TECHNIQUES FOR AUDIO RECORDING VOCALIZATIONS OF TROPICAL BIRDS

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ABSTRACT.--Audio recordings of tropical birds are important tools for biologists involved in the study, management, and conservation of birdlife; the ability to acoustically identify a species in a number of tropical habitats is essential. Recording method, equipment, and the condition of equipment can affect the accuracy and quantity of audio recordings collected. Suitability of currently available analog recording systems, emerging digital recording formats, and differing microphone designs for field work varies. This paper discusses essential and effective criteria that can be used to select a recording system based upon research goals and financial resources.

To survey and study tropical birds, biologists increasingly recognize that it is essential to be able to identify the birds by their sounds and to have the skill to make audio recordings of their voices (Parker 1991). Although several papers have been written on making audio recordings of bird sounds for research (Gulledge 1976, Wickstrom 1982, Ranft 1991, Vielliard 1993), recent advances in recording technology, together with the specific requirements of the tropical researcher, warrant revisiting and updating the information presented in these publications. This paper presents the fundamental technical information required to master the operation of a field recording system and prepares the recordist for situations that may be encountered in the tropics.

THE IMPORTANCE OF RECORDING

About 3,100 bird species (Ridgely and Tudor 1989), roughly a third of the world's bird species, occur on the continent of South America. Although much of the region's baseline natural history remains undocumented, the rate of habitat destruction is outpacing the ability of scientists to document and study these species and populations. The next decade offers a critical window of opportunity in which to document the voices of wildlife in the Neotropics before many disappear.

Every researcher collecting sound recordings in this region can make a unique contribution to bird research and conservation (Kroodsma et al. 1996a). Relative to temperate latitude birds, the biology of tropical species is little known. Recordings of their voices provide important baseline data for research in the fields of avian systematics, behavior, and bioacoustics, and are essential to conservation initiatives as training and playback tools for surveys and censuses.

The researcher who records in the tropics faces not only unprecedented opportunities, but also unique challenges. Many bird species are elusive, hidden in impenetrable vegetation, or high in the canopy. Recording equipment must be transported to remote locations with limited repair facilities and often must function under conditions of extreme humidity. With a combination of good field technique, common sense, and appropriate recording equipment, a recordist can ensure that equipment remains operational and that the objective of recording tropical bird voices is consistently achieved.

TECHNIQUE

Good recording technique combines advance preparation with field savvy, the ability to recognize and create recording opportunities, and the knowledge of how to operate recording equipment properly. Good technique maximizes the recorded level of the target bird's sound compared to the level of background sounds and the recording system's self-noise. It also involves an understanding of animal behavior and using it to one's best advantage. Proper technique will yield superior acoustic data for analysis, experimentation, and publication.

PREPARING TO RECORD

Many important recordings have been made as a result of serendipitous encounters in the field (e.g. recordings of the flight calls of parrots). To have the maximum chance of success in unpredictable situations, one must have the recording system in a constant state of readiness. When an opportunity arises, the action of turning on the recorder and aiming the microphone should be reflexive.

Operational readiness begins with the testing of a fully assembled recording system prior to entering the field. Assemble the components of the system, connect them, and make certain the system is capable of recording. If a system is in daily use, check it routinely at the end of each day's work. Prepare the system for the next day's operation the night before, remembering to load new tape and batteries if required.

SETTING A RECORDING LEVEL:

To maximize the signal-to-noise ratio, one must set the record level on the tape recorder correctly. The objective is to record as strong a signal (bird sound or other animal sound) as possible on tape without distortion. For analog recorders the signal-to-noise ratio of the recorded sound is maximized with respect to inherent noise produced by the tape and components of the recorder itself. For digital recorders, recording at an optimal level on tape ensures that signals are recorded at or near the maximum bit rate (16-bit in modern 16-bit digital recorders). This practice helps reduce quantizing errors. To properly convert an analog signal to digital, two dimensions must be stored. Sampling implicitly creates a value representing time information while quantization creates a value for amplitude information. With quantization, as with the measurement of any analog event, accuracy is limited by the system's resolution. Because of a 16-bit word length, the digital system's resolution also is limited, thereby introducing a measuring or quantizing error. Carefully recording at or near the maximum allowable level permits the recordist to use the system's resolution capabilities more fully, thereby minimizing quantizing errors.

Skilled recordists familiar with a particular system will set their recorder’s gain control at an intermediate setting before venturing into the field. If the record level is turned completely down or left at the maximum setting, it will certainly require adjustment. With experience, one will have an idea of the appropriate operating range for the record gain setting, depending on the type or class of sound and the distance. Set the record level control at the low end of this range before recording. If the recorder must be turned on quickly to capture a suddenly heard sound, the chance of recording the signal without distortion will be greatly increased.

AUDIO RECORDER METERS:

The ideal recording level can be difficult to determine. To understand proper record level setting, one must understand the characteristics of a recorder's meter. Three types of meters are typically found on commercially available audio recorders: VU (Volume Unit), PPM (Peak Program Meter), and bar graph, or LED (Light Emitting Diode) meters.

The integration time of a meter is of paramount interest to those who record wildlife. In simplest terms, a meter's integration time is the time it takes the needle, or LEDs, to go from a position of rest to "0," the point beyond which distortion will occur. The response time or speed of a meter determines whether it can provide accurate readings when a bird sound is recorded. Of the three meter types, VU meters offer the slowest ballistics (response time), with an integration time of 300 msec. Peak Program Meters are considerably faster, with an integration time of 12 msec. Bar graph meters offer the fastest integration time, typically 10 msec. or less.

The slow response time of the VU meter makes it less desirable than the PPM and bar graph meters for recording wildlife sounds. This is due to the fact that many of the sounds produced by birds such as warblers, sparrows, and tanagers have such quick onsets or rapid transients that the VU meter's pointer shows little or no response to the sound. An inexperienced recordist who sees no meter movement or only a slight deflection of the meter pointer often reacts by increasing the record gain until the meter indicates a satisfactory level. But this action is a mistake; if the meter's ballistics were capable of indicating the true signal amplitude, the VU meter pointer would likely register well into the range of distortion.

Despite the disadvantages of VU meters, several popular field cassette recorders are equipped with them (Sony TCM-5000EV, Sony TC-D5 Pro II, Marantz PMD221, and PMD222). If a recorder has off-tape monitoring capability (e.g., Marantz PMD221, PMD222, and Sony TCM-5000EV), one can circumvent the VU meter’s foible by using headphones to listen carefully for distortion while making the recording. Marantz and Sony, recognizing the limitation of the VU meter alone offer a "Peak" light to supplement the recorder's VU meter in the models PMD222 and TC-D5 Pro II respectively . This "Peak" light has the integration time of a Peak Program Meter, 12 versus 300 msec., and is therefore capable of accurately indicating signals with a quick onset or transients (e.g., wood-warbler call notes or songs).

HOW LONG TO RECORD

Turning on a tape recorder at the appropriate time is important when making any recording. Sound archives are filled with "decapitated" recordings--recordings that lack the introductory portion of a song or call. For example, of the nine examples of Nightingale Wren (*Microcerculus marginatus*) from north of the Amazon River archived in the Cornell Laboratory of Ornithology's Library of Natural Sounds, four do not contain a complete song. The problem of decapitation in *M. marginatus* recordings is restricted to the form north of the Amazon River, where song consists of a very brief series of musical rising and falling notes followed by an extended series of single whistled notes descending in scale, each song separated by long periods of silence. Decapitated recordings are the result of waiting until the bird vocalizes before turning on the recording system. The most common rationale for recording in this manner is "to save tape," but tape is the least expensive component of any recording system or recording expedition. The solution to this problem is straightforward: anticipate when a bird will vocalize and start the recorder in advance.

Allowing the tape to run 5-10 seconds after the bird stops vocalizing is also important. It will be invaluable if the recording is used in an audio publication; the brief amount of ambient sound lets the producer insert transitional fades into and out of the recording. Again, tape is the least expensive component in a recording system -- don't be afraid to use it.

Assuming that one has anticipated the bird's song and captured the beginning, for how long should one record? The answer depends on one's purpose for recording, of course. The longer a recording is, the broader its potential range of uses and the greater the number of potential users.

If one wants to document the song repertoire of a Brazilian Sedge Wren (*Cistothorus platensis*), for example, one will need several hours and thousands of songs (Kroodsma, pers. com.). For biological inventory purposes or some types of taxonomic investigations relatively brief recordings will suffice. For example, while conducting biological surveys, Parker (1991) recommended recording at least one minute of "natural" song (barely long enough to record a complete song of a Nightingale Wren). For many suboscines, songs may be very stereotyped, but if one is interested in their singing behavior, a recording of 10-20 minutes in length is not excessive for a bird that sings for extended periods. Similarly, a recording with intact intersong intervals is infinitely more valuable for research than 20 brief song samples from the same song bout of an individual. In contrast, some species may vocalize only sporadically or only for a brief period of the day or season. Most species of woodcreepers sing naturally only in the hours prior to or at dawn. It may be necessary to record for significant stretches of time during that period to obtain just a few vocalizations.

INTEGRATING TECHNICAL KNOWLEDGE AND FIELD SKILLS

Although the quality of recording equipment is important, one's recording technique is even more important. In competent hands, a modest cassette system can yield excellent results. Conversely, high quality gear will yield inferior results if improperly used.

The distance from the microphone to the bird is crucial. One of the most important recording techniques to remember is that one can substantially increase the sound level of a recording by halving the distance between the microphone and the bird. By cutting the distance to the singing bird in half, one can potentially achieve as much as a 6dB increase in the signal going to tape.

When recording a bird, attempt to get as close as possible without causing the bird to flee. Ted Parker maintained that if one heard an unusual sound, one should pursue it, because rarely does the sound come to the recordist. Although not without its risks (remember to carry a compass and note reference points to avoid getting lost), moving toward the sound will increase the probability of obtaining a recording (and visually identifying the bird). Closer proximity to the vocalizing bird also maximizes the signal-to-noise ratio and reduces unwanted interference from other vocalizing animals. Plan an approach accordingly, so that when aiming the microphone at a bird, an unobstructed line of sight can be achieved. Foliage can affect the transmission of sounds, particularly high frequencies, which have shorter wavelengths and are therefore more subject to scattering.

Try to be aware of the noise that you, the recordist, make. Avoid nylon clothing or any other type of apparel that makes a great deal of noise with slight movement. Minimize the movement of feet when standing on a potentially noisy surface, such as leaf litter or gravel. If necessary to turn while recording to keep the microphone focused on a moving bird, pivot the upper body to avoid shifting one's feet.

Because of naturally high levels of ambient sound, many habitats pose inherent challenges to acquiring good quality recordings. The sounds of swift-running mountain streams, for example, are inescapable in many Andean locations. To attenuate background sound relative to the vocalizing bird, take advantage of topography. Look for features that can act as barriers between the microphone and unwanted ambient noise. Retreating just a few meters from the edge of a ravine with a swift and loud stream below will attenuate higher frequency elements of "white" noise generated by the rushing water; the edge now effectively cuts off the direct reception of those frequencies from the microphone. Moving to a position behind a buttressed tree has a similar effect. In windy, open situations, take cover behind a rock or earthen berm, or construct a wind break to shield against wind that would otherwise vibrate a microphone diaphragm uncontrollably. Conditions will vary and so will the resources available, but in nearly every instance, one can find a way to improve the signal-to-noise ratio through careful positioning.

Another aspect of good recording technique is timing. Be at the research site before first light (Parker 1991). For many species, the pre-dawn and dawn hours represent the period of greatest (and sometimes only) activity. Forest-falcons (*Micrastur spp.*) vocalize in the pre-dawn hours and are easily overlooked during the rest of the day. Some Tyrranid flycatchers give vocalizations at dawn that they do not make during any other period of the day.

Learning the habits of individual birds also helps. If one is aware of a bird’s habitual behaviors, such as the repetitive use of a particular song perch, attempt to position oneself near the perch and be prepared to record before the bird arrives. One can also use a remote microphone with a long cable to record birds that predictably return to a certain location. For example, lekking manakins use the same display sites for extended periods of time. By placing a microphone near a male's display arena and running a long microphone cable back to an unobtrusive vantage point, one can observe the birds’ behavior and make recordings of a high signal-to-noise ratio.

USING PLAYBACK

Whether working with a known species or an unidentified one, "playback" (broadcasting a recording of a song or call) is an essential and invaluable tool for detecting and identifying birds in the tropics. In many cases playback is the only practical method for observing a species. An elusive bird hidden in thick foliage will often move into the open to investigate playbacks.

The successful use of playback involves not only operating a recording system, but also understanding bird behavior. For example, when feasible, determine that you are within the territory of the target individual. Also, try to select a location that contains suitable cover through which a "skulking" bird can approach, but also a break in the vegetation where the bird can be lured into view. Next, play one or two songs and wait for a response. Impatience and sudden movement by the recordist can lead to failure. The response time varies among species. Some species, such as wrens, can be attracted with playback of only one or two songs, whereas other species, such as tapaculos, may require additional playback and patience.

Be aware that birds may use different vocalizations or alter the temporal pattern of their song in response to playback. Therefore, we strongly recommend that recordists clearly announce on tape when vocalizations are in response to playback.

Playback can be used in extraordinary circumstances, with seemingly extraordinary results. Ted Parker used playback to call in parrots in flight. As soon as he heard parrots in the distance, he would immediately turn on his recorder and tape their flight calls as they passed nearby. Then, directing his recorder toward the departing parrots, he would play back the tape. Often the parrots would respond by changing their flight direction and moving toward the sound of the playback. A positive identification and an additional recording opportunity were then possible.

Playback is often used as a research tool because it is so effective at eliciting a vocal response from a bird or causing it to reveal itself (Johnson et al. 1981). Birds will respond to signals of varying fidelity, including distorted signals. The equipment used for playback can directly influence the results of one's research, however (Weary and Krebs 1992, Dhondt and Lambrechts 1992). If an investigation involves a quantitative and qualitative study of a species' response to playback, then it is essential to know the frequency response of each component in the playback system, including the system used to record the original source recording.

DOCUMENTATION

To have scientific value, a recording must be accompanied by documentation: species, how identified (sight and/or sound), sex, behavior, habitat, time of day, exact locality (including latitude, longitude, and elevation, if known), and model numbers of recording equipment. These data can be announced directly on tape, at the end of a recording. Announcing this information during a recording makes the recording less useful. If some of the information remains constant for several recordings, one need not announce it following every recording, only when some parameter changes (such as habitat description or the type of equipment used). Taped notes can be brief, just enough to jog the memory when more detailed text records are constructed. Kettle and Vielliard (1991) and Kroodsma et al. (1996 b) provide recordists with a detailed text data convention for audio recordings that is accepted by most major sound archives.

Another important aspect of documentation is assigning numbers to the original field tapes. When tapes are numbered, recordings are more easily located within a collection. One commonly used method is a sequential numbering system, akin to the sequential specimen numbering used by collectors of museum specimens. Another scheme involves numbering reels first by year, then by reel within a year. Some far-ranging researchers find a country prefix to be a useful part of a numbering scheme. For more detailed information on the organization of field recordings see Kroodsma et al. (1996 b) and Kroodsma et al. (1996 b).

EQUIPMENT

A range of analog and digital recorders, directional microphones, shockmounts and windscreens, and related equipment are available to researchers. Selecting the most suitable recording components depends on the frequency range produced by the subject, field conditions, and money available for purchasing equipment.

For work in the tropics, a good portable field recording system should have the following features:

(**1**) resistance to humidity,
(**2**) off-tape monitoring,
(**3**) playback capability,
(**4**) the option to use conventional dry-cell batteries as a power source,
(**5**) a PPM or LED record-level meter, and
(**6**) a three-pin-XLR style microphone input.

Every system, regardless of its capabilities, should be calibrated to known standards before taken into the field.

ANALOG RECORDERS

Cassette and reel-to-reel recorders are the two most commonly used types of analog field recorders, with cassette recorders by far the most common. Analog recording systems offer proven reliability to researchers even under the harsh conditions of the tropics. Analog tape transport mechanisms are virtually immune to humidity-related problems.

To record faithfully the vocalizations that birds produce, recordists must be certain that their analog recorders are properly calibrated to a recognized standard (NAB, AES, CCIR, DIN & IEC). These internationally recognized standards were adopted by the audio recording industry to allow accurate interchangability of tapes from machine to machine, i.e., cassette to cassette, open reel to open reel, and R-DAT to R-DAT. Track placement, recording equalization, and reference flux levels are just a few of the many standards that apply to audio recording. Also important is that the recorder be calibrated for the exact tape stock (type of tape). Even newly purchased audio-recorders may not perform to specification because of the rigors of shipment. Head misalignment, speed errors, and improper bias settings are just a few of the problems that plague even new machines.

Cassette recorders.--Cassette recorders have limited-frequency bandwidth and a lower signal-to-noise ratio, but are much lighter and use longer-running tapes than reel-to-reel machines. Cassette recorders are a low-cost alternative to other types of recorders: the highest price for a portable cassette recorder is about $1125. When calibrated and used properly, they can produce excellent results.

Several cassette recorders offer the basic features required of a field recorder for tropical field work: off-tape monitoring, good metering capability, professional microphone connectors, playback speaker, durable construction, and light weight. Although no one recorder has all features desired by field recordists, several offer combinations of most of the these features: such as Sony's TCM-5000EV and TC-D5 Pro II, and Marantz's PMD221, PMD222, and PMD430 models. All but the Sony TC-D5 Pro II has off-tape monitoring. All have VU meters. The Sony TC-D5 Pro II and Marantz PMD222 also provide a Peak light in addition to the VU meter.

Noise reduction features such as Dolby or DBX *should be not be used*. These features may work well for voice and music recording but are detrimental to bird song recording. Similarly, avoid using any limiter or AGC (automatic gain control) feature. Limiters and noise reduction processors all have a response or reaction time that in most cases is slower than most birds produce sounds. This lag in response time creates undesirable artifacts that are recorded along with the target sound. Once recorded, it is impossible to remove them.

Connectors are the components in a recording system most likely to fail, because they are subject to tugging, flexing, and other forms of strain. The Sony TC-D5 Pro II and Marantz PMD222 offer the best type of microphone input connectors, namely professional 3-pin Cannon (also known as XLR) connectors. The Marantz PMD430 uses a less desirable, but durable, º" phone connector, whereas the Sony TCM-5000EV and Marantz PMD221 use a 3.5 mm mini-plug connector that is unreliable under difficult field conditions.

Of the machines discussed here, the Sony TCM-5000EV has the loudest playback capability. Many field biologists find the playback volume of other recorders insufficient, where others find the playback adequate. For those who require loud playback, but prefer the performance of recorders other than the TCM-5000EV, a small battery-powered playback speaker usually solves the problem.

Durability of a recorder is determined by the quality of its construction. With one exception, the recorders mentioned are well designed and constructed. With proper care and regular maintenance, a life span of 3-5 years under hard use is reasonable. One recorder stands out with respect to durability among this group of cassette recorders, the Sony TC-D5 Pro II. It is very well made and able to withstand field work, maintaining speed and head alignment even under rough conditions. Weight and dimensions are also important considerations for anyone working in remote locations. All of these cassette recorders are of the same approximate weight and dimensions.

Analog reel-to-reel tape recorders.--Reel-to-reel analog recorders, also known as open-reel recorders, have wider tape width and faster linear tape speeds than do cassette recorders; they offer the widest frequency bandwidth, greatest fidelity, and best signal-to-noise ratios of any analog recorder. These machines are capable of accurately recording sonically challenging bird sounds, such as tanager songs and calls, sounds that most cassette recorders cannot record accurately.

At present, the only portable analog reel-to-reel recorder suitable for recording bird sounds is the stereo Nagra IV-S. The IV-S features off-tape monitoring, a Peak Program Meter, professional Cannon-style microphone inputs, and recording speeds of 15 ips (inches per second), 7.5 ips, and 3.75 ips. The Nagra IV-S is extremely durable, has excellent speed stability, and is unaffected by humidity. Power usage by a IV-S is conservative, up to 25 hr on 12 D-cell batteries, a distinct advantage in remote locations.

Other aspects of reel-to-reel tape recorders are potential limitations for field work. The IV-S weighs approximately 22 lbs (8.2 kg) with 12 D-cells installed. At 7.5 ips, a 5-inch reel of 1.5 mil tape provides 16 minutes of recording time, and only 8 minutes at 15 ips. The weight of both the machine and tape present significant concerns with respect to portability in the field and shipment to a field location.

With the price of a new Nagra IV-S exceeding $10,000, a reel-to-reel recorder might not be an option for many researchers. However, used recorders offer an alternative. It is possible to acquire a used stereo Nagra in good condition for $2,500 - $3,000; monaural Nagras cost somewhat less and are excellent alternatives.

DIGITAL RECORDERS

Digital audio recording is an extremely promising technology, one that offers great potential as a field recording format for research. Three digital format portable recorders are commercially available in North America: R-DAT (Rotary Head Digital Audio Tape), Nagra open-reel digital, and MiniDisc (MD). Simply put, digital recorders convert audio signals to binary code stored either on magnetic tape or optical disc. R-DAT and Nagra digital recorders record signals on magnetic tape. The MiniDisc format uses an optical disc as its storage media.

The convenience of digital recorders is seductive. Digital machines are lightweight, typically weighing 2 to 4 lbs (~0.75-1.5 kg), compared to more than 20 lbs (7.5 kg) for portable reel-to-reel analog recorders. They are small, with dimensions comparable to most cassette recorders. The Sony TCD8 is the smallest digital recorder, weighing only 1lb 1 oz (510 g) , including battery, and measuring 5 1/4" x 1 1/2" x 3 1/2" (132 mm x 36.7 mm x 88.2 mm) . Furthermore, a single R-DAT cassette has a maximum running time of two hours, far more than the few minutes for some reel-to-reel recorders. R-DAT recorders also feature a convenient track indexing scheme, making it possible to program a maximum of 99 randomly accessible points.

R-DAT recorders.--Of the digital formats mentioned, R-DAT is the one most often used for field recording. To record a signal, the R-DAT recorder uses a helical scanning head-drum assembly, a structure mechanically similar to the head on a video cassette recorder. This head assembly spins rapidly (2,000 rpm) while recording on slow-moving tape (8.15 mm/sec). In the "play" mode, this same head functions as a playback head. Few R-DAT recorders actually have separate record and play heads (discussed in a later paragraph).

R-DAT recorders deliver high-quality audio, comparable to that of a reel-to-reel recorder. The standard professional sampling rate of 48 kHz yields a frequency bandwidth limited to approximately 24 kHz. Although some R-DAT machines are capable of recording at lower sampling rates (44.1 kHz and 32 kHz), recordings should be made at the highest possible sampling rate.

Many recordists have successfully used R-DAT recorders in tropical climates, although others have had problems. The R-DAT recorder’s main drawbacks for tropical field use are susceptibility to humidity (the recorder records unreadable data or shuts down), heavy power consumption, and lack of off-tape monitoring capability for most machines. Under humid conditions, condensation can form on the spinning head drum of R-DAT recorders. This moisture creates what audio engineers refer to as "stiction:" as the tape moves over the rapidly spinning head, moisture-induced friction causes the head to slow down or stall completely. The net result is that no readable data are recorded on the tape. If operation of the recorder continues under such conditions, damage to the recorder can result.

R-DAT recorders consume considerably more power than conventional analog recorders. Running out of tape may be the bane of the open-reel recordist, but running out of battery life is the bane of the R-DAT recordist. Most R-DAT recorders are powered by ni-cad (nickel-cadmium) battery packs. Although the running time for a fully charged pack is typically 1.5 to 2 hrs, recharging ni-cad batteries can be difficult under remote field conditions. Furthermore, R-DAT recorders take several seconds to go from a "power off" mode to "record-ready" state. So, a recordist who wants to be ready to record unpredictable vocalizations must keep the recorder in "pause" mode. But, in contrast to reel-to-reel analog recorders, which draw little power when paused, R-DAT recorders consume almost full power, so batteries are depleted quickly.

A final drawback of R-DAT recorders is that most do not have off-tape monitoring. The recordist is therefore unable to listen to what is actually stored on the tape. R-DAT manufacturers Fostex, HHB, and Sonosax offer recorders with off-tape monitoring, a feature reflected in their higher purchase prices. Additionally, Sonosax has engineered "climate-control" on their recorders, resulting in machines virtually unaffected by humidity. The advent of off-tape monitoring and climate-control on portable R-DAT recorders are positive developments toward addressing the requirements of field work. Machines offering one or both of these features should receive careful consideration, in spite of additional cost, by anyone recording in the tropics.

One of the most difficult decisions a recordist makes in assembling a recording system today is whether to invest in a digital recorder. Anecdotal accounts both support and refute the reliability of R-DAT recorders under extremely humid conditions. The lack of off-tape monitoring capability of most R-DAT recorders, together with problems under humid conditions and heavy power consumption, contribute additional risks to the rigors of collecting tropical bird sound recordings. The cost of R-DAT machines is not inconsequential and reflects important distinguishing features. Prices range from $750 for the Sony TCD8 with 3.5 mm microphone input, to $1,500 for the basic professional Tascam DA-P1, to $4,000-6,000 for HHB and Fostex recorders that provide off-tape monitoring. Recordists should weigh the convenience, light weight, and cost of an R-DAT recorder against the possibility of equipment failure in a remote location or at the moment when a rare recording opportunity presents itself. Some recordists address this issue by carrying a back-up recorder, such as a reliable analog cassette recorder.

The Nagra D recorder.--A second digital format was introduced by Kudelski S.A., manufacturer of the renowned Nagra portable reel-to-reel analog tape-recorders. The Nagra D is a digital, open reel, two or four channel, 20 bit, rotary head recorder with a sampling rate of 48 kHz and uses º" DASH, PD type tape. It has off-tape monitoring capability, a feature absent from many R-DAT digital cassette recorders. Recording time per 5" reel is 2.0 hrs when recording on two channels and 1 hr when recording on four channels. Tape speeds are 49.6 mm/sec and 99.2 mm/sec respectively. Weight of the recorder is 17.8 lbs (6.64 kg) with the battery.

Nagra tape-recorders are renowned for their reliability under adverse field conditions. The Nagra D's rotary-head configuration and open-reel tape transport are designed with field use in mind. The tape transport is covered by a hermetically sealed, clear, plastic cover, thus minimizing potential damage from dust and moisture. "Confidence monitoring," the ability to listen to the signal recorded on tape during recording, is a standard feature that is invaluable for field recording.

Two aspects of this recorder limit its suitability for field recording, however. The Nagra D has been designed for on-location use for movie shoots and music recording. This is reflected in the placement of meters and many controls (i.e., record level controls) on the recorder's top surface rather than on the front panel as with analog Nagras. Carried "over the shoulder," as required in most wildlife field recording situations, it is virtually impossible to view the meters while recording. With a price of nearly $20,000, cost is also a significant factor. For those who can afford its cost and are not handicapped by the position of its meters, the Nagra D will undoubtedly offer years of reliable and outstanding performance.

Digital recorders with data compression.--Recently introduced, the Mini-Disc recorder outwardly appears that it might have application for field use. Mini-Disc is a compact digital recorder that stores up to 74 minutes of audio on optical disc. Like other digital formats, the MiniDisc offers convenient track numbering along with the rapid accessing of a compact disc.

A significant drawback to this recording system is that it uses data compression algorithms to maximize data storage capacity. These algorithms are based on psychoacoustic research -- the study of how humans hear and perceive sound. As a result, when bird sounds are recorded, harmonic content at the upper margin of human hearing can be lost. Furthermore, the "program material" (i.e., the bird song plus the background noise) is "reviewed" as a whole. This means that if, in processing the algorithm, the machine determines that the background sounds are masking elements of the signal of principal interest, the "masked" components of the principle signal are not necessarily recorded. Data compression algorithms may also add spurious data during the recording process (**Fig. 1**). For the present, we cannot recommend Mini-Disc recorders or other recorders that use data compression, although they do have utility as a sound storage system with quick access capability for listening purposes.

MICROPHONES

Two types of directional microphone systems are typically used to record in the tropics: the parabolic reflector/microphone combination and the shotgun microphone. Both have excellent directional characteristics and minimize interference from other sound sources. Each has advantages and disadvantages, depending on recording circumstances.

The parabolic reflector.--The terms "parabolic reflector" and "parabola" are used interchangeably to mean the combination of a reflector (a mechanical amplifier) and a microphone (which can be either omni-directional or cardioid in pick-up pattern). The reflector's amplification capability is what makes it useful for field work. The parabola's surface area determines the degree of amplification, whereas its diameter determines its low-frequency operating range (Little 1964, Wickstrom 1982). All properly designed parabolas amplify the source signal hundreds of times; furthermore, amplification is achieved without addition of electronic noise that commonly occurs with in-line preamplifiers. A field recordist using a parabola can make recordings with a high signal-to-noise ratio at a greater operating distance than is possible with other microphone systems. Canopy species, such as tanagers or Terenura antwrens, are probably best recorded with a parabola.

