording (two minutes) sampled at 50 kHz even over a fast connection. We will not use the various compression algorithms currently in favor for delivering music online because they are based on human psychoacoustics and thus alter the sound. Recordings are delivered to users in any analog tape format, or on a variety of digital media (R-DAT tape, CD, Zip disk). Recordings can be provided in the BLB format at a sample rate of 50 kHz, or resampled to 44.1 kHz as .wav or CD audio files.

To facilitate the accession of new material to the collection, we are preparing to allow data entry via the Internet. The original recordist has the most complete information about the recordings that s/he gives to the BLB. If that person did the initial data entry, the completeness of the database would increase. Additionally, when the recordings are digitized into the collection at least a portion of the data entry time (verification and consistency checks would need to be done) would be saved.

In common with the custodians of many other databases, we feel the Internet promises to ease accessability to, and increase the use of, our database and the collection of recorded sounds the database describes. Hopefully this will facilitate creative uses of the sounds by researchers and commercial users alike.

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C.L. Bronson is a Ph. D. candidate in the Department of Evolution, Ecology and Organismal Biology at The Ohio State University, Columbus, and is the manager of the BLB's digital project. She received her B.S. from the University of Illinois. She is currently studying a hybrid zone between Carolina and black-capped chickadees.

Timothy J. Kloth Jr. assisted with the design and development of the database system. He is currently employed as a business applications developer for an engineering firm in Dublin, Ohio. He holds degrees in computer information systems and political science.

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References

[1] E. Mayr, *Animal Species and Evolution*. Cambridge: Belknap Press, 1963.

[2] W.F. Blair, "Mating call and stage of speciation in the Microhyla olivacea–M. carolinensis complex," *Evol.,* vol. 9, pp. 469-480, 1955.

[3] R.D. Alexander, "The song relationships of four species of ground crickets," *Ohio J. Sci.*, vol. 57, pp. 153-163, 1957.

[4] R.C. Stein, "Isolating mechanisms between two populations of Traill's flycatcher," in *Proc. Am. Phil. Soc.*, vol. 107, pp. 21-50, 1963.

[5] D.A. Nelson and S.L.L. Gaunt, "Borror Laboratory of Bioacoustics (BLB) and the bioacoustics research group at the Ohio State University," *Bioacoustics*, vol. 8, pp. 281-286, 1997.

[6] M.E. McVey, L. Fairchild, and S.L.L. Gaunt, "A microcomputer DBMS for a sound-recording collection," *Curator*, vol. 32, pp. 91-103, 1989.

[7] D.C. Wickstrom, "Factors to consider in recording avian sounds," in *Acoustic Communication in Birds: Vol 1. Production, Perception, and Design Features of Sounds*, D.E. Kroodsma and E.H. Miller, Eds. New York: Academic, 1982.

[8] H.C. Gerhardt, "Temperature coupling in the vocal communication system of the gray tree frog, Hyla versicolor," *Science*, vol. 199, pp. 992-994, 1978.

[9] J.A. Doherty, "Temperature coupling and 'trade-off' phenomena in the acoustic communication system of the cricket, Gryllus bimaculatus De Geer (Gryllidae)." *J. Exp. Biol.*, vol. 114, pp. 17-35, 1985.