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Migratory Bird Monitoring Using Automated Acoustic and Internet Technologies

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Abstract

Department of Defense (DoD) installations require accurate assessments of migratory landbird migration patterns and population sizes. Yet, for most DoD locations no inventory of bird species has been established; a year round inventory of all bird species that provides a continuous database on the distribution and abundance of all birds, all year at these sites also rarely exists. Our innovative acoustic and internet monitoring network provides tools to monitor migratory activity by species, to contribute towards more accurate population estimates for these species, and to provide information for more accurate environmental risk assessments (for Migratory Bird Treaty Act, MBTA, and Endangered Species Act, ESA) and Integrated Natural Resource Management Plans (INRMPs). This network documents migratory phenomena that are unobservable by other means and enables studies that extend beyond the boundaries of DoD installations. In this multi-year project we addressed three challenges confronting DoD - acquiring more detailed information to help inform protocols for minimizing bird strike hazards, meeting environmental stewardship obligations while managing the ongoing financial and operational costs, and engaging broader societal support and solutions for environmental problems. The DoD Legacy Resource Management Program has funded the three years of this project in full. At the end of this three-year effort, we have automated and vastly increased the speed and efficiency of acoustic monitoring and we have provided access and development of a robust system for recording, archiving, and accessing bird observation data. We have shown that bioacoustic monitoring not only yields valuable data on the distribution and behavior of birds, including several threatened and endangered species, but also provides a cost-effective and reliable means to both enhance existing monitoring protocols for target species and develop new, automatic protocols. We recorded over 200 species by voice during the three-year project, detecting over 50,000,000 sounds of interest representing approximately 100,000 flight calls. We increased efficiency of energy detection process to over 200X faster than real time for extracting signals of interest, and we implemented a template (matched filter) detection process that, in many real world cases, returned nearly 100% correct detection rate for target species. We also developed the durable and portable autonomous recording unit, a device that can record on a pre-programmed schedule for up to 10 weeks. All of these accomplishments also are directly related to proposed monitoring plans in the DoD Coordinated Bird Monitoring plan, and they all have invaluable follow on work that is both applied, conservation-based, and biological important.

Executive Summary

Birds are critical to ecosystem function and avian monitoring can enhance science and conservation efforts alike. Because acoustic communication in birds is rich, and the vast majority of birds have species-specific acoustic signatures, sound provides a means to explore the composition of avian diversity in particular regions of interest (Brandes 2008). In fact, bioacoustic methods play a prominent role in avian monitoring efforts because many birds can be heard more reliably and at much greater ranges than they can be seen (e.g. Scott et al. 1981).

Avian vocalizations represent an efficient means to survey birds (Parker 1991, Riede 1993, Kroodsma et al. 1996). Acoustic surveying lends itself to point and transect counts as well as rapid assessment program (RAP) to evaluate biodiversity of specific areas (Riede 1998). However, the most significant drawback to point and transect counts is the reliance on highly trained personnel for making identifications of species and the inherent subjectivity of their data due to skill level. This can make comparisons between data from different personnel unreliable (Angehr et al. 2002). More explicitly, such factors constrain the robust translation of bird sound detections into reliable estimates of density:

1) human listeners differ significantly in hearing thresholds and psychoacoustic acuity (e.g. Cyr 1981, Ramsey and Scott 1981);
2) human observers vary in abilities to identify sounds, cope with dense choruses and judge distances to sounds (e.g. Faanes and Bystrak 1981, Emlen and DeJong 1981); and
3) the patterns of bird sound production (rates) are inadequately quantified (e.g. Diehl 1981, Ekman 1981, Best 1981).

However, the use of acoustic recorders can greatly reduce this variability, and some studies have suggested that acoustic recordings alone are preferable to trained personnel without recorders, since recordings are more consistent and achievable (Haselmayer and Quinn 2000, Hobson et al. 2002, Rempel et al. 2005).

Regardless, these limitations apply to ground-based monitoring of diurnal, terrestrial birds and to monitoring of the vast numbers of aerial, nocturnal migrants that vocalize in flight. In addition to the bounds of these limitations, bird behavior, particularly migratory behavior, adds another level of difficulty to these issues.

Hemispheric-scale migrations involve billions of birds; however, much migration occurs under the cover of darkness, and direct monitoring methods are impossible for species that migrate nocturnally. For these species, indirect methods such as radar imagery of passing migrants or acoustic recording of nocturnal flight-calls provide the only reliable means to monitoring bird movements. Use of radar imagery has been problematic for the following reasons:

1) species identification is impossible;
2) interpretation is confounded by other nocturnal animals, both migratory and non-migratory, including bats and insects;
3) access to appropriate equipment for studies at a diverse range of scales is challenging (i.e. NEXRAD radar is very useful for monitoring at 100s to 1000s of km scale, whereas tracking radar is perhaps useful only under 5-10 km); and
4) purchasing and installing radars are costly.

Acoustic recording of nocturnal migrants provides the best opportunity for both reliably and economically monitoring migrant species on a broad geographic scale. Additionally, monitoring migratory species acoustically on their breeding grounds provides critical information for surveying these species and for defining best practices when it comes to protocols for monitoring them.

Flight-calls of passerine, related birds (e.g. cuckoos), and non-passerines are defined as species-specific notes of up to several syllables, generally in the 1-11 kHz frequency band and 50-300 ms in duration. These calls are the primary vocalizations given by many species of birds during long, sustained flights, particularly migratory flights (Evans and O'Brien 2002). Despite the name flight-call, birds may produce these calls in a variety of contexts other than migratory flight, including while perched and while interacting with fledged young. Many species also use their flight-calls year-round (Evans and O'Brien 2002), and some species regularly give flight-calls while in diurnal flight (e.g. Yellow-rumped Warbler *Dendroica coronata*; Evans and O'Brien 2002). Flight-calls are distinct from songs, and more importantly they are distinct from other types of short calls, such as chip notes and alarm calls. Many migratory bird species produce flight calls audible from the ground (Ball 1952, Graber and Cochran 1959, Farnsworth 2005), and many of these vocalizations are typical frequency modulated signals that are stereotyped and species-specific (Evans 1994, Evans and Mellinger 1999, Evans and Rosenberg 2000, Evans and O'Brien 2002). Flight-calls have been studied most intensively in North America, and Evans and O'Brien (2002) compiled a guide to passerine and allies' flight-calls occurring in the eastern part of the continent (mostly east of the 100th meridian) with detailed information on flight-calls. Not all of the species contained in the guide regularly give flight-calls, and not all of those that regularly give flight-calls give them at night. For example, cuckoos, woodpeckers, corvids, larks, swallows, thrushes, wood-warblers, tanagers and grosbeaks, emberizid sparrows, blackbirds, and finches flight-calls regularly, but most woodpeckers, corvids, larks, swallows, and finches rarely use these calls at night. Groups of species that do not regularly give flight-calls include New World flycatchers (Tyrannidae), vireos (Vireonidae), and mimids (Mimidae).

A frequently asked question is, how does one know the identity of a calling bird when it is migrating at night and is not visible? Identification of some calls is simple because the nocturnal vocalizations are the same as the diurnal vocalizations (*Catharus*; Howes 1912, Evans 1994). However, identification of many species is more complicated and requires deeper investigation, generally from two distinct sources (Evans and Mellinger 1999, Evans and Rosenberg 2000):

1) Comparisons of spectrograms of diurnal flight-calls of known species and unknown nocturnal flight-calls –birds in morning flights often give flight-calls (Evans and Rosenberg 2000, Evans and O'Brien 2002; see Gauthreaux 1978, Hall and Bell 1981, Weidner et al. 1992 re: morning flight); also, direct comparison of unknown nocturnal vocalizations and flight-calls recorded from birds in captivity or from birds with attached miniature microphones, is possible (Hamilton 1962, Lanzone et al. in press, Cochran unpublished data).

2) Correlating the seasonal timing and geographic range of nocturnal calls with known timing and migration ranges for each species. Species-specific migration calendars are available for many species and locations in North America, often generated from accounts of the species killed during nocturnal migration and collected at tall structures (colliding with television towers, lighthouses or buildings) and historical arrival and departure dates (see Evans 1994, Evans and Rosenberg 2000; also Hedges 2001).

Automated detection and identification of these calls affords an opportunity to monitor nightly bird migration over and around DoD installations. These are short and simple vocalizations, and automatic identification has been demonstrated for some guilds. In addition, the night-time recording environment is often ideal for providing high-quality, low-noise data. For example, during a 1999 EPA-funded project called BirdCast (Mills 2000, Hedges 2001), CLO produced preamplified microphones and a Java application that enabled volunteers to automatically detect FCs using the sound card inputs on their personal computers. Calls were uploaded over the Internet each morning, and logged in a database that hosted graphical tools for reviewing and labeling the sounds. Numbers of migrants detected at night were then compared directly with ground-based censuses from nearby sites, to assess the composition of species passing overhead versus stopping to use habitats on the ground. These numbers also were compared with NEXRAD radar imagery, providing information on the species composition of radar-detected migration events (additional similar studies: Larkin et al. 2002, Farnsworth et al. 2004). We followed a similar approach to the collection of nocturnal acoustic data for the nocturnal migration portion of this project. Thus, in addition to being a high priority for conservation, the study of night flight call data can provide an excellent model for the exploration and development of many machine-based detection and classification techniques. Developing automated and robust detection and classification software is critical to realizing our vision of using flight-calls to monitor migrants. It will allow us to expand our monitoring capabilities on a hemispheric scale and to increase our understanding of migration exponentially.

Monitoring the diversity and abundance of migrant birds is a critical conservation priority that can establish baseline population information, important because migrant birds are declining in many parts of their ranges as a result of changing habitat and climate. Of principal interest is gathering information on the following:

1) the presence/absence (night-by-night, week-by-week) of those species over (spring, fall) 2-3 month migration period (eventually at various scales such as over the whole migration, 1000s km geographic scales; also, eventually generate species composition at multiple temporal and spatial scales);
2) the timing of migration for certain indicator species, including start, end, and stopover points, as well as patterns of activity over this interval (eventually would relate to abundance at various scales as well as potential differences in behavior at various scales);
3) the abundance of those species (night-by-night, week-by-week; eventually, at various geographic scales—this would get into estimates of individual counts, or proxies for that value); and
4) geographic patterns of migration (for example, timing, presence/absence, abundance at certain hemispheric locations of indicator or other species).

Obtaining information of this sort is critical for creating informed and relevant strategies for management and policy planning related to migrant birds. Generally, migrant birds are a proxy for habitat conservation across political borders and for conserving endangered habitats at multiple scales simultaneously. For example, with information about species-specific timing of use of stopover locations, we can target certain, highly localized locations that are high priorities for conservation, management, or outright purchase while at the same time doing so on breeding, stopover, and wintering grounds that may be connected by thousands of kilometers.

Methods for making reliable and affordable long-term, autonomous environmental recording are currently available. In fact, hundreds of thousands of hours of acoustic data targeting nocturnal migrants have already been recorded from a variety of locations. With these recordings comes a wealth of metadata (geographic location, time of day, climactic conditions) that can be used in concert with species identification based on night-flight calls to begin to address some of the critical biological questions outlined above. Given the mature state of autonomous data acquisition (born of a long-standing effort and tradition on this front) our ability to collect acoustic data currently outpaces our ability to fully and efficiently analyze these data. The typical analysis methods being employed by researchers require substantial and largely unsustainable amounts of human interaction and effort. Being able to speed the processing of sound data through machine-directed approaches could allow the extraction of a wealth of biological information on migrants that, due to practical constraints on resources and time, is largely inaccessible. For example, methods for fast and automated extraction of night flight calls with identification to species would give researchers easy access to information on spatial presence/absence, migration timing and group composition that is otherwise impractical to systematically extract from massive volumes of sound data. Such automated processes would open up the possibility for even casual observers (citizen scientists) to place microphones atop their houses, creating a nationwide network of monitoring stations. Passing migrants could be passively recorded, and software could be used to automatically detect and classify flight-calls to species. Such a network could capture details of migration patterns not previously possible. Because most DoD sites do not have year round inventories of all bird species that provides a continuous database on the distribution and abundance of birds at these sites, such a network provides tools to monitor migratory activity by species and documents migratory phenomena unobservable by other means and enables studies extending beyond the boundaries of DoD installations.

Cornell Laboratory of Ornithology (CLO) is in a unique position of having expertise in both migrant flight-call biology and in bioacoustic signal processing and analysis. To address some of these issues and clarify some solutions to these problems, CLO developed digital autonomous recording units (ARUs) that record mp3 and binary (BIN) sound files for periods of up to 10 weeks in duration. These units can provide a valuable extension to traditional point counts because they can detect species that are not surveyed efficiently by point count methods because they vocalize infrequently, and be deployed in advance at many sites and programmed to record simultaneously to produce true matched samples enabling ground personnel to cover more sites. These devices are also useful for monitoring audible bird migration. Furthermore, these units allow DoD to monitor difficult to reach areas or difficult to survey vocal species in a way that is substantially more cost efficient and effective than any other means can provide. During this project we sought to:

1) test and evaluate protocols for digital ARUs to
    a) enable ground-based surveys of species that vocalize infrequently,
    b) provide critical data to improve the accuracy of any acoustic census, and
    c) produce acoustic datasets for observer training;
2) implement, ground-truth, and expand a network of acoustic detectors to monitor flight-calls of migrating species, to predict species-specific stopover use on and around DoD installations;
3) expand analysis capabilities for large acoustic monitoring datasets by improving automated software and algorithms for extracting, processing, viewing, and analyzing acoustic data; and
4) customize the Internet-based eBird application to allow DoD to collect, store, and manage sighting data on all bird species throughout the year.

The first two components address directly the limiting factors of observers monitoring birds acoustically and monitoring birds that may otherwise be missed by traditional observation methods and provide solutions that will enhance DoD capacity to monitor avian resources on and around DoD lands. The third and fourth components facilitate the analysis and summary of these data as well as their presentation in a convenient and accessible format.

We deployed ARUs at DoD installations at a variety of locations in the continental US to record vocal nocturnal migrants and target species of concern. We have collected over 50,000 hours of data between fall 2005 through fall 2008, and we have successfully proved that the concept of acoustic monitoring is a powerful and invaluable method for studying the species present on DoD lands and for generating cost effective protocols for monitoring in the future. We successfully stored, processed, and initiated analysis of the sound recordings. We have successfully generated temporal patterns for suites of migrant species across multiple military installations, and we have succeeded in using ARUs to record the presence and behavior of elusive or otherwise difficult to monitor species. We indicate future areas to improve our data collection and analysis, to expand our research, and to form partnership that will further bolster the use of this technology. We outline problems and constraints we encountered in developing and applying hardware and software technologies. We encountered numerous problems and constraints in developing and applying hardware and software technologies, though we have met each of these challenges, developing solutions for many of these issues. We indicate future areas to improve our data collection and analysis, to expand our research, and to form partnership that will further bolster the use of this technology. We tested all devices with the planned application of this technology: to monitor acoustically species that vocalize infrequently, to improving accuracy of existing census methods, to produce acoustic datasets for training purposes, and to monitor flight-calls of migrant birds for predicting migration and stopover use on DoD installations. We address the limiting factors of observers monitoring birds acoustically and of protocols monitoring birds that may be missed by traditional observation methods and provide solutions and sample data that enhance DoD capacity to monitor avian resources on and around DoD lands and analysis and summary of these data. We also examine ARU reliability, applicability to tasks, and recording quality.

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1. Scope of Work

a. 2005-2007

(Ken Rosenberg, Melanie Driscoll, and Stefan Hames with Mike Powers providing support and Andrew Farnsworth joining the team in early 2007)

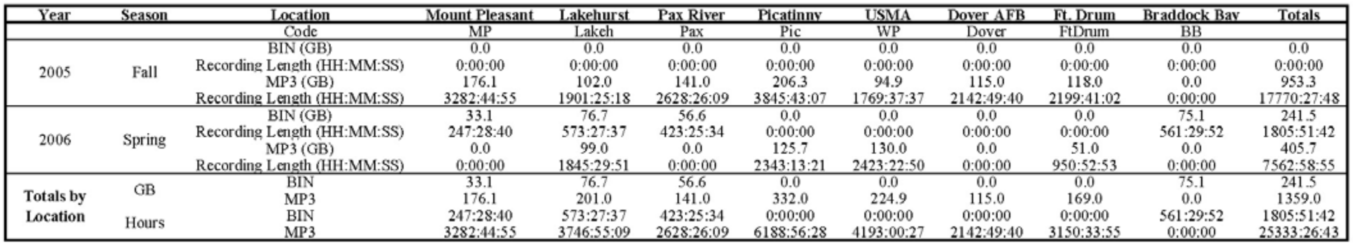
CLO installed a wide aperture, nocturnal flight-call network and assessed point count performance utilizing a lightweight stereo recording system. CLO and DoD personnel installed acoustic monitoring arrays at seven sites stretching from the border with Canada to the southern end of the Chesapeake Bay, six bases and one non-DoD site at Mount Pleasant in the Finger Lakes region of central New York (approximately 4 miles from CLO) to fill a gap in geographic coverage and to provide a convenient array for testing (Figure 1). The fall deployment fulfilled several practical needs: obtaining the necessary permissions, finding suitable locations for monitoring equipment, developing efficient deployment protocols, and extended field testing of new Autonomous Recording Units (ARU). The spring deployment afforded us an opportunity to correct some of the problems we experienced during the fall while collecting additional training datasets for use in developing energy detectors and flight-call temporal patterns.

We deployed ARUs as three-unit arrays designed to examine the feasibility of localizing flying birds. We positioned the three units in a triangular configuration at each site. This was done, in part, to provide redundancy for recording flight-calls of migrating songbirds, although we were not aware of any unit failures or the propensity for unit failure at the time and, in part, to enable us to estimate altitude of night flight-calls (FC) and bearings to them, to better document morning flight, and use of DoD lands for stopovers during migration. Each array consisted of three ARU placed approximately 50 m from each other. Each ARU consisted of a stereo pair of sensitive, horn-loaded, pre-amplified dynamic microphones feeding a recording unit that stored the sounds digitally on a 100 GB hard drive as compressed MP3 sound files. In spring 2006 we also deployed ARUs that record binary files (BIN), uncompressed sound files. Each ARU recorded 24 hours/day, 7 days/wk for approximately 70 days, generating approximately 100 GB of compressed sound data when units functioned at full capacity without failure. Each BIN unit recorded during a pre-programmed schedule from civil twilight to civil twilight. The installations occurred in the following order: Mt. Pleasant, Ithaca, NY, Picatinny Arsenal, Mt. Hope, NJ, Naval Air Engineering Station, Lakehurst, NJ, Naval Air Station at Patuxent River, MD, West Point Military Academy, West Point, NY, Dover Air Force Base, Dover, DE, and Fort Drum Military Reservation, Fort Drum, NY. During fall we deployed and removed the units from north to south (except for Mt. Pleasant and Ft. Drum) in order to capture the maximal amount of FC and morning flight data, because high migration traffic persisted longer at southern sites. During spring we reversed the deployment strategy.

Pivotal questions regarding variability in observer performance and the utility of long-term recording equipment for bird monitoring motivated a second phase of Legacy data collection. The same horn-loaded microphones used in the ARUs were paired with compact, solid-state MP3 recorders (iRiver iFP-899, 1 GB flash memory, $300 total system cost) and sent out with bird monitoring personnel who conducted point count surveys. Three systems were sent out with the NY Audubon grassland survey team, who conducted hundreds of point counts throughout the state. In addition, a BBS survey route (50 stops) and an Ontario Bird Atlas block point count survey (30 stops) were recorded using the same equipment. The Canadian effort included real-time notes by an experienced observer as well as recordings made by two digital acoustic systems. The compact CLO unit was run in parallel with a more expensive and cumbersome system that was developed for Canadian forest surveys (E3A: $6900, www.riverforks.com). These data will enable direct comparisons of performance between recording systems, as well as comparisons between the real-time and offline bird counts. This work in Canada enabled us to take advantage of later breeding activity at high latitudes, and we fostered a partnership with Dr. Charles Francis, the Chief of the Migratory Bird Population Division of the Canadian Wildlife Service. The success of acoustical technology development will rely on both the gains in monitoring performance that can be realized and broad acceptance by the ornithological community.

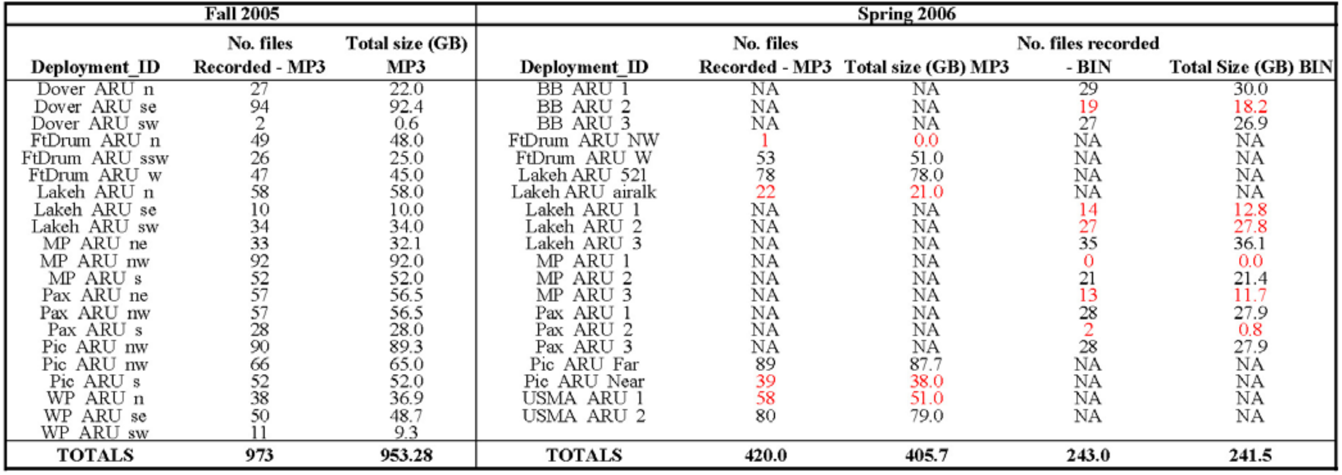
We summarized total data generated in 2005-2006 by the 21 ARU deployed in seven arrays by location in Table 1 (a and b). We recorded a total of over 27,000 hours during deployments in this period (Table 2). We highlight a number of challenges with these analyses that we discuss in the following sections that are relevant for all years of recording and analysis. Additionally, we used only a portion of this substantial data set to exercise the automated processing software system and to develop statistical protocols for further data reduction and graphical display; our reasoning and our needs to do this stem from the format of the data collected, the bulk of which was compressed, mp3 format audio files.

Table 1a. Total data recorded by season and location in hours and gigabytes. Zeros (0) represent sites without the recording unit type at the location.



Year	Season	Location	Mount Pleasant	Lakehurst	Pax River	Picatinny	USMA	Dover AFB	Ft. Drum	Braddock Bay	Totals
		Code	MP	Lakeh	Pax	Pic	WP	Dover	FtDrum	BB	
2005	Fall	BIN (GB)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Recording Length (HH:MM:SS)	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00	0:00:00
		MP3 (GB)	176.1	102.0	141.0	206.3	94.9	115.0	118.0	0.0	953.3
		Recording Length (HH:MM:SS)	3282:44:55	1901:25:18	2628:26:09	3845:43:07	1769:37:37	2142:49:40	2199:41:02	0:00:00	17770:27:48
2006	Spring	BIN (GB)	33.1	76.7	56.6	0.0	0.0	0.0	0.0	75.1	241.5
		Recording Length (HH:MM:SS)	247:28:40	573:27:37	423:25:34	0:00:00	0:00:00	0:00:00	0:00:00	561:29:52	1805:51:42
		MP3 (GB)	0.0	99.0	0.0	125.7	130.0	0.0	51.0	0.0	405.7
		Recording Length (HH:MM:SS)	0:00:00	1845:29:51	0:00:00	2343:13:21	2423:22:50	0:00:00	950:52:53	0:00:00	7562:58:55
Totals by Location	GB	BIN	33.1	76.7	56.6	0.0	0.0	0.0	0.0	75.1	241.5
		MP3	176.1	201.0	141.0	332.0	224.9	115.0	169.0	0.0	1359.0
	Hours	BIN	247:28:40	573:27:37	423:25:34	0:00:00	0:00:00	0:00:00	0:00:00	561:29:52	1805:51:42
		MP3	3282:44:55	3746:55:09	2628:26:09	6188:56:28	4193:00:27	2142:49:40	3150:33:55	0:00:00	25333:26:43

Table 1b. Total number of files recorded and their sizes by season and station. NA represents locations at which we did not deploy the type of unit represented. Zeros (0) represent no data collected in the sound file, indicating a problematic recording unit. Codes follow Table 1a, with locations at recordings sites with multiple units indicated by typical cardinal directions.



Fall 2005			**Spring 2006**				
Deployment_ID	**No. files Recorded - MP3**	**Total size (GB) MP3**	**Deployment_ID**	**No. files Recorded - MP3**	**Total size (GB) MP3**	**No. files recorded - BIN**	**Total Size (GB) BIN**
Dover ARU n	27	22.0	BB ARU 1	NA	NA	29	30.0
Dover ARU se	94	92.4	BB ARU 2	NA	NA	19	18.2
Dover ARU sw	2	0.6	BB ARU 3	NA	NA	27	26.9
FtDrum ARU n	49	48.0	FtDrum ARU NW	1	0.0	NA	NA
FtDrum ARU ssw	26	25.0	FtDrum ARU W	53	51.0	NA	NA
FtDrum ARU w	47	45.0	Lakeh ARU 521	78	78.0	NA	NA
Lakeh ARU n	58	58.0	Lakeh ARU airalk	22	21.0	NA	NA
Lakeh ARU se	10	10.0	Lakeh ARU 1	NA	NA	14	12.8
Lakeh ARU sw	34	34.0	Lakeh ARU 2	NA	NA	27	27.8
MP ARU ne	33	32.1	Lakeh ARU 3	NA	NA	35	36.1
MP ARU nw	92	92.0	MP ARU 1	NA	NA	0	0.0
MP ARU s	52	52.0	MP ARU 2	NA	NA	21	21.4
Pax ARU ne	57	56.5	MP ARU 3	NA	NA	13	11.7
Pax ARU nw	57	56.5	Pax ARU 1	NA	NA	28	27.9
Pax ARU s	28	28.0	Pax ARU 2	NA	NA	2	0.8
Pic ARU nw	90	89.3	Pax ARU 3	NA	NA	28	27.9
Pic ARU nw	66	65.0	Pic ARU Far	89	87.7	NA	NA
Pic ARU s	52	52.0	Pic ARU Near	39	38.0	NA	NA
WP ARU n	38	36.9	USMA ARU 1	58	51.0	NA	NA
WP ARU se	50	48.7	USMA ARU 2	80	79.0	NA	NA
WP ARU sw	11	9.3					
TOTALS	**973**	**953.28**	**TOTALS**	**420.0**	**405.7**	**243.0**	**241.5**

Table 2. Seasonal totals of mp3 and BIN recordings. In 2005 we did not deploy BIN units.

Year	2005	2006
Total MP3 units:	21	8
Total MP3 units with significantly less data than possible:	12	4
Total BIN:	-	12
Total ARUs with significantly less data than possible:	-	6

Table 3. Failure rates for mp3 and BIN units in 2005 and 2006. In both seasons our project realized failure rates of approximately 50%.

Conversion:	Size (GB)	Recording Length (HH:MM:SS)
MP3	1.0	18:38:29
BIN	1.0	7:28:36
BIN	1.07	8:00:00

Table 4. Conversion factors for mp3 and BIN files. Note that the same size mp3 and BIN files represent drastically different total recording lengths. After the 2005-2006, we made some major changes to the recording setup. We began to use only BIN-recording ARUs and converting these files into AIF files for easier analysis in multiple sound analysis packages developed at CLO. We increased the size of our sound archive to approximately 4 TB, switching to all BIN-recorded, aif file format data by spring 2007.

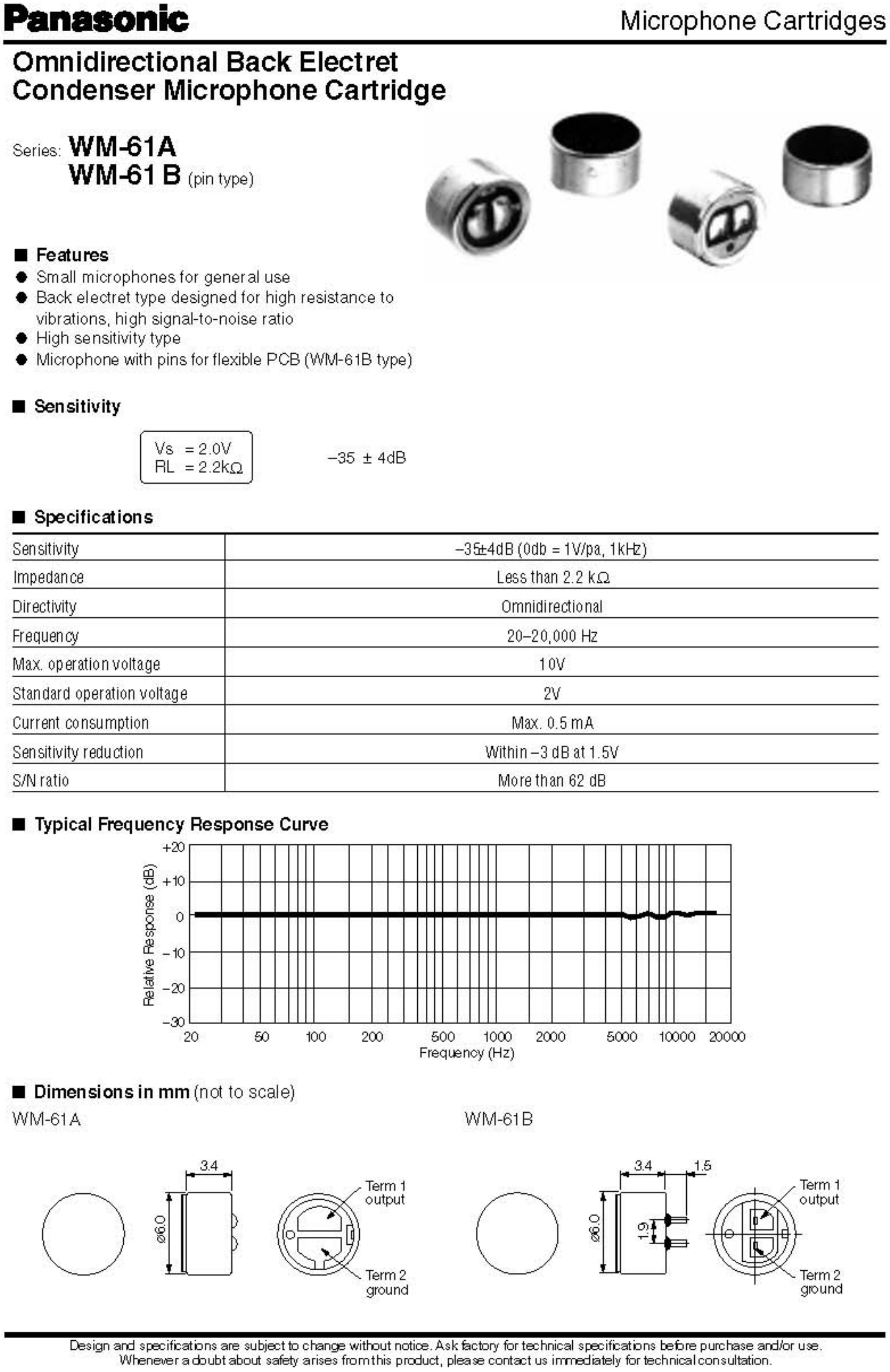
Year	**Format**	**Recording Hours**	**Number of Units (Deployments)**	**GB**
2005	BIN	N/A	N/A	N/A
2005	MP3	740.4359667	24	953.28
2006	BIN	115.2917576	18	370.085
2006	MP3	315.1242517	8	405.70915
2007	BIN	826.4236111	40	1399.2
2007	MP3	285.1762384	19	864.9550778
2008	BIN	Still processing	12	Still processing
2008	MP3	Still processing	4	Still processing
2005	Total	740.4359667	24	953.28
2006	Total	430.4160093	26	775.79415
2007	Total	1111.59985	59	2264.155078
2008	Total	Still processing	16	Still processing
Combined	Total	2282.451826	125	3993.229228

Critical to the success of our projects was the development and implementation of autonomous hardware for recording bird vocalizations in difficult to survey locations. Our efforts yielded the evaluation of two, successful monitoring platforms, one of which (BIN-recording ARUs) has become the tool of choice for our terrestrial monitoring program for avian acoustic experiments. This autonomous platform is perfect for DoD applications to monitoring, and we advocate further enhancements to this approach in the future. Installation of these became exceptionally simple during the course of this project, as we refined the protocols for deployment and the steps needed to make them operational: initial deployments required travel and on-site effort from Cornell staff, requiring approximately 1.5 hours to setup the devices for recording; by the end of the project, we had refined these protocols and instructions such that Cornell staff could send instructions that required approximately 10-15 minutes of staff time to make the units operational and deploy them. This major improvement indicates the promise of these units in the future to be even easier to operate and to deploy.

What follows are the specifications of the devices we have deployed, as well as a comparison of what we believe to be the next generation of autonomous acoustic recorder.

2005-2006 units: initial specifications for mp3 recording ARUs
Frequency range: 500 - 20,000 kHz (recorder); 15 - 22,000 kHz (microphone)
Microphone Type: Condenser; Pre-amplifier: High-gain FET pre-amp, with Automatic Gain Control
Sensitivity (nominal microphone sensitivity): -50dB +/- 4dB; (acoustic horn gain): ≈20 dB
S/N Ratio (DMC500): > 90dB
THD (DMC500): < 0.01%
Est. recording range: Human speech @ 60 dB - ≈ 50-100 m; motor @ 90 dB - 400 m; Jet takeoff @ 120 dB - 200 m
Hard-drive capacity: 100 gb; File System : FAT 32; Hard Disk: 2.5", Low Power HDD, ATA I/F
Compressed audio capacity: 18 hours/gb @ 128 kb/s bit rate and 44.1 khz sample rates.
Buffer Memory (DMC500): Max. 12MB
MP3 Encoding (DMC500): 32kbps - 320kbps
Sampling Frequency : 8 - 48KHz
Audio Input : Line-in, Built-in microphone; Audio Output : Headphone Out
Earphone Out : 10mW + 10mW (RMS)
PC Interface : USB 1.0/1.1/2.0, Mass Storage Device
OS Compatibility: Windows 98SE, ME, 2000, XP & MAC
Power Supply: Microphones and pre-amp - 6 Volt alkaline lantern battery
MP3 player - internal - 3.5 v lithium
- external - 6.0 v air-alkaline

2006-present units: specifications for BIN-recording ARUs



Panasonic Microphone Cartridges

Omnidirectional Back Electret Condenser Microphone Cartridge

Series: **WM-61A**
WM-61 B (pin type)

Features

- Small microphones for general use
- Back electret type designed for high resistance to vibrations, high signal-to-noise ratio
- High sensitivity type
- Microphone with pins for flexible PCB (WM-61B type)

Sensitivity

Vs = 2.0V
RL = 2.2kΩ

−35 ± 4dB

Specifications

Sensitivity	−35±4dB (0db = 1V/pa, 1kHz)
Impedance	Less than 2.2 kΩ
Directivity	Omnidirectional
Frequency	20–20,000 Hz
Max. operation voltage	10V
Standard operation voltage	2V
Current consumption	Max. 0.5 mA
Sensitivity reduction	Within −3 dB at 1.5V
S/N ratio	More than 62 dB

Typical Frequency Response Curve

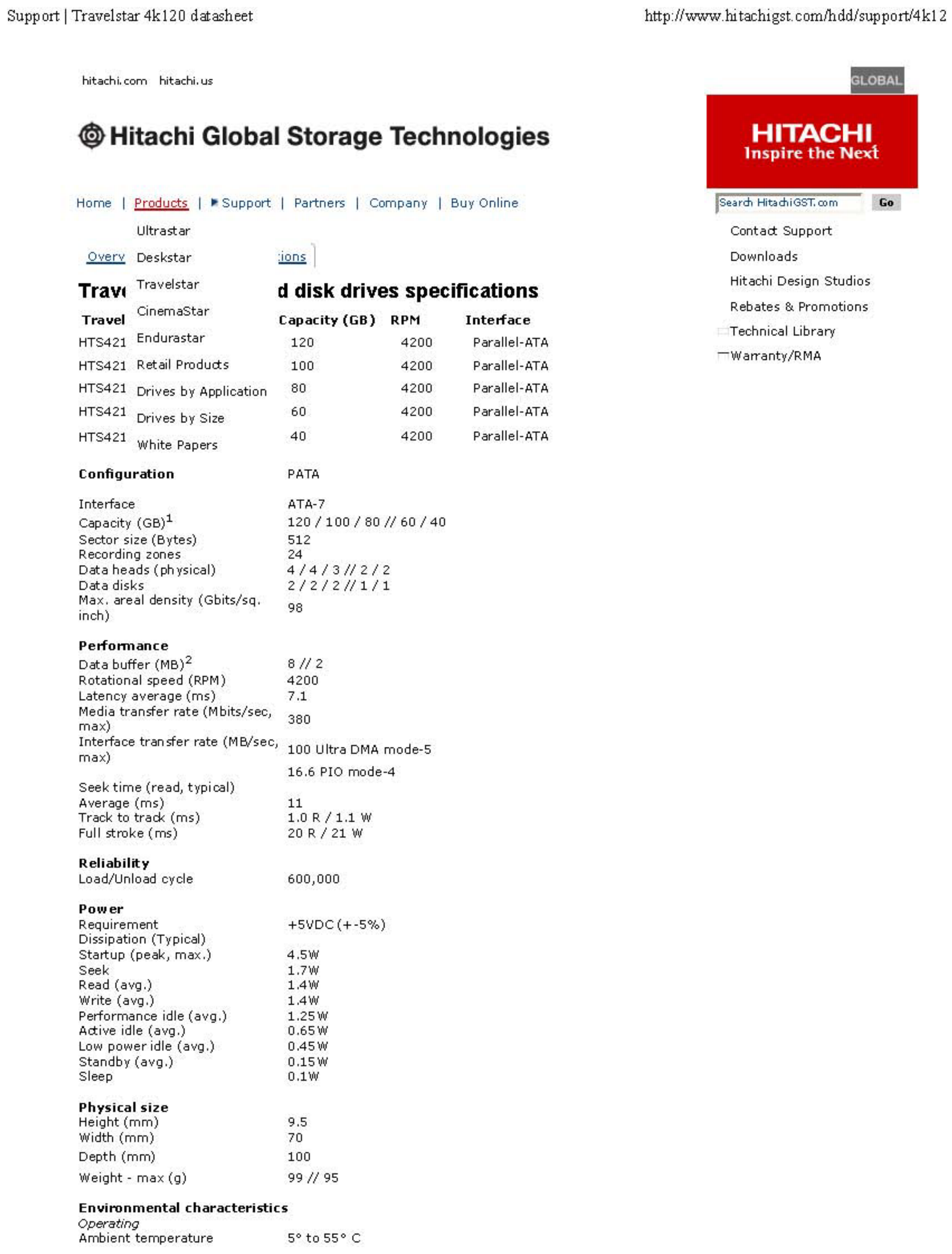
Dimensions in mm (not to scale)

WM-61A

WM-61B

Design and specifications are subject to change without notice. Ask factory for technical specifications before purchase and/or use.
Whenever a doubt about safety arises from this product, please contact us immediately for technical consultation.

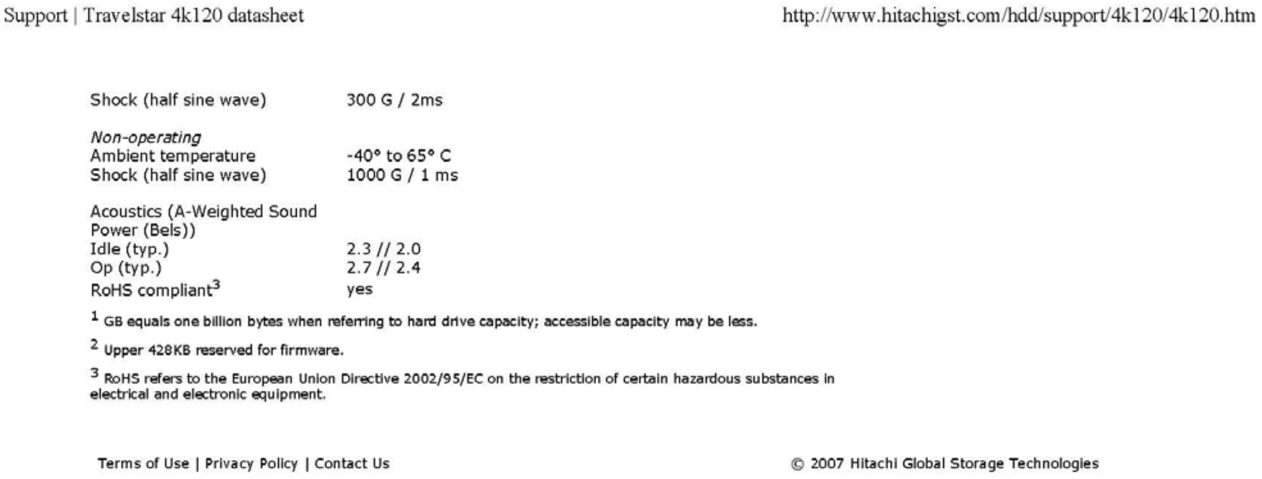
Support | Travelstar 4k120 datasheet http://www.hitachigst.com/hdd/support/4k12



Trav d disk drives specifications

Travel	Capacity (GB)	RPM	Interface
HTS421	120	4200	Parallel-ATA
HTS421	100	4200	Parallel-ATA
HTS421	80	4200	Parallel-ATA
HTS421	60	4200	Parallel-ATA
HTS421	40	4200	Parallel-ATA

Configuration	PATA
Interface	ATA-7
Capacity (GB)[1]	120 / 100 / 80 // 60 / 40
Sector size (Bytes)	512
Recording zones	24
Data heads (physical)	4 / 4 / 3 // 2 / 2
Data disks	2 / 2 / 2 // 1 / 1
Max. areal density (Gbits/sq. inch)	98
Performance	
Data buffer (MB)[2]	8 // 2
Rotational speed (RPM)	4200
Latency average (ms)	7.1
Media transfer rate (Mbits/sec, max)	380
Interface transfer rate (MB/sec, max)	100 Ultra DMA mode-5 16.6 PIO mode-4
Seek time (read, typical)	
Average (ms)	11
Track to track (ms)	1.0 R / 1.1 W
Full stroke (ms)	20 R / 21 W
Reliability	
Load/Unload cycle	600,000
Power	
Requirement	+5VDC (+-5%)
Dissipation (Typical)	
Startup (peak, max.)	4.5W
Seek	1.7W
Read (avg.)	1.4W
Write (avg.)	1.4W
Performance idle (avg.)	1.25W
Active idle (avg.)	0.65W
Low power idle (avg.)	0.45W
Standby (avg.)	0.15W
Sleep	0.1W
Physical size	
Height (mm)	9.5
Width (mm)	70
Depth (mm)	100
Weight - max (g)	99 // 95
Environmental characteristics	
Operating	
Ambient temperature	5° to 55° C

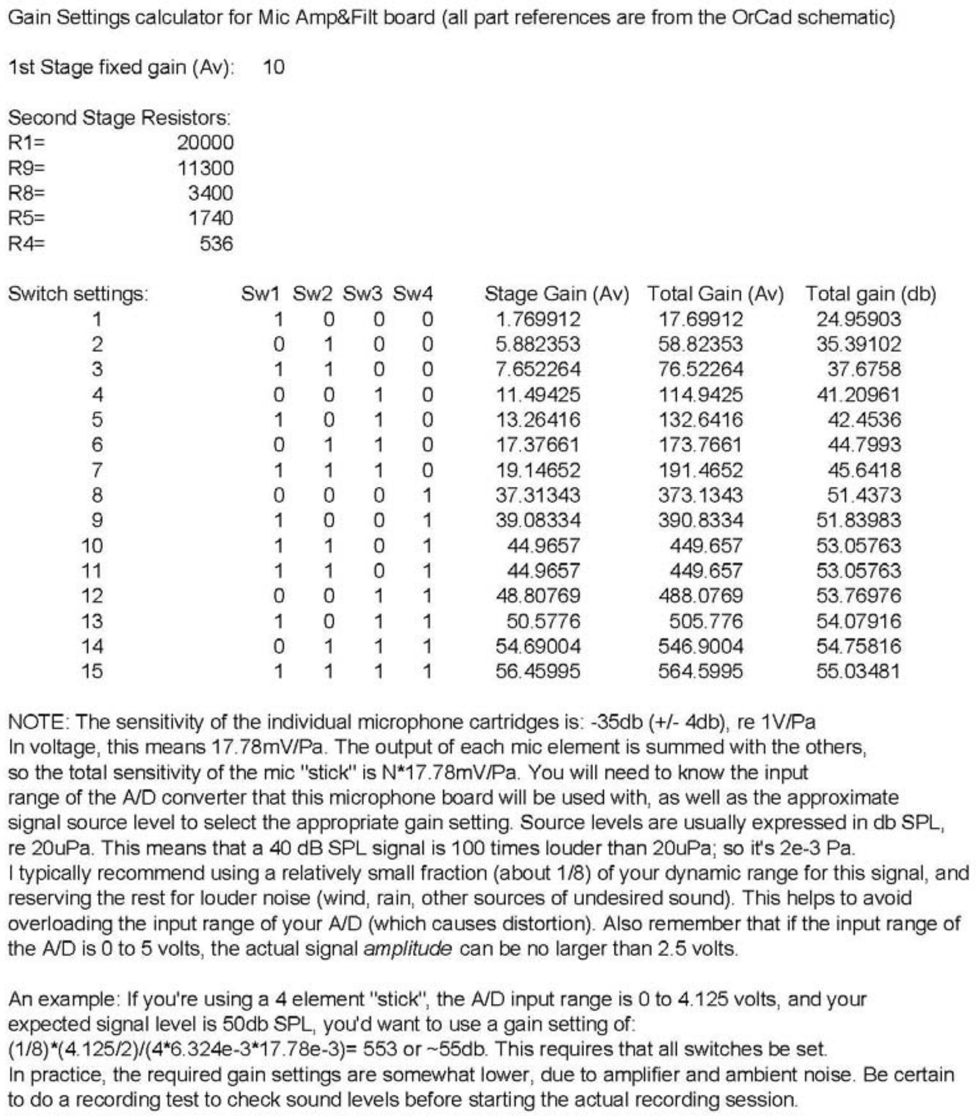


Shock (half sine wave)	300 G / 2ms
Non-operating	
Ambient temperature	-40° to 65° C
Shock (half sine wave)	1000 G / 1 ms
Acoustics (A-Weighted Sound Power (Bels))	
Idle (typ.)	2.3 // 2.0
Op (typ.)	2.7 // 2.4
RoHS compliant[3]	yes

[1] GB equals one billion bytes when referring to hard drive capacity; accessible capacity may be less.

[2] Upper 428KB reserved for firmware.

[3] RoHS refers to the European Union Directive 2002/95/EC on the restriction of certain hazardous substances in electrical and electronic equipment.



Gain Settings calculator for Mic Amp&Filt board (all part references are from the OrCad schematic)

1st Stage fixed gain (Av): 10

Second Stage Resistors:

R1=	20000
R9=	11300
R8=	3400
R5=	1740
R4=	536

Switch settings:	Sw1	Sw2	Sw3	Sw4	Stage Gain (Av)	Total Gain (Av)	Total gain (db)
1	1	0	0	0	1.769912	17.69912	24.95903
2	0	1	0	0	5.882353	58.82353	35.39102
3	1	1	0	0	7.652264	76.52264	37.6758
4	0	0	1	0	11.49425	114.9425	41.20961
5	1	0	1	0	13.26416	132.6416	42.4536
6	0	1	1	0	17.37661	173.7661	44.7993
7	1	1	1	0	19.14652	191.4652	45.6418
8	0	0	0	1	37.31343	373.1343	51.4373
9	1	0	0	1	39.08334	390.8334	51.83983
10	1	1	0	1	44.9657	449.657	53.05763
11	1	1	0	1	44.9657	449.657	53.05763
12	0	0	1	1	48.80769	488.0769	53.76976
13	1	0	1	1	50.5776	505.776	54.07916
14	0	1	1	1	54.69004	546.9004	54.75816
15	1	1	1	1	56.45995	564.5995	55.03481

NOTE: The sensitivity of the individual microphone cartridges is: -35db (+/- 4db), re 1V/Pa In voltage, this means 17.78mV/Pa. The output of each mic element is summed with the others, so the total sensitivity of the mic "stick" is N*17.78mV/Pa. You will need to know the input range of the A/D converter that this microphone board will be used with, as well as the approximate signal source level to select the appropriate gain setting. Source levels are usually expressed in db SPL, re 20uPa. This means that a 40 dB SPL signal is 100 times louder than 20uPa; so it's 2e-3 Pa.
I typically recommend using a relatively small fraction (about 1/8) of your dynamic range for this signal, and reserving the rest for louder noise (wind, rain, other sources of undesired sound). This helps to avoid overloading the input range of your A/D (which causes distortion). Also remember that if the input range of the A/D is 0 to 5 volts, the actual signal *amplitude* can be no larger than 2.5 volts.

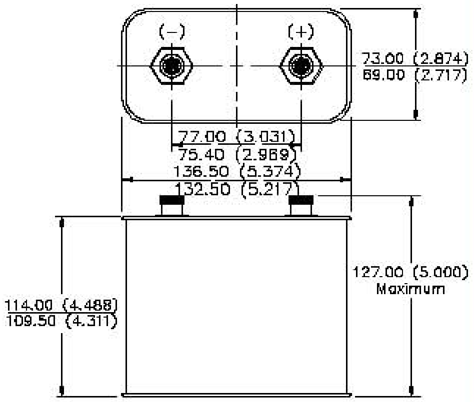
An example: If you're using a 4 element "stick", the A/D input range is 0 to 4.125 volts, and your expected signal level is 50db SPL, you'd want to use a gain setting of:
(1/8)*(4.125/2)/(4*6.324e-3*17.78e-3)= 553 or ~55db. This requires that all switches be set.
In practice, the required gain settings are somewhat lower, due to amplifier and ambient noise. Be certain to do a recording test to check sound levels before starting the actual recording session.

EVEREADY BATTERY CO.
Internet: www.energizer.com
1-800-383-7323 / USA
1-800-383-7323 / CANADA
+ 44 (0) 208 920 2306 / EUROPE

ENERGIZER NO. 521

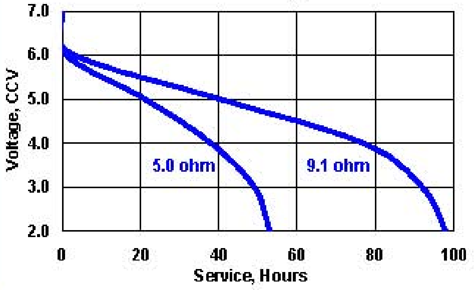
6V

Industry Standard Dimensions in mm (inches)

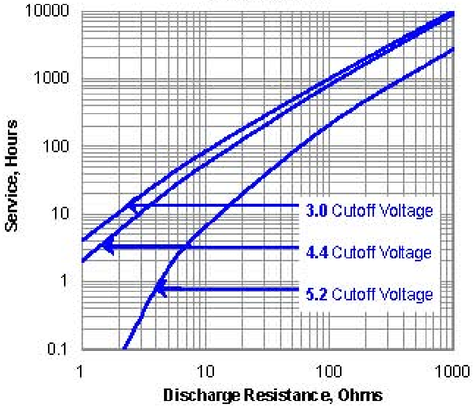


Chemical System:	Alkaline Zinc-Manganese Dioxide (Zn/MnO_2) *(No Added Mercury or Cadmium)*
Designation:	ANSI-918A, IEC-4LR25-2
Battery Voltage:	6.0 Volts
Operating Temp:	-18°C to 55°C (0°F to 130°F)
Average Capacity:	52,000 mAh (to 0.8 volts / cell) (Rated capacity at 25 mA continuous drain.)
Average Weight:	1,900 grams (67.3 oz.)
Volume:	1,123 cubic centimeters (68.5 cubic inch)
Cell:	Eight No. 3-361 Two parallel strings of four in series
Jacket:	Metal
Terminal:	Screw Post

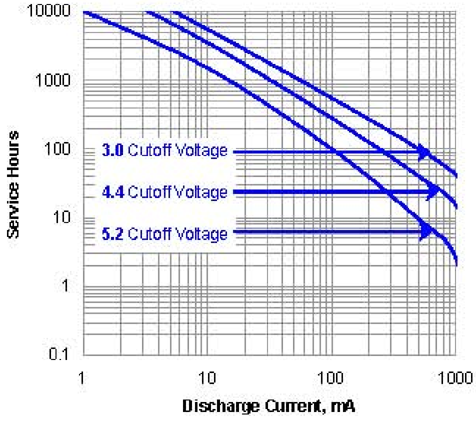
PORTABLE LIGHTING
Continuous Tests @ 20°C



CONSTANT RESISTANCE PERFORMANCE
Typical Service



CONSTANT CURRENT DISCHARGE
Typical Service



Important Notice

This data sheet contains information specific to batteries manufactured at the time of its publication.
Contents herein do not constitute a warranty.

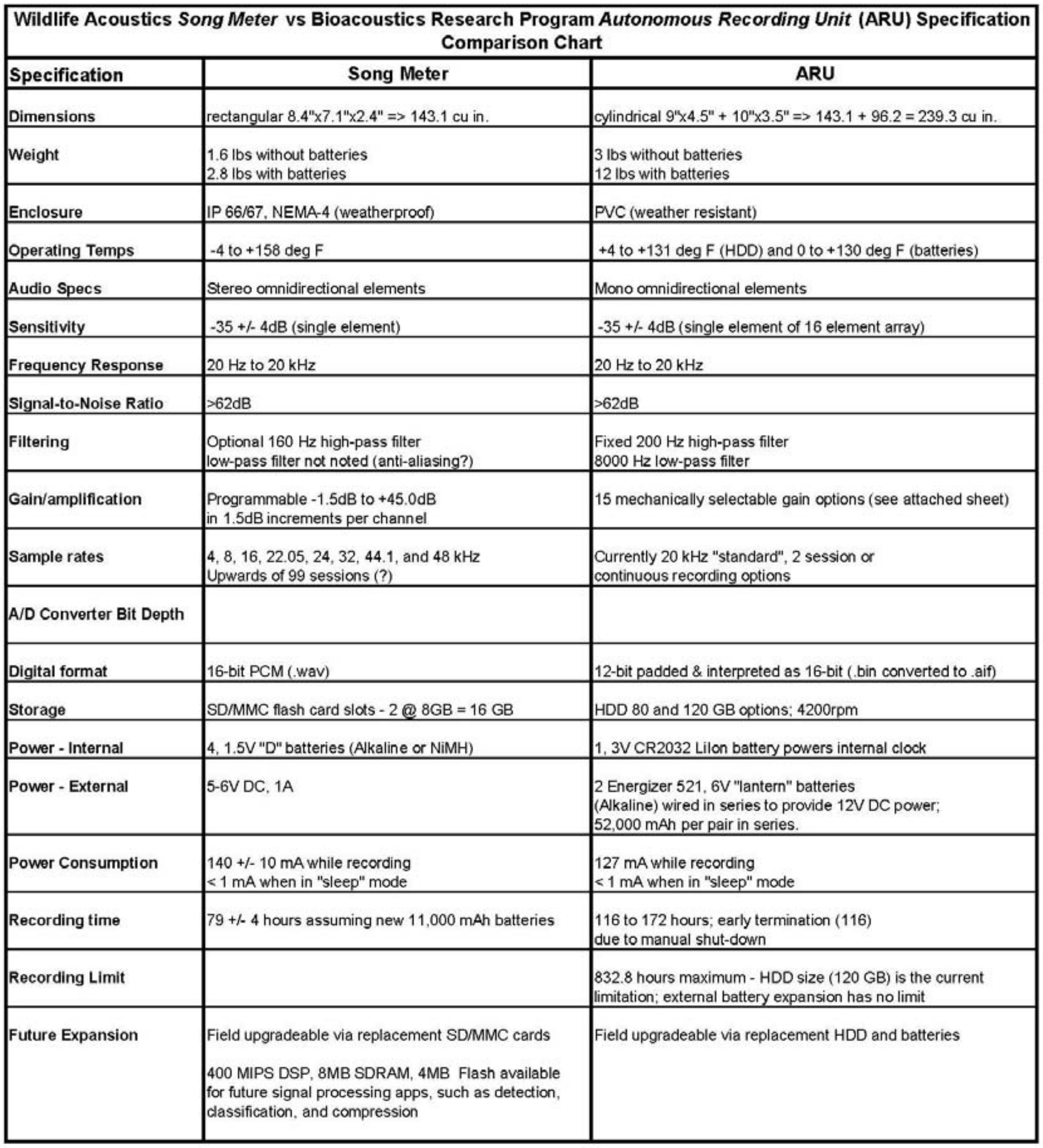
Two types of autonomous recording units (ARUs), as deployed in the desert north of Yuma, AZ in spring 2007. a) CLO BIN-file ARU with external microphone and battery packs. b) mp3-file ARU with mp3 player (bottom right) and battery pack.

Hardware failure was a major problem during the first year of this program. We deployed ARUs and mp3 units, with a failure rate approaching 50% at times. In general, the ARUs failed as a result of suboptimal design of the housing for the units and problems with the operating systems of the mp3 and BIN units. Reasons for failure included compromised housing design, producing situation in which water leaked into the compartment housing the microphone and recording drives; drive failures, in which the operating system underlying the recording in the drives failed and did not record; and microphone failure in which the microphone design was not optimal. We corrected many of these problems in time to collect data; however, because many units failed we were unable to collect as much data as possible. As a result of these failures, we began to develop new housing for the microphone and recording devices as well as to choose new recording devices with higher success rates. We found that, whereas ARUs required some major developmental changes, mp3 units required much additional testing. One problem with mp3 units is that there is an unknown amount of time between writing a sound file and beginning a new sound file. This period of time is in the range of 5-15 minutes, but we do not know the exact periods over which this delay occurs. This makes automatic localization impossible, because recording in these units is not synchronized. Future use of such units for location purposes absolutely requires additional testing with external sound sources to calibrate and to synchronize time among units. For some units, determining start times was impossible because of the manner in which the mp3 units we employed write data to sound files. The amount of time that the unit is not recording is unknown, and as such we need to recalibrate all of our recordings such that each new file begins at a slightly different time. An additional complication is that we needed to establish this time relative to civil twilight to understand what portions of a sound file contain useful nocturnal data.

By the second and third years of the project, we had resolved many of the issues with the ARUs, including: developing a waterproof cylinder to house the recorder, motherboard, and programming components; using larger but more efficient and reliable hard drives for recording; improved pre-programming capabilities; new, skyward pointing microphones composed of 16 elements with increased gain; and better components across the board leading to more durability and greater efficiency of battery usage and power management. After these design changes, ARUs rarely failed as a result of technical causes. Water leakage is no longer a problem, nor is battery failure. However, with the increased time in the field now possible with sufficient weatherproofing and battery life, we discovered a new series of problems - small animals. Rodents, in particular, can gnaw through connecting cables, and we found this to be a problem in numerous deployments. Although the resolution of this is easy, involving either sealing the connectors or moving them off ground level into the air close to the unit, it is likely that this problem will resurface in the future. This is particularly problematic in locations with large rodent populations, perhaps indicative of very remote, grassland locations or highly urbanized city locations.

Numerous challenges to successful ARU design, development, and deployment were time consuming and difficult to address. Yet, despite these challenges, we improved the capabilities and the durability of the recording units. We have improved from a 50% failure rate among units in the fall 2005 and spring 2006 seasons to a 0% failure rate in the spring and fall 2007 season. Only a single deployment of 35 did not work properly in the 2008. Although this near perfect record may not continue, this is a drastic improvement. However, future projects should most certainly consider budgeting for potential challenges in functionality, reliability, and variability of hardware. In particular, a new challenge has arisen in the most recent recording season: rodents. Addressing a means to protect recording devices and their components from rodents should be an important part of new projects.

For military purposes, the ARUs are ideal in that they do not transmit or receive any signals and they have become increasingly easy to deploy. However, one of their primary drawbacks is their lack of easy access to the hard drive. As currently designed, extracting data from the units is both time consuming and difficult. At times, extracting the recordings can take hours or more, as the current configuration has no easy port with which to make these units plug and play. This is a major need, one that is already being addressed in next generation ARUs being developed by CLO in conjunction with Wildlife Acoustics in Massachusetts. Comparison of BIN-recording ARUs with SongMeter, a potential next generation hybrid between Cornell University and Wildlife Acoustics representing advance in acoustic recording in terms of ease of use and recording. Such units would be cheaper and easier to use in DoD deployments. The BIN-recording ARU developed by CLO and the SongMeter developed by Wildlife Acoustics have many similarities. However, the SongMeter has many unique features, and CLO has been investigating hybrid units with CLO microphones (Legacy-applied microphones similar to the ones deployed since spring 2007) and SongMeter motherboards and hardware for recording. So far, tests have been impressive, and we plan to apply this device to field evaluations in 2009.



Wildlife Acoustics *Song Meter* vs Bioacoustics Research Program *Autonomous Recording Unit* (ARU) Specification Comparison Chart

Specification	Song Meter	ARU
Dimensions	rectangular 8.4"x7.1"x2.4" => 143.1 cu in.	cylindrical 9"x4.5" + 10"x3.5" => 143.1 + 96.2 = 239.3 cu in.
Weight	1.6 lbs without batteries 2.8 lbs with batteries	3 lbs without batteries 12 lbs with batteries
Enclosure	IP 66/67, NEMA-4 (weatherproof)	PVC (weather resistant)
Operating Temps	-4 to +158 deg F	+4 to +131 deg F (HDD) and 0 to +130 deg F (batteries)
Audio Specs	Stereo omnidirectional elements	Mono omnidirectional elements
Sensitivity	-35 +/- 4dB (single element)	-35 +/- 4dB (single element of 16 element array)
Frequency Response	20 Hz to 20 kHz	20 Hz to 20 kHz
Signal-to-Noise Ratio	>62dB	>62dB
Filtering	Optional 160 Hz high-pass filter low-pass filter not noted (anti-aliasing?)	Fixed 200 Hz high-pass filter 8000 Hz low-pass filter
Gain/amplification	Programmable -1.5dB to +45.0dB in 1.5dB increments per channel	15 mechanically selectable gain options (see attached sheet)
Sample rates	4, 8, 16, 22.05, 24, 32, 44.1, and 48 kHz Upwards of 99 sessions (?)	Currently 20 kHz "standard", 2 session or continuous recording options
A/D Converter Bit Depth		
Digital format	16-bit PCM (.wav)	12-bit padded & interpreted as 16-bit (.bin converted to .aif)
Storage	SD/MMC flash card slots - 2 @ 8GB = 16 GB	HDD 80 and 120 GB options; 4200rpm
Power - Internal	4, 1.5V "D" batteries (Alkaline or NiMH)	1, 3V CR2032 LiIon battery powers internal clock
Power - External	5-6V DC, 1A	2 Energizer 521, 6V "lantern" batteries (Alkaline) wired in series to provide 12V DC power; 52,000 mAh per pair in series.
Power Consumption	140 +/- 10 mA while recording < 1 mA when in "sleep" mode	127 mA while recording < 1 mA when in "sleep" mode
Recording time	79 +/- 4 hours assuming new 11,000 mAh batteries	116 to 172 hours; early termination (116) due to manual shut-down
Recording Limit		832.8 hours maximum - HDD size (120 GB) is the current limitation; external battery expansion has no limit
Future Expansion	Field upgradeable via replacement SD/MMC cards 400 MIPS DSP, 8MB SDRAM, 4MB Flash available for future signal processing apps, such as detection, classification, and compression	Field upgradeable via replacement HDD and batteries

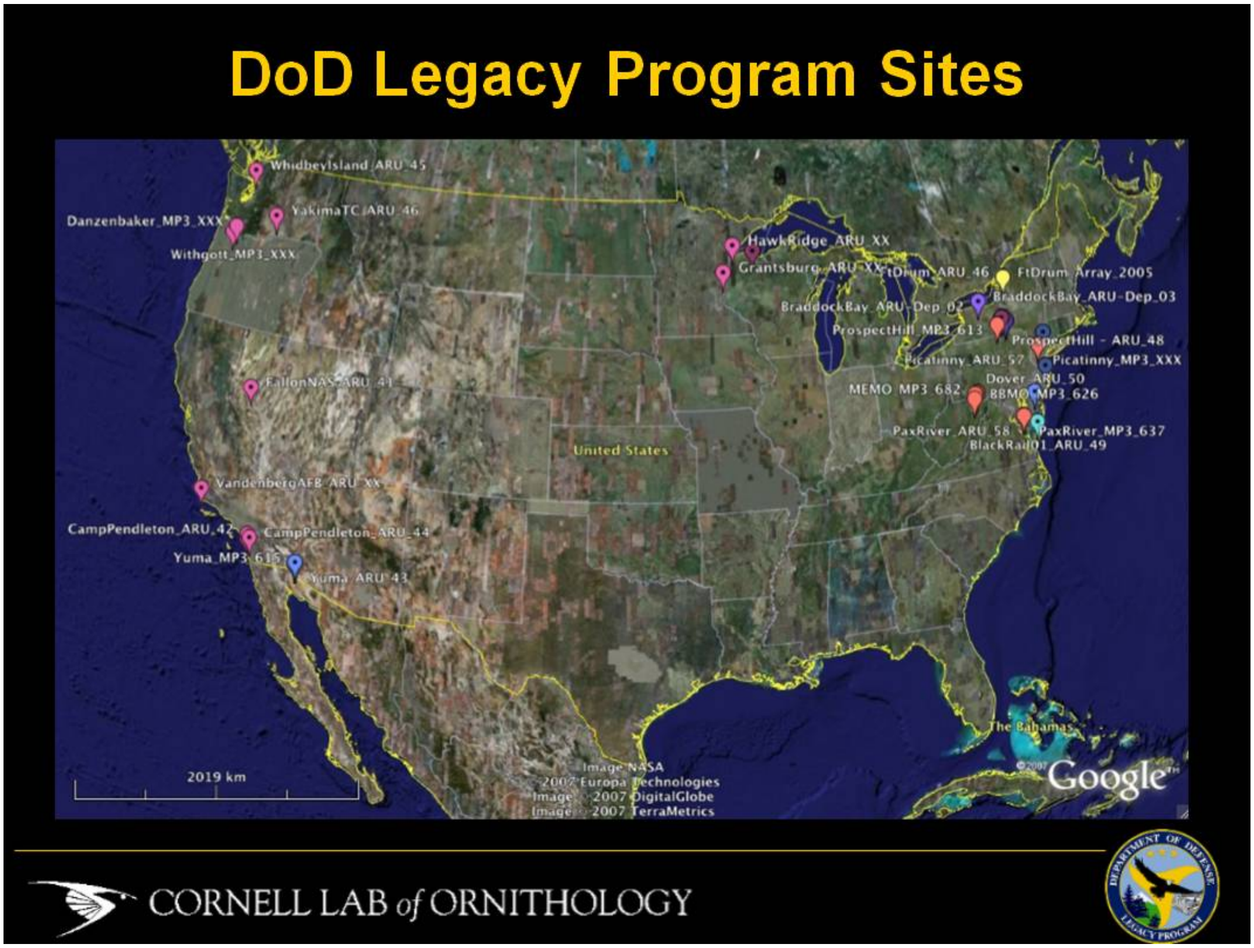
b. 2007-2008
(Stefan Hames, Mike Powers, Andrew Farnsworth, with Andrew Farnsworth becoming the lead analyst in early-2007 and assistance from Anne Klingensmith, Tom Johnson (work study undergraduate) and Lewis Grove (part time technician)

We collected over 27,000 hours of data in fall 2005 and spring 2006, and we successfully stored, processed, and initiated analysis of this information. We collected an additional 30,000 hours since Spring 2007. We identified problems and constraints we encountered in developing and applying hardware and software technologies. We indicate future areas to improve our data collection and analysis, to expand our research, and to form partnership that will further bolster the use of this technology.

We developed, tested, and implemented acoustic technologies for improved monitoring of migrant birds, both during migration and the breeding season and to assist DoD in establishing and managing a bird-monitoring database. We expanded the capacity of DoD to monitor birds by deploying acoustic and Internet technologies developed at the Cornell Lab of Ornithology (CLO). Specifically, in year-three of this study we completed the field test and evaluation of detection and classification software. We have also fostered numerous new partnerships in the end of 2007 for further work in the first 6 months of 2008 - these will include an attempt to examine detectability issues and enhancing software automation. In addition, we have begun a major investigation of thrush classification issues with the plan to develop a thrush classification algorithm by the end of 2008. During this year we:

1) tested and evaluated protocols for using digital autonomous recording units (ARUs) to enable and to improve ground-based acoustic censusing of species that vocalize infrequently and to produce acoustic datasets for observer training, in particular Black Rail (Delmarva collaborative study off DoD land) and Whip-poor-will (DoD and non-DoD sites included);
2) expanded our network of acoustic detectors to monitor flight calls of migrating species, explicitly adding recording stations into the Midwestern and western United States beginning in Spring 2007 and continuing in Fall 2007;
3) expanded analysis capabilities for large acoustic monitoring datasets by improving automated software and algorithms for extracting, processing, viewing, and analyzing acoustic data; and
4) developed web-based applications to allow DoD to collect, store, and manage sighting data on all bird species throughout the year. We have also continued to examine ARU reliability, applicability to tasks, and recording quality.

In the final months of year-three, we continued our improvement and evaluation of detection software for extracting data from digital autonomous recording units (ARUs) deployed to DoD lands in the Northeastern, mid-Atlantic, Southwestern, and Pacific regions of the country. In addition, we continued to analyze acoustic data to improve the accuracy of acoustic monitoring. In previous seasons we expanded our network of acoustic detectors to monitor flight calls of migrating species, to monitor bird migration on and around DoD installations and to analyze large acoustic monitoring datasets. In recent months we have achieved success in optimizing automatic analysis processes, improving the speed of some of these processes by over one order of magnitude from those reported in previous progress. Additionally, we successfully used template detectors to automatically extract vocalizations of a particular species of interest (Whip-poor-will) from data we collected in previous seasons. We continue to develop and to improve methods to handle our extensive datasets. We developed a web-based application to allow DoD to collect, store, and manage observational data on all bird species throughout the year.



DoD Legacy Program Sites

CORNELL LAB of ORNITHOLOGY

By fall 2007 our project was monitoring migratory and resident birds during diurnal and nocturnal periods at a diverse array of locations in the continental United States. Although focused in the Eastern United States at the project's outset, we expanded to Western site to gather additional biologically valuable information on the passage of nocturnal migrants and to qualify, at the least, species composition from a broad array of DoD installations.

At any one time in the fall 2007, we had 20 sites recording simultaneously. In advance of this deployment, we had already corrected a variety of hardware problems, including major problems with weatherproofing and microphone sensitivity. After stabilizing the hardware platform for recording and the software platform to a point at which it could be applied in a robust and efficient way, we began to analyze our increasingly large datasets. These analyses included quantifying and qualifying patterns in our recordings as well as additional substantial testing and evaluation of the software platform (XBAT first and then Raven; Raven became the primary platform by early 2008). By the summer of 2007, we had achieved functionality of energy detection diagnostics in XBAT, facilitating a leap in our abilities to extract signals of interest automatically from our recordings. Semi-regular meetings with the Bioacoustics Research Program (BRP) staff helped us implement the energy detector with increasing regularity, such that band limited energy detection became our primary tool for processing. However, though partially automated, this process included a series of time consuming steps, including: accessing data through XBAT libraries or Raven file menus; engaging energy detectors to extract flight-calls from sound streams; refining and iterating existing energy detection parameters based on results from previous runs for use with mp3 and aif data in XBAT using diagnostics and primarily by trial and error without diagnostics in Raven; and use template detectors to try to extract flight-calls from sound streams in XBAT (successfully implemented to extract WPWI data in 2008), though this feature does not exist in Raven.

We produced results including:

1) two datasets that we have analyzed at professional ornithological conferences, the American Ornithologists' Union in Laramie, Wyoming and the Western Field Ornithologists conference in Las Vegas, Nevada;

2) species lists by deployments highlighting a number of species of interest, including Bicknell's Thrush (USMA, October 2005), Black Rail (Chesapeake Bay and Delmarva deployment), Yuma Clapper Rail (Yuma, April 2007), and Whip-poor-will (Lakehurst, Spring 2006 and 2007); and

3) recordings of tens of thousands of flight-calls, including weekly totals ranging as high as 10,000 (USMA, October 2005).

In collaboration with Rich Fischer and Dr. Sidney A. Gauthreaux, we began monitoring in the Yuma area in conjunction with radar monitoring and ground-based visual surveys. Radar data was to be used to delimit important stopover areas on military installations in the vicinity and document the patterns of migration in these areas, whereas ground observation was to verify and to characterize the sites identified by radar as important hotspots and survey migrant activity along transects. The acoustic monitoring was to monitor these hotspots automatically for comparison with both radar and visual surveys. We deployed both mp3 style and BIN style ARUs at six sites in the Yuma area for one month during the spring 2007.

Each site had seven continuous transects for visual surveys that ran along the Colorado River and All-American Canal north of Yuma, and each of these transect surveys began 30 minutes after sunrise. No transect was surveyed on consecutive days. We deployed ARUs to each site, setting a pre-recorded program of recording from 1930-0600 local time, with two mp3 units recording 24 hours/day. All analysis focused on the hours between civil twilights, a standard for nocturnal migration research. We analyzed all the data in XBAT, using six band limited energy detection algorithms of 1500 Hz with signal to noise ratio 3.0, and 0.02-0.05 durations between 2-11 kHz.

We chose to analyze data to produce several basic products: 1) temporal distribution of calls (total no. calls/hour/night); 2) species list (identified calls/hour/night); 3) targeted species frequency distribution (detailed patterns of movements); and 4) patterns among sites. To produce these data, our initial protocols in 2006-2007 for generating the calls-only logs were as follow: 1) Because of the amount of data we have and the limitations of the computers, software, and personnel (all variables combined here), we chose to "high-grade" our data, using only a) mp3 data with explicit time stamps, and b) aif data from the longest recording ARU of duplicate deployments; 2) we used energy detectors exclusively in XBAT, running a detector with INBAND of 1500 Hz six different times across the 2-11 kHz frequency range in which most flight-calls occur; 3) after a log is generated, we reviewed and removed non-flight-call detections manually. After this process, we were left with a calls-only log (after copying the original log files as a backup); and 4) after a calls only log file is produced, we exported this into a folder. As of mid-2008, these protocols completely changed because of the widespread use of Raven to these tasks. Substantial work on Raven detectors, based on foundations from SERDP SI-1461, yielded some big improvements in the speed and capabilities of Raven. To produce these data from Raven, our initial protocols in 2006-2007 for generating the calls-only logs changed to what follows: 1) using only aif data from the longest recording ARU of any deployments, we expanded our server capacity and loaded sounds to a remote server where they reside for analysis; 2) we used energy detectors exclusively in Raven, running a detector with INBAND of 4500 Hz two different times across the 2-11 kHz frequency range in which most flight-calls occur; 3) Raven generated a selection table, which we reviewed and removed non-flight-call detections manually. This process was much easier than it had been in XBAT, making removal of non-flight calls and annotations possibly simultaneously. After this process, we were left with a calls-only log in Raven that we could export as a text file (We have included ALL of these on the accompanying DVDs); and 4) we imported these files into Excel, where we had created a worksheet that automatically synthesized the time, date, and identifier of the calls for generating patterns and analyses.

2. Results

a. Sound Analysis Automation

(Andrew Farnsworth, Michael Powers, Anne Klingensmith, Tim Krein, Russell Charif, Kathryn Cortopassi, Ann Warde, Michael Pitzrick)

During the three-year project, we investigated two primary forms of automated detection in the sound recordings we collected: band limited energy detection and template (matched filter) detection. We pursued several approaches to energy detection. The first was a very strict approach that would find only very high SNR calls. We chose to cast a "wider net" to try to get all calls and then reduce the number of detections by manually browsing the events. The approach is similar to that taken by the Ivory-billed Woodpecker search team in 2005-2006, in that they did not want to miss any calls. The sacrifice here is that in order to get the most possible true detections, one must comb through a large number of false positives. The woodpecker team often had to deal with large numbers of false detections, but this is a natural result of setting permissive parameters so it was expected. The three primary issues to overcome were:

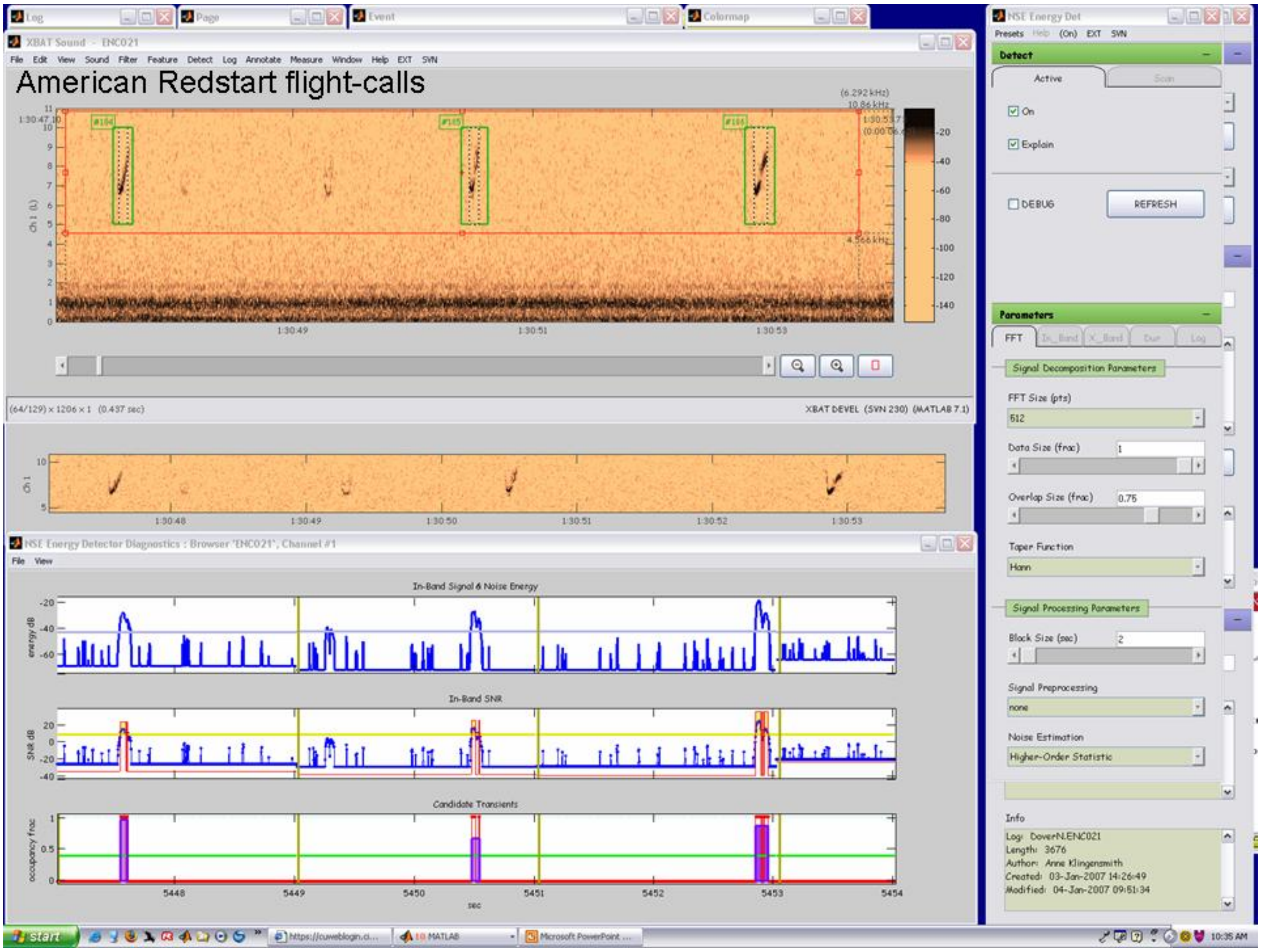
1) large log issues (which are much more easily resolvable in Raven and in the development version of XBAT);
2) number of false detections (which remains an issue of second stage filtering or second pass through the data with simple classifiers); and
3) lack of a multiband detector that can run several bandwidths at once (rather than requiring multiple, computational expensive runs).

We also applied template detection. We examined data template (matched filter) detection in numerous analyses of different species (songbirds, waterbirds, nightjars), but we did not pursue it extensively on anything more than a single species at a time because of lack of power relative to the energy detector for finding flight-calls. However, we have not had the chance to develop this to fruition, given time constraints for data analysis based on already using a specific series of energy detection protocols. Yet, the results of target species analysis using a template detector hold tremendous promise - we present an analysis of Whip-poor-will data later in this report, explicitly examining previously archived data and acquiring new data for specific application to Whip-poor-will monitoring. Along these lines, to generate these types of data, we tested and evaluated protocols for using ARUs to enable and to improve ground-based acoustic censusing of species that vocalize infrequently and to produce acoustic datasets for observer training, in particular Black Rail and Whip-poor-will; these tests lead to the deployment of ARUs to collect WPWI data on summer 2008.

In 2005, because of the plan to record with mp3 style recorders, we needed to use XBAT (see www.xbat.org), a MATLAB based sound analysis program, for all of our analysis. We applied various techniques to the analysis our library collected by that point, including applying the newly developed energy detection tool for band limited energy detection. This tool proved invaluable for speeding the process of data processing and analysis by approximately an hour of magnitude from what it took a skilled analyst to do the same processing by ear and eye. Examples of the types of visualizations and analyses we used follow, including depictions of the energy detectors, the diagnostic tools that allowed for optimization of energy detection, some sample images of what signals of interest (flight calls, for example) look like in energy detector and XBAT space, and some of the descriptions of what each of the features of the detection process mean. These diagnostic tools are useful for any level of analysts working with sound data, from the most skilled bioacoustician to a trained technician with little knowledge of bioacoustic science.

As part of our effort to try to improve the speed and efficacy of automation, we continued working to implement new and better features in our sound analysis packages. Once we made the shift to AIF files and BIN-style ARUs, we could begin to use another very powerful but even more user-friendly package, Raven (birds.cornell.edu/Raven). This package was developed as an outgrowth of the old Canary program developed at Cornell in the 1980s, and it has become a powerful and easy to use sound analysis package downloadable and licensable from the Cornell BRP site. We worked closely with the Raven development team to implement many of the features that were lacking or were less efficient in XBAT, and we did so explicitly to fill a need missing from previous problems with the SERDP SI-1461 efforts. By implementing new detectors, new abilities to handle large quantities of data, new ways to correlate signals of interest with example signals, and new visualization tools, our work with BRP developed yielded a major increase in efficiency of processing and analysis, corresponding to approximately a two-order of magnitude improvement in analysis times (150-200X faster than real time).

More recently, with the collaborations surrounding flight call classification; we have improved XBAT efficiency in similar ways, such that both platforms are now available for use in acoustic monitoring analyses. XBAT is focused toward the developer side, with less user interface and more ability to design different tools one might need; whereas Raven is geared to the end user, with easy to use and powerful interfaces that display analyses and allow for manipulation of sound and visualizations effectively.



☑ On

☑ Explain

☐ DEBUG

Signal Decomposition Parameters

FFT Size (pts): 512

Data Size (frac): 1

Overlap Size (frac): 0.75

Taper Function: Hann

Signal Processing Parameters

Block Size (sec): 2

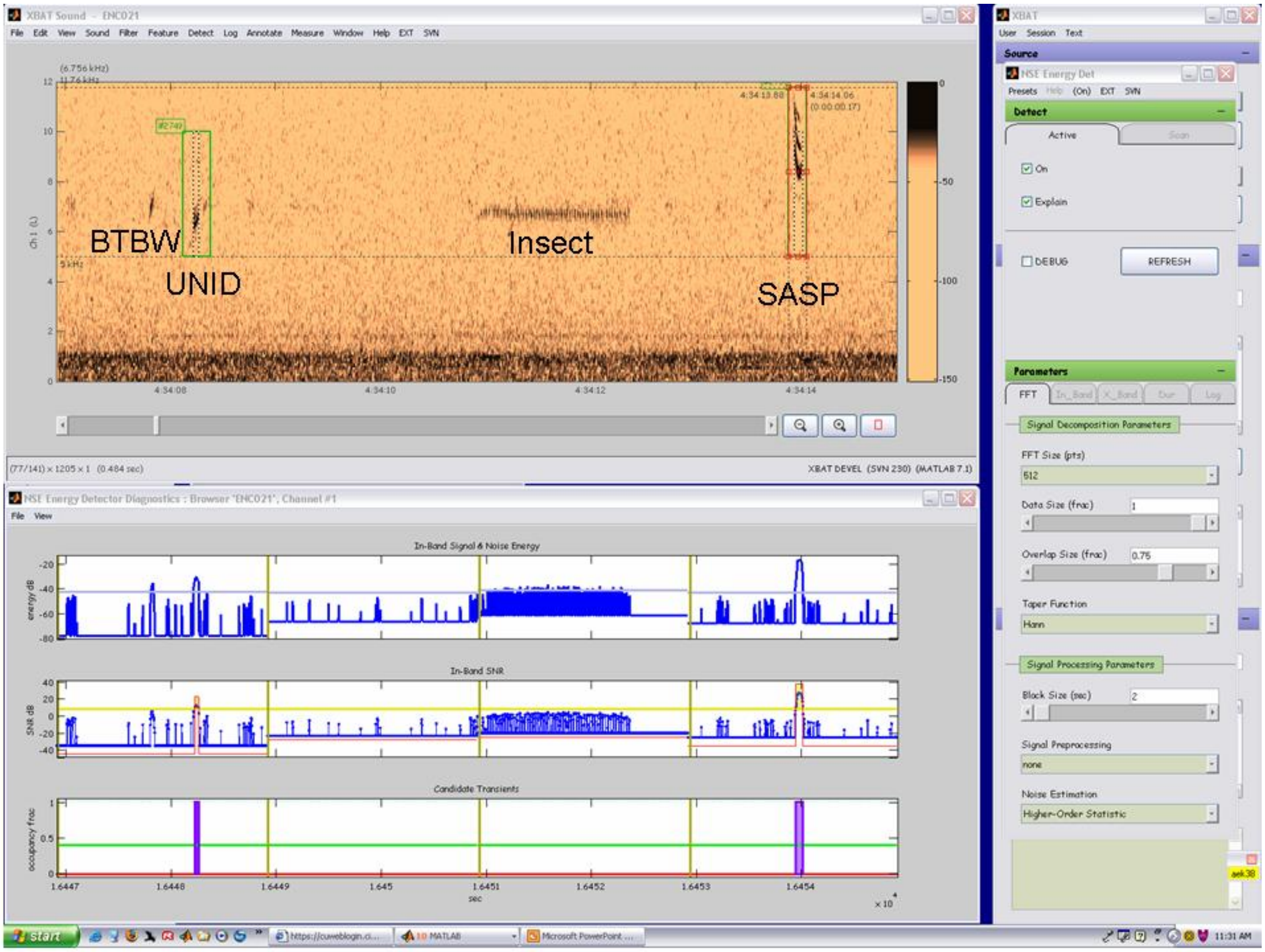
Signal Preprocessing: none

Noise Estimation: Higher-Order Statistic

Info

Log: DoverN.ENC021
Length: 3676
Author: Anne Klingensmith
Created: 03-Jan-2007 14:26:49
Modified: 04-Jan-2007 09:51:34

Figure 4a. Energy detection algorithm used on American Redstart flight-calls as seen on screen in XBAT version 0.7. Upper left, mp3 sound file spectrogram with American Redstart flight-calls highlighted as green selections indicating visually detected calls. Black and white hatching indicates energy detector detection. Below is a zoomed window of the three calls highlighted in the red box. Bottom left is the diagnostic tool showing frequency band of analysis (in-band), signal to noise ration (SNR), and candidate transients (flight-calls highlighted in purple). Right of the screen is the dialog box to set parameters of the energy detector.



☑ On

☑ Explain

☐ DEBUG

FFT Size (pts): 512

Data Size (frac): 1

Overlap Size (frac): 0.75

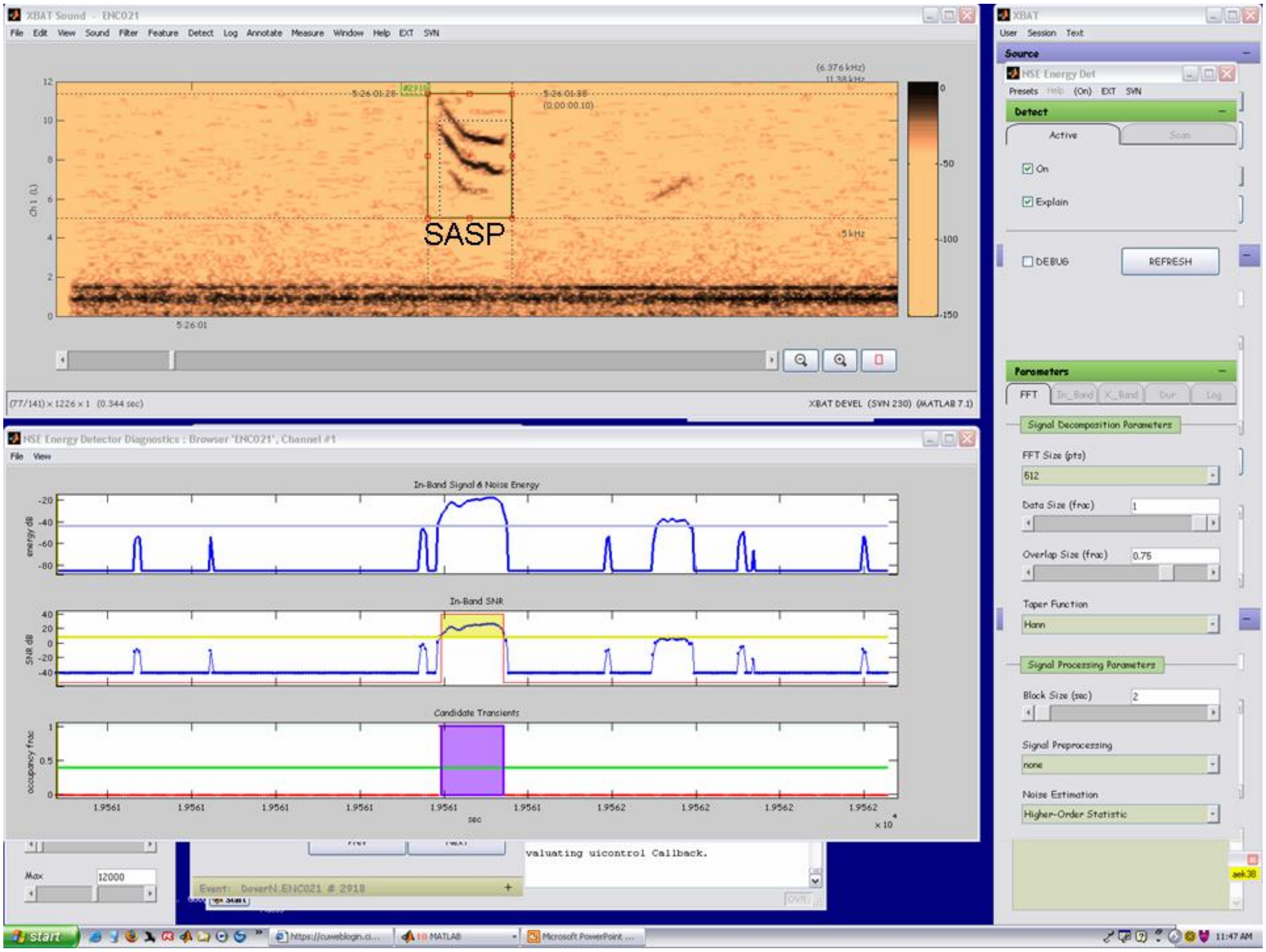
Taper Function: Hann

Block Size (sec): 2

Signal Preprocessing: none

Noise Estimation: Higher-Order Statistic

Figure 4b. Energy detection algorithm used on flight-calls and insect stridulating as seen on screen in XBAT version 0.7. Upper left, mp3 sound file spectrogram with Black-throated Blue Warbler (BTBW), unidentified flight-calls (UNID), and Savannah Sparrow (SASP) flight-calls highlighted as green selections. The additional portions of the window follow the description of Figure 4a.



(77/141) x 1226 x 1 (0.344 sec)

XBAT DEVEL (SVN 230) (MATLAB 7.1)

FFT Size (pts): 512

Data Size (frac): 1

Overlap Size (frac): 0.75

Taper Function: Hann

Block Size (sec): 2

Signal Preprocessing: none

Noise Estimation: Higher-Order Statistic

Max: 12000

valuating uicontrol Callback.

Event: DoverN.ENC021 # 2918

Figure 4c. Energy detection algorithm used on Savannah Sparrow (SASP) flight-calls as seen on screen in XBAT version 0.7. Details of the screen follow descriptions of Figure 4a and 4b.

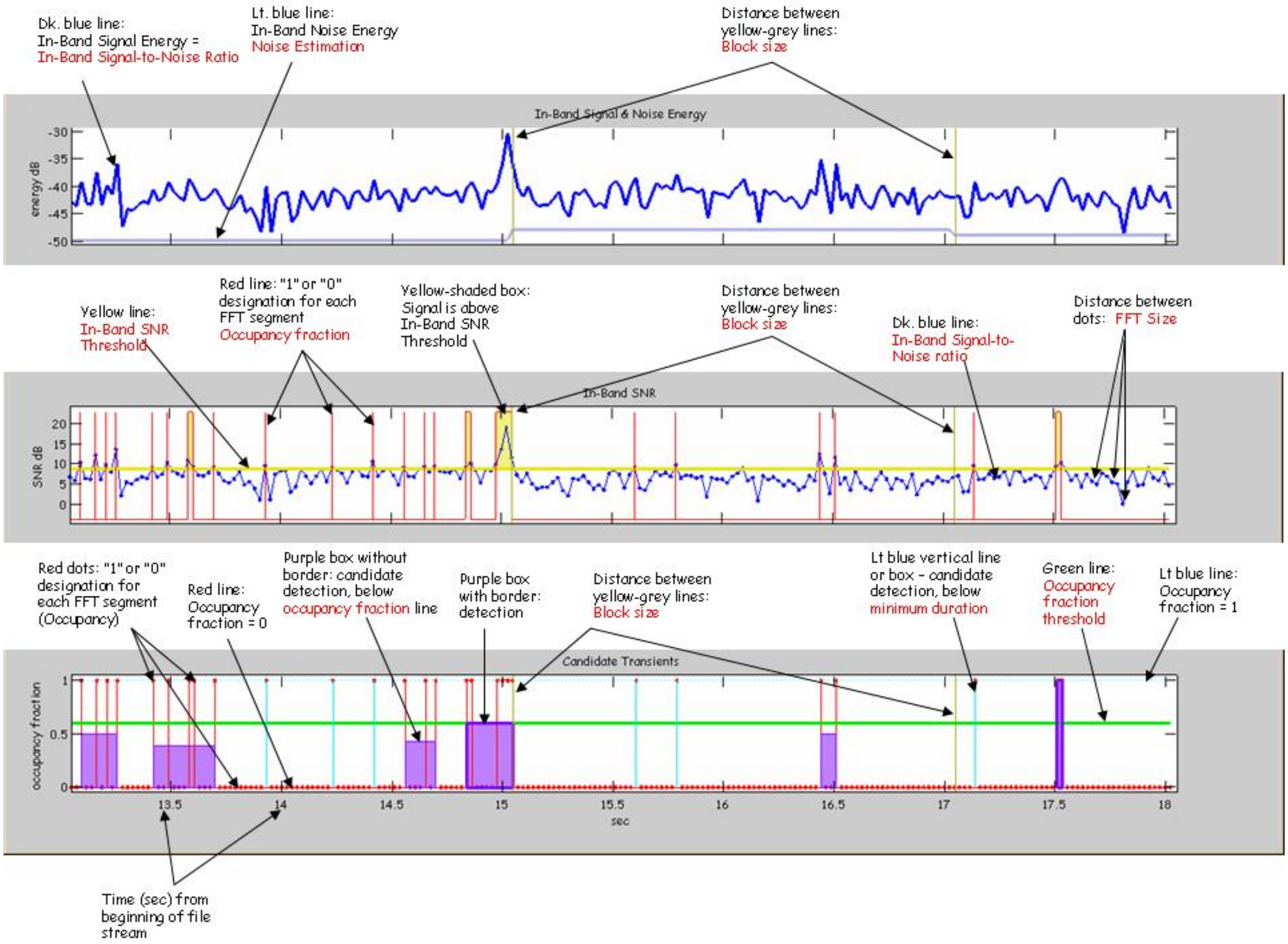
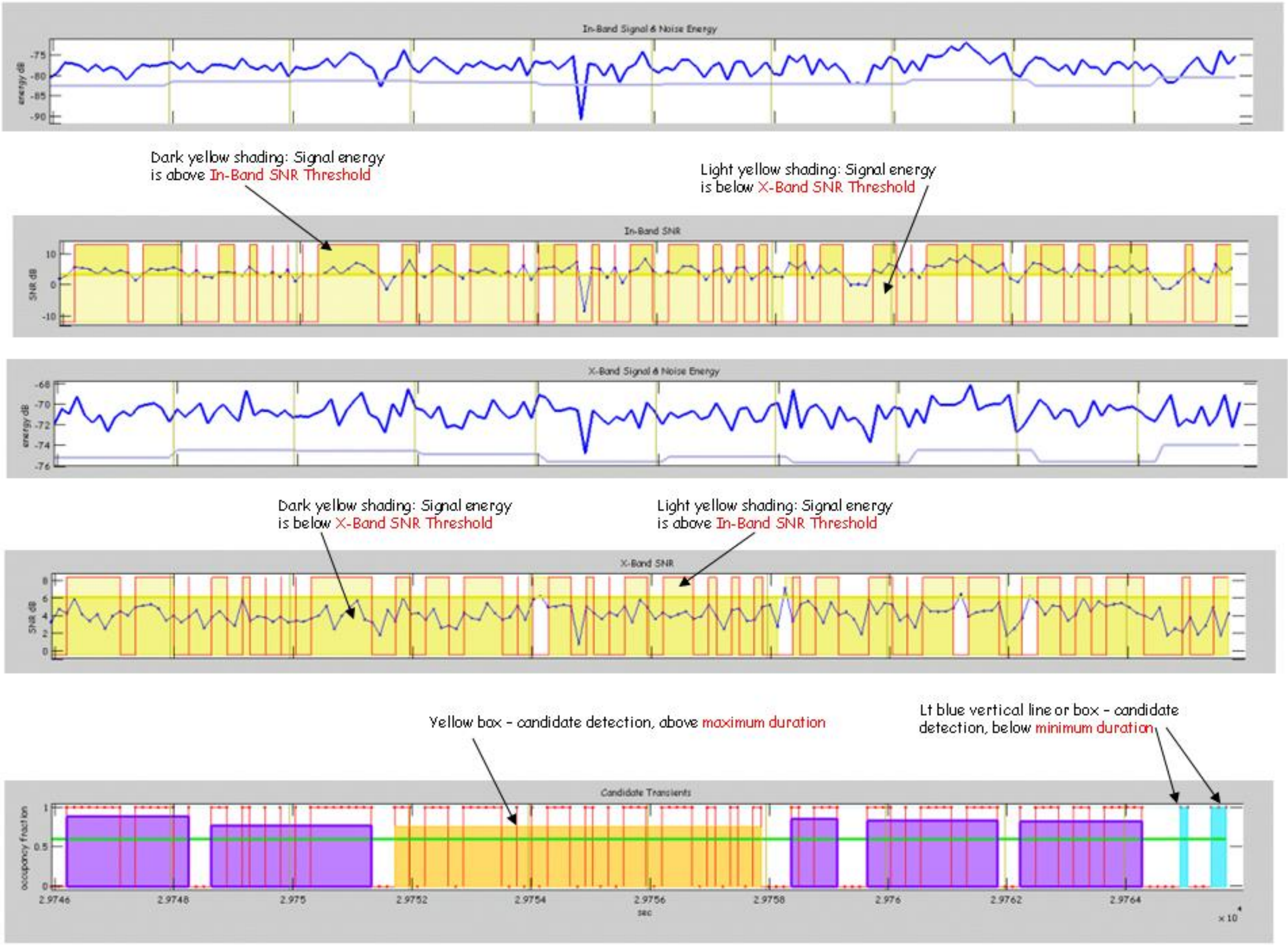


Figure 5a. Diagnostic tool definitions. Each definition represents a parameter setting in the dialog box to set energy detector algorithm settings for automated detection. Of particular importance to Legacy research are the signal to noise ratio (SNR) and duration.



Dark yellow shading: Signal energy is above In-Band SNR Threshold

Light yellow shading: Signal energy is below X-Band SNR Threshold

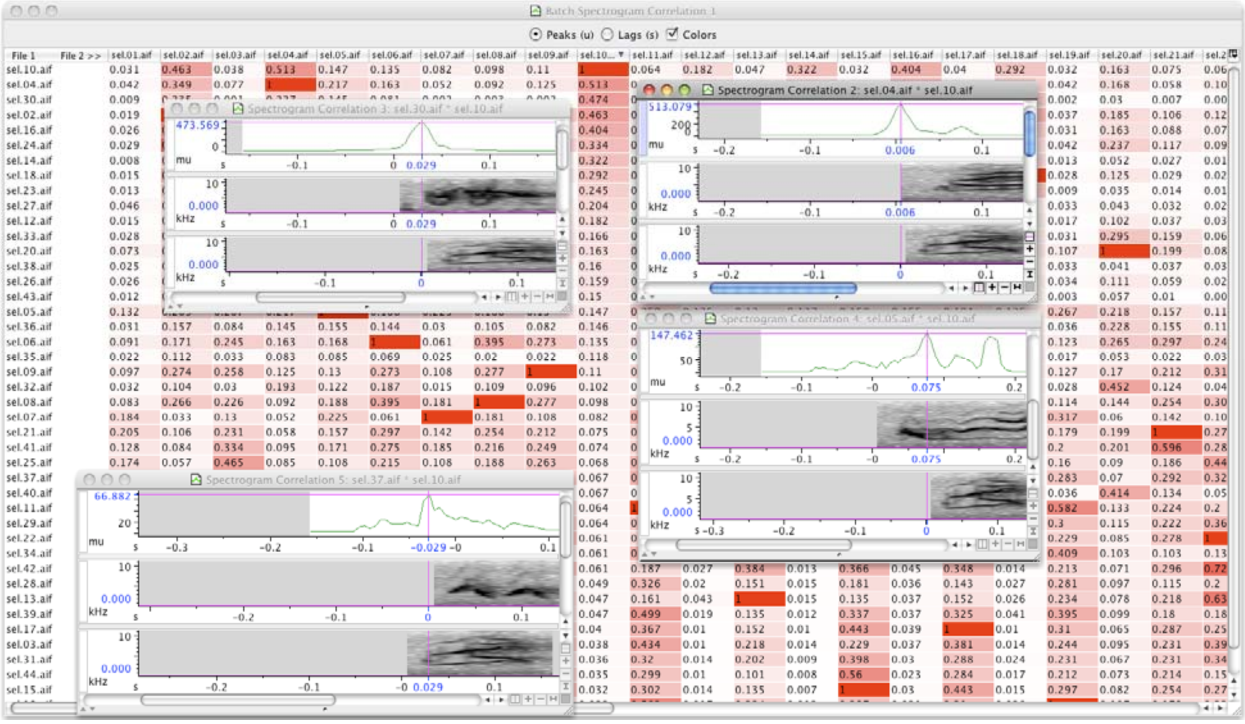
Dark yellow shading: Signal energy is below X-Band SNR Threshold

Light yellow shading: Signal energy is above In-Band SNR Threshold

Yellow box – candidate detection, above maximum duration