It is important to note that a parabolic reflector must be set up properly to achieve the best results. The parabolic reflector can be thought of as a system made up of a microphone and a reflector. The microphone must be accurately placed in the focal point (the area where all the collected sound energy is concentrated or focused) of the reflector. Dan Gibson and Telinga are two parabolic reflector manufacturers who solve this problem by providing a fixed rigid-mounting system for the microphone. When the system is fully assembled the microphone is guaranteed to be in the proper placement. However, if one chooses to assemble a system using discrete parts, e.g., a RochÈ reflector and a Sennheiser microphone, then it is necessary to determine the correct position. There are a couple of ways to accomplish this.

One such method requires using a small portable FM radio as a fixed sound source. Set up the recording system, complete with parabola, microphone and recorder. Next place the radio on a table or chair. Turn it on and adjust the volume to a comfortable listening level. Now tune the radio between stations so that only noise is heard. Position the recording equipment about 20 feet away from the radio. Turn all of the equipment on and place the recorder in the record pause mode. Manually aim the reflector so that it is pointing in the direction of the radio speaker. Adjust the record level on the recorder so that the meter is indicating mid-scale. Be sure to keep the reflector perfectly still. Mounting the reflector to a camera style tripod works very well. Now carefully and slowly slide the microphone back and forth in its mount while watching the meter on the recorder. One should be able to see the level rise and fall as one moves the microphone around the focal point. The point at which the highest sound level is attained is the optimal position to place the microphone. One can also monitor the sound level with headphones, although the differences may not be as easy to determine.

The second method utilizes the sun, but the microphone must be removed before attempting this procedure. The concentrated energy from the sun will create dangerously high temperatures that can easily destroy a microphone. While aiming the reflector at the sun, move a small white card around the area of the microphone mount. As the card is moved in and out of the reflector, the reflected light pattern moves in and out of focus. Find the spot that gives the sharpest focus and note the relative position from the center of the reflector. This dimension is the focal point. The next step is to determine where the diaphragm in the microphone capsule is located. Usually the diaphragm (which looks like a gold or silver disc) can be seen by holding the microphone up to a light and looking through the wire screen mesh of the capsule. Note its position relative to the actual face of the microphone. To complete the installation make sure that the face of the diaphragm is positioned precisely at the focal point determined in the first step.

The optical and acoustic focal points should be the same for a parabola. However, this is not always the case. For this reason the preferred method for establishing the focal point is the acoustic technique. The optical method offers an alternative when resources required for the acoustic method are not available.

Aiming a parabola in the field also requires precision. If the parabola is not aimed accurately at the sound source, the recording will lack the high-frequency content (detail) of the sounds. To aim a parabola correctly, one must listen through headphones while the recording is made. When the bird is not visible use the following technique to aim the parabola. First, smoothly "pan" the parabola across the horizon, beginning at the extreme right or left of where the bird is believed to be and listen through headphones for the point at which the sound's clarity and loudness, particularly high frequency elements, are the greatest. Once the correct position on the horizontal axis is determined, pan along the vertical axis until the angle of elevation at which the sound is the loudest is determined. At this point, the parabola will be properly aimed.

Parabolas are available in both clear and opaque materials. Clear parabolas are typically constructed of plastic and enable one to see a vocalizing bird through the parabola and to aim the parabola accurately. Opaque parabolas may be made of plastic, fiberglass, or carbon fiber. Many recordists outfit opaque parabolas with a sight, which allows them to use visual cues for accurate aiming.

The parabola is not without its drawbacks. The reflector's unwieldy shape makes it inconvenient in some situations, such as seeking out a bird in dense undergrowth. Furthermore, parabolas are better at capturing high-frequency (short wavelength) sounds than low-frequency (long-wavelength) sounds, so recordings made with a parabola generally have a high-frequency emphasis. A bird song that contains both high-frequency and mid-frequency sounds will be altered when recorded with a parabola, with a relative increase in the amplitude of high frequencies with respect to the source sound. How low of a frequency can be recorded is limited by the diameter of the parabola. Very low frequency (long-wavelength) sounds may be picked up by the microphone but will not be amplified by the reflector at all, because these wavelengths are larger than the reflector's diameter.

The parabola's large size can also make shipping it to remote locations a problem. Shipping cases that will stand up to abuse are available and worth the investment. Such cases not only protect a parabola but often provide ample room to pack a recorder, cables, blank tapes, and other gear. One parabola that is especially easy to pack is the 22-inch (56 cm) Telinga Pro parabolic reflector/microphone system. The dish is made of a clear, thin plastic that can be rolled up into a cylinder 22 inches (56 cm) long and 8 inches (20 cm) in diameter. The microphone and handle apparatus can be removed and conveniently stored inside the rolled dish for transport. The entire system weighs approximately 1.5 lbs (0.56 kg) Although the Telinga Pro's diameter is somewhat smaller than ideal, this system's transportability makes it especially useful for work in remote locations, particularly where there is a need to record canopy species.

Shotgun microphones.--Shotgun microphones are well suited for all-around use in tropical situations. This type of microphone does a good job of selecting a target sound from surrounding noise by rejecting off-axis sound. Shotgun microphones achieve their directionality through the hollow, ported, interference tube that surrounds the microphone; the longer the interference tube, the more directional the microphone. The ports in a shotgun microphone create a time delay for sounds arriving off-axis (sounds not from the direction aimed). This time delay causes certain frequencies to be canceled out, thus giving the shotgun its directionality.

The shotgun microphone has a broader "angle of acceptance" than the parabola and is, therefore, easier to aim. A shotgun microphone is ideal for recording loud, moving signals, such as the flight calls of parrots and the song or call of a moving antbird.

Shotgun microphones have some disadvantages, too. Although shotguns are directional, they are not as directional as parabolic reflectors. Also, shotgun microphones lack the amplifying capability of parabolic reflectors. This can be a problem when recording distant birds or low level signals. Thus, a recordist using a shotgun microphone must be much closer to the bird than a recordist with a parabola to get a recording of the same amplitude.

Condenser and dynamic microphones.--The two microphone designs most commonly used for bird sounds are dynamic and condenser microphones. Both shotgun microphones and the omni-directional or cardioid microphones used in parabolas can be either dynamic or condenser in design. Dynamic microphones are durable and require no electrical power, but are typically low in signal output strength. Condenser microphones typically have greater sensitivity and higher signal output than dynamic microphones, but also require electrical power and can be affected by humidity.

Condenser microphones come in two designs: electret condenser and rf (radio frequency) condenser. An example of an electret condenser microphone is the Sennheiser ME66/K6 "short" shotgun microphone. An example of an rf condenser shotgun microphone is the Sennheiser MKH70. Under humid conditions, electret condenser microphones are susceptible to static discharge, which is manifested in the form of audible crackling and popping on the recording (it is easy to mistake the sound of static discharge for a failed cable or connection). RF condenser microphones are more resistant to humidity. No matter what kind of microphone one selects, it should be stored with desiccant and be serviced routinely to minimize humidity related problems. An alternative to desiccant is to use a "hot closet", a closet with a light bulb or heating element in the bottom. If a "hot closet" is used avoid placing equipment close to the light bulb or heating element as temperatures may exceed that which is safe for some types of equipment.

Because the microphone is the first stage of the recording system, one should purchase the best microphone affordable. One superb all-purpose shotgun microphone for tropical recording is the Sennheiser MKH70 rf condenser shotgun microphone. The Sennheiser MKH20 rf condenser omnidirectional microphone is the rf condenser equivalent for use with a parabolic reflector.

SHOCKMOUNTS AND WINDSCREENS

With today's sensitive microphones, shockmounts and windscreens are essential components for field recording. Shockmount systems are mechanical devices in which a microphone is typically suspended by elastic cords or bands, effectively isolating it from hand-held vibration. With the sensitive microphones preferred for field research, handling noise can be substantial, and because it is picked up by the microphone, it is recorded directly on tape. It is not uncommon for recordist-generated noise of this type to be as loud as the bird vocalization recorded.

Windscreens are essential, too. Without a windscreen, light breezes of wind can often obscure the bird vocalization on tape. Windscreens perform their isolating function by creating a turbulence-free zone around the microphone itself, while allowing the sought-after sound to arrive effectively at the microphone's diaphragm.

Use of a windscreen and shockmount are relatively inexpensive ways to minimize noise created by wind and by hand-holding a microphone. These two accessories come in many different styles. Most microphone manufacturers offer a range of custom-fit windscreens and shockmounts for their microphones. A few manufacturers also offer universal shockmounts that will accommodate many different styles of microphones. One example of a universal shockmount is Audio Technica's AT- 8415, which is popular among researchers who use shotgun microphones. With a little ingenuity, it is also possible to fabricate a shockmount at little cost from a variety of basic materials, such as aluminum strap stock, rubber bands, plastic conduit, and neoprene tubing.

PREAMPLIFIERS, TRANSFORMERS AND ATTENUATORS

Nearly all audio equipment that bird sound recordists use today has been designed with another purpose in mind, such as recording concert or studio music, spoken interviews, or on-location motion picture sound-tracks. Most portable audio equipment comes with enough built-in "gain" or amplification to accommodate these types of recording events, because the target signal is usually strong and the microphone is typically placed close to the subject.

Recording birds in the field is another matter. Many bird sounds are not loud, and it is not always possible to place the microphone close to the bird without disturbing it. The recording of bird sound thus requires more "gain" than most portable recorders typically offer. Furthermore, the dynamic range of wildlife sounds pushes audio equipment to its performance limits.

One way that field recordists can address this problem is by using an in-line preamplifier to achieve a stronger signal on tape. An in-line preamplifier installed between the microphone and tape recorder will boost the signal from the microphone prior to arrival at the tape recorder's internal microphone preamplifier. These devices require power, typically supplied by a dry-cell battery. "Pre-amps" are generally small and relatively inexpensive ($100-$600). Unfortunately, most inexpensive preamplifiers add a significant amount of electronic noise to recordings.

Some recorder/microphone combinations can also benefit by using a matching transformer between the microphone and the recorder. To facilitate the transfer of electrical energy from the microphone to the recorder, it is important to have the microphone's impedance (AC resistance) closely match that of the recorder's input. In the case of the Sony TCM-5000EV cassette recorder and the Sennheiser ME80, one does not have the optimal match. They will function as a system, but the usable gain will be less than ideal.

To solve the problem of a mismatched recorder and microphone, many recordists use an impedance matching transformer between the microphone and recorder. The recordist can realize a 10-12 dB increase in recorder sensitivity by adding the proper matching transformer between the microphone and the recorder. Because these devices are free of electronic noise, they have an advantage over preamplifiers in that they give a similar, but cleaner result. They also do not require electrical power, and so they work well in field conditions. Note, however, that matching transformers will not work with all recorder/microphone combinations; check with a competent audio engineer for recommendations.

Just as the above section addresses ways to increase signal strength, some situations may arise where the target signal is so strong that distortion occurs. This is where the microphone attenuator switch comes into play. The attenuator is a resistive device designed to lower the signal strength. It can be found on some of the more expensive Sennheiser RF condenser microphones, as well as on many of the recording machines. One situation that sometimes causes distortion is having a microphone set up remotely to record a vocalizing bird. When the bird is close to the microphone, it is possible that the signal level is so strong that a condenser microphone's internal preamplifier is overloaded (distorting) or the signal coming from the microphone is overloading the microphone input preamplifier of the recorder. When these situations arise, simply lowering the record level will not solve the problem. An overloaded signal occurring at the microphone cannot be corrected or cleaned up at the recorder. Lowering the record level on the machine simply lowers the signal level, distortion included. A good telltale sign of a possible overload condition (aside from listening) is to note the level control setting on the recording device. Let’s say the record level control has a range of 1 to 10. If one is forced to set the control at around 1.5 or 2.0 to obtain proper meter levels, then the signal coming from the microphone is probably too strong. A better operating position for the control would be in the 5 to 7 range. One way to correct this overloaded condition is to switch the attenuator on at the microphone (if it is so equipped). For those using microphones that do not have attenuators or if the microphone attenuator alone proves insufficient, the next option is to use the attenuator switch on the recorder. If neither option is available, simply moving the microphone further away from the bird should correct the problem. Always remember to switch the attenuator off when it is not needed because it will significantly degrade the system's signal-to-noise ratio.

CABLES:

The quality of the cables that connect the components of a recording system are critical. Select high-quality cables that are flexible, shielded (braided shield only), and only as long as required. Balanced cables with three-pin XLR-style connectors are preferred whenever possible. (Look for three-pin connectors also when selecting a recorder and microphone.) Use professional-grade connectors that incorporate good strain-relief mechanisms.

No matter how good the cables are, carry spares. No component in a recording system undergoes more physical stress, and failure is always a possibility. It is far easier to attach a new cable to a recording system than to try to repair a damaged one in the field.

AUDIO TAPE

Analog tape-recorder manufacturers design and calibrate their machines to meet "general" technical tolerances (electronic performance specifications) on a variety of different tape stocks (brands). For example a Marantz PMD222 will function satisfactorily with TDK, Scotch, Sony, BASF, and Fuji tapes. Open reel machines are similar. Although these "general" calibrations are fine for music and speech applications, sounds produced by animals are much more complex and difficult to store on tape; thus the calibration requirements for recording these natural sounds must be much more precise. To insure the best possible recordings, it is important to calibrate a recorder for a single tape stock and then to consistently use it for all of one's recording work. When an analog tape-recorder is calibrated for a particular tape stock, it is literally "fine tuned" to optimally match the recorder’s electronic performance to the magnetic properties of that tape stock.

Digital tape-recorders are exempt from this fine-tuning. For example, any R-DAT digital tape from any manufacturer can be used on any R-DAT recorder without compromising machine performance.

Cassette tape.--Cassette tape is physically small and delicate. Its thickness is 0.67 mil, 0.47 mil, and 0.33 mil for C-60/C-90/C-120 lengths, respectively. The tape width is 3.81

mm (1/8"). Each manufacturer has its own tape stocks (formulations), each of which offers different performance levels. These performance levels are known as "IEC types" of tape. Three "IEC types" (not to be confused with brands) of tapes are made for use in analog cassette recorders, and a given cassette recorder may accommodate one or more of these three types. The three types of tape are IEC Type I (also called ferric oxide/normal bias), IEC Type II (chromium dioxide/high bias), and IEC Type IV (metal/high bias). All cassette tape manufacturers make all three types.

Obtaining optimal performance from a cassette recorder demands that one must use the type or types of tape recommended by the manufacturer. For example, a Sony TCM-5000EV is designed only for Type I (ferric oxide) tape. If Type II tape is used in this machine, the resulting recording may contain machine-generated distortion, such as spurious harmonics, and the recording will not be a faithful representation of the original sound (**Figs. 2A and 2B**). If a cassette recorder accepts more than one tape type (the Marantz PMD222 and Sony TC-D5 Pro II are examples), be sure that the tape selector switch is set for the tape used. Type II is the preferred tape for bird sound recording, provided the recorder is designed to accommodate it. Metal tape also offers good recording performance, but battery life is somewhat reduced when this type is used because of the extra demands placed on the recorder electronics.

For best results, use only C-60 (60-min) or shorter cassettes. Long-playing cassettes, the kind that record for 90 or 120 minutes, are made with a thinner backing material than 60-min tapes. These thin-backing tape stocks are more susceptible to stretching, deformation, and print-through. Print-through occurs when high level recorded signals are transferred from one layer of tape to adjacent layers. It manifests itself as a pre- and post-echo of the principal signal when a tape is played back.

To increase recording time and to minimize costs, one might be tempted to record on both "sides" of a cassette or open reel tape. Whenever possible, however, one should record on only one side. Signals on opposite sides of a tape can sometimes bleed across "guard bands" (unrecorded areas that separate tracks) onto adjacent tracks. This is called "cross-talk." The contaminating signal will appear as low level backwards audio in the background of the recording. Once this problem has occurred, the offending signal cannot be removed.

Reel-to-reel tape.--Reel-to-reel or open-reel tape is available from many manufacturers. As with cassettes, each manufacturer has its own various tape stocks that offer varying degrees of performance. These different formulations are also available in different lengths. The length (running time) of the tape is determined by three factors: the size of the reel, 5" or 7"; the thickness of the tape used, 1.0 or 1.5 mil; and the recording speed, 3.75 ips, 7.5 ips, or 15 ips. As mentioned in the "AUDIO TAPE" section, it is imperative to calibrate the reel-to-reel recorder for the specific tape stock being used. Reel-to-reel tape is time proven as a reliable field recording format. When compared to cassette audio tape, open-reel tape's physical proportions of 1.0 and 1.5 mil thickness and its º" width make it less susceptible to stretching, damage from dust, and tape-edge damage. Reel-to-reel tape is capable of sustaining considerable damage or contamination and yet remaining playable, whereas an R-DAT tape under the same circumstances would become unplayable.

R-DAT tape.--The DAT cassette, slightly more than half the size of the analog cassette, was developed and standardized exclusively for the R-DAT recording format. As with a video cassette, the tape is protected until the cassette is installed in a recorder. At that time a small flap on the cassette opens, and the tape is extracted and wrapped around the head-drum assembly. R-DAT tapes, which use a metal-powder oxide, come in standard lengths of 15, 30, 46, 60, 90 and 120 minutes. The tapes are 3.81 mm wide, the same as the standard 1/8" analog cassette tape, and 0.47 mils thick, the same as analog cassette C-90 tape stock. Because R-DAT tape is transported past the heads at about one third the speed of an analog cassette, tape length required for 120 minutes is 60 meters with R-DAT and 171.45 meters for analog cassette. The combination of the rapid spinning head assembly, the helical data writing pattern, and the slow linear tape speed of the R-DAT allow tremendous amounts of data to be stored on very little tape. This is a mixed blessing, however. Although R-DAT allows long recording time and the ability to search an entire tape quickly, a small crinkle or even a finite amount of dirt or dust can render significant amounts of R-DAT data useless.

PROTECTIVE FIELD CASES

Protective cases for field recorders are a frequently overlooked but useful accessory. A well-designed field case, constructed of Cordura cloth, will protect a recorder from dust, detritus, and rain, and will cushion it if dropped. A case will also cover and protect cables and connections and will put gear in a tidy package that is less likely to snag in dense undergrowth. Padded shoulder straps and waist belts, a common feature of high-quality cases, distribute weight and reduce fatigue associated with carrying a heavy recorder. Although the initial investment of $125-200 for a good case may seem high, the protection it provides will add years to a tape recorder's life.

CALIBRATION AND MAINTENANCE

Recorders should receive routine maintenance and be calibrated prior to the start of each field season, as well as before any major expedition. Audio recorders are complex mechanical and electronic devices. All internal moving parts are subject to wear. Many moving parts also have some kind of lubricant coated on them to help overcome friction. This lubricant is like a magnet for any dirt, dust, and small debris. Routine maintenance (changing belts, drive rollers/idlers, and internal cleaning) can greatly reduce the chances of total machine failure in the field.

Calibration should be performed by a professional audio service center or the manufacturer's authorized service facility. When sending a machine in for calibration you should do the following:

1. Supply a new, unused tape from the stock you will be using. The performance of the recorder can then be optimized for your tape stock.

2. Give detailed instructions as to the level of calibration required (see calibration instruction list below).

3. Request proof of performance, i.e., charts, graphs, documentation etc., that states the recorder's performance after calibration.

4. Provide a time-table so the service center is aware of when you need the recorder back. Be aware that the turn-around time for service centers can typically run 4-6 weeks.

Audio recorder **calibration instruction** list (*applies only to analog recorders*): check take-up and supply reel tensions; check and set absolute speed; check wow and flutter specification; check speed drift; demagnetize and adjust record/playback head azimuth (head height if needed); calibrate playback level and frequency response to reference standards; adjust bias and record equalization for flattest frequency response using the tape stock provided; adjust recorder calibration for unity gain in record/play mode (if unable to obtain unity gain please note record/playback gain offset); check distortion levels (THD, 3rd and 2nd harmonic); check signal-to-noise ratio (both "A" weighted and flat); print-out calibrated performance data.

Once the above is completed, your machine will be calibrated to known reference standards. These procedures will maximize the scientific validity of your recordings.

Clean the recorder routinely, even daily if frequently used. For analog recorders, a good agent for cleaning the tape path (the heads, guides, and capstan) is **isopropyl alcohol**. (Do *not* use agents such as *rubbing alcohol*, which contain lubricants and *will leave a residue*.) Cotton swabs moistened with isopropyl alcohol, the excess squeezed out, are effective for reaching and cleaning recorder heads and guides. If an excessive amount of alcohol comes into contact with the recorder's bearings and motor lubricants, it can cause premature failure.

R-DAT recorders should not be cleaned in the same manner as analog recorders. Use only the manufacturer-recommended cleaning tape or have the recorder cleaned by a professional, certified technician.

FIELD REPAIRS

With a modest amount of preparation and a bit of common sense, the recordist can ensure that a recording system will operate. A schematic of a recorder's circuitry will be invaluable if one can locate a good repair facility. Be aware, however, that an unskilled technician can do more damage than good.

Problems such as broken cables can completely disable a recordist. With an assortment of simple tools, however, one can handle most small repairs in the field. **We recommend carrying the following:**

1. Leatherman™ or equivalent multipurpose tool (includes knife, screwdrivers, scissors, and pliers. A Leatherman-type tool together with a Swiss Army knife will cover a wide range of tool requirements.
2. Wire cutters and strippers.
3. Black electrical tape.
4. Portasol™ (or equivalent) butane-powered soldering iron and 60/40 rosin core solder. Note that butane is not typically permitted on commercial aircraft. It will, therefore, be necessary to purchase butane in the country of destination.
5. Simple, battery-powered voltage/continuity multi-meter.
6. "Helping hand" holding apparatus (available through most electronic repair shops) or vice.
7. Extra batteries. In remote locations it is not uncommon to discover that newly purchased, name-brand batteries have already been partially or completely discharged.
If soldering is required to repair a broken cable and a suitable electronic repair facility cannot be located, jewelry shops often have soldering equipment.

SOUND ARCHIVES

Once recordings are collected, the recordist must consider how to preserve them for long-term use. Depositing recordings in an established sound archive ensures not only that they will be preserved for others to use in research and conservation, but also that they are protected against damage or destruction. Sound archives provide safe, long-term storage of recordings and also provide centralized access to recordings, which facilitates their use by others (Kroodsma et al. 1996 b). Some sound archives extend their service role to include the repair and calibration of field recording equipment.

The five sound archives with the largest collections of Neotropical recordings are the **Arquivo Sonoro Neotropical**, **Universidade Estadual de Campinas, Brazil**; **Laboratorio de Sonidos Naturales, Museo Argentino de Ciencias Naturales 'Bernardino Rivadavia', Argentina**; **Library of Natural Sounds at the Cornell Laboratory of Ornithology**; **Bioacoustics Archives and Library, Florida State Museum, University of Florida**; and the **Wildlife Section of the British National Sound Archive** (formerly the British Library of Wildlife Sounds [BLOWS]).

Most archives provide copies rather than original tapes to those who wish to use archived recordings. Users may range from biologists studying animal communication and taxonomy, to resource managers who use recorded sounds to prepare for and conduct censuses, to commercial users such as television or film producers.

Responsible sound archives take the following steps to preserve original recordings:
1. High-quality copies of the original tapes are generated using rigidly calibrated professional studio recorders. One of these copies is the "working" copy, which is used as the source recording when additional copies are made, thus avoiding wear and tear on the original recording.
2. A good archive will also produce a first-generation safety copy. This copy should be stored off-site.
3. To prevent tape deterioration, original tapes, working copies, and safety copies should be stored under strict climate-controlled conditions.
4. The archive should restrict access to working copies, originals, and safety copies, allowing only authorized personnel to work with them.
5. The archive provides copies to users and does not loan the original on a routine basis.
6. The archive requires users to sign an agreement that outlines the manner in which copies may be used.

SUMMARY STEPS FOR RECORDING

To maximize your recording opportunities here is a short list of the steps one should follow:
1. Assemble the entire recording system and check the equipment in advance.
2. Be at the investigation site before first light.
3. Position the microphone so that a clear path exists between it and the vocalizing bird.
4. Carefully aim the microphone.
5. Get closer to the bird; remember that halving the distance to the vocalizing bird (repeatedly if necessary) doubles the signal level reaching the microphone.
6. Position the microphone so that interference from background sounds is minimized.

7. Set the record level for the loudest element in the target bird's vocalization, and then leave it there.
8. Record for at least one minute, or longer if the bird allows.
9. Minimize handling and machine noise.
10. Announce basic data at the end of each recording.
11. Review and organize your field tapes at the end of each day.

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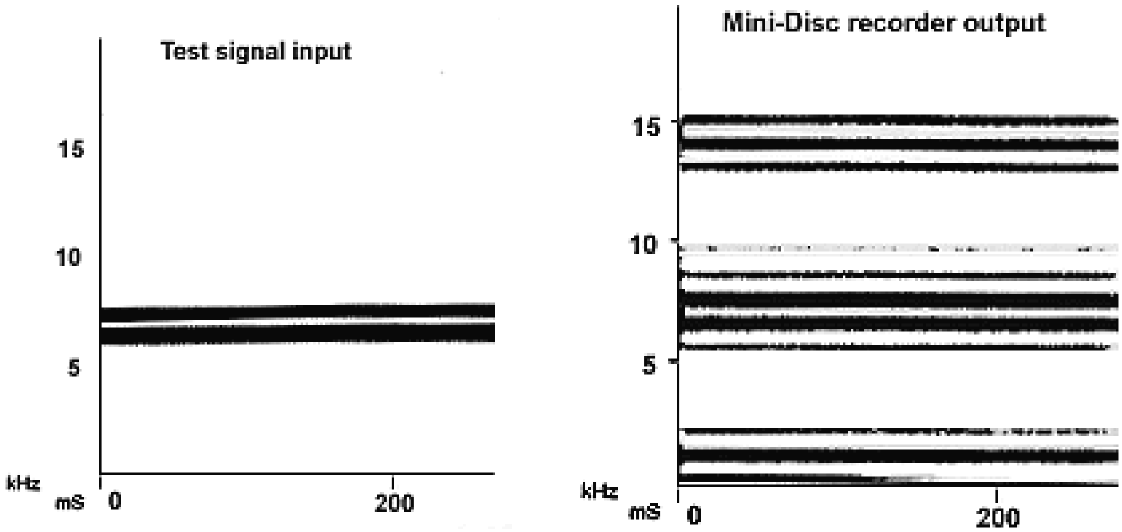

A. Spectral analysis of a 3 kHz test signal recorded at "0" VU on a "modified" Sony TCM-5000EV cassette recorder, which is designed for using IEC normal-bias tape (we used Maxell XLI-S60). Aside from the overall noise and the 3 kHz fundamental test signal, the only harmonic clearly visible is the 3rd harmonic, at 9 kHz. When a cassette recorder is properly calibrated, this 3rd harmonic, an inescapable byproduct of magnetic audio recording, is about 50 dB below that of the test signal; it should not be audible or cause serious problems in any spectral analysis.

B. The same test, but this time using IEC Type II high-bias tape (Maxell XLII-60). Note that the 3rd harmonic is now only 20 dB below that of the test signal, and that the 5th harmonic becomes significant, too, at 40 dB below the fundamental. Abscissa, signal amplitude in dBu; ordinate, frequency in Hertz.

Fig. 2 A. Correct: Type I tape on Type I settings

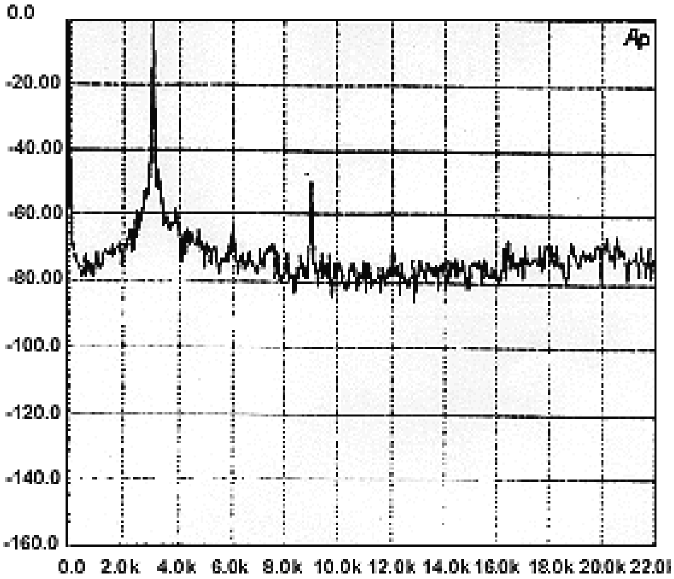

Fig.2 B. Incorrect: Type II tape on Type I settings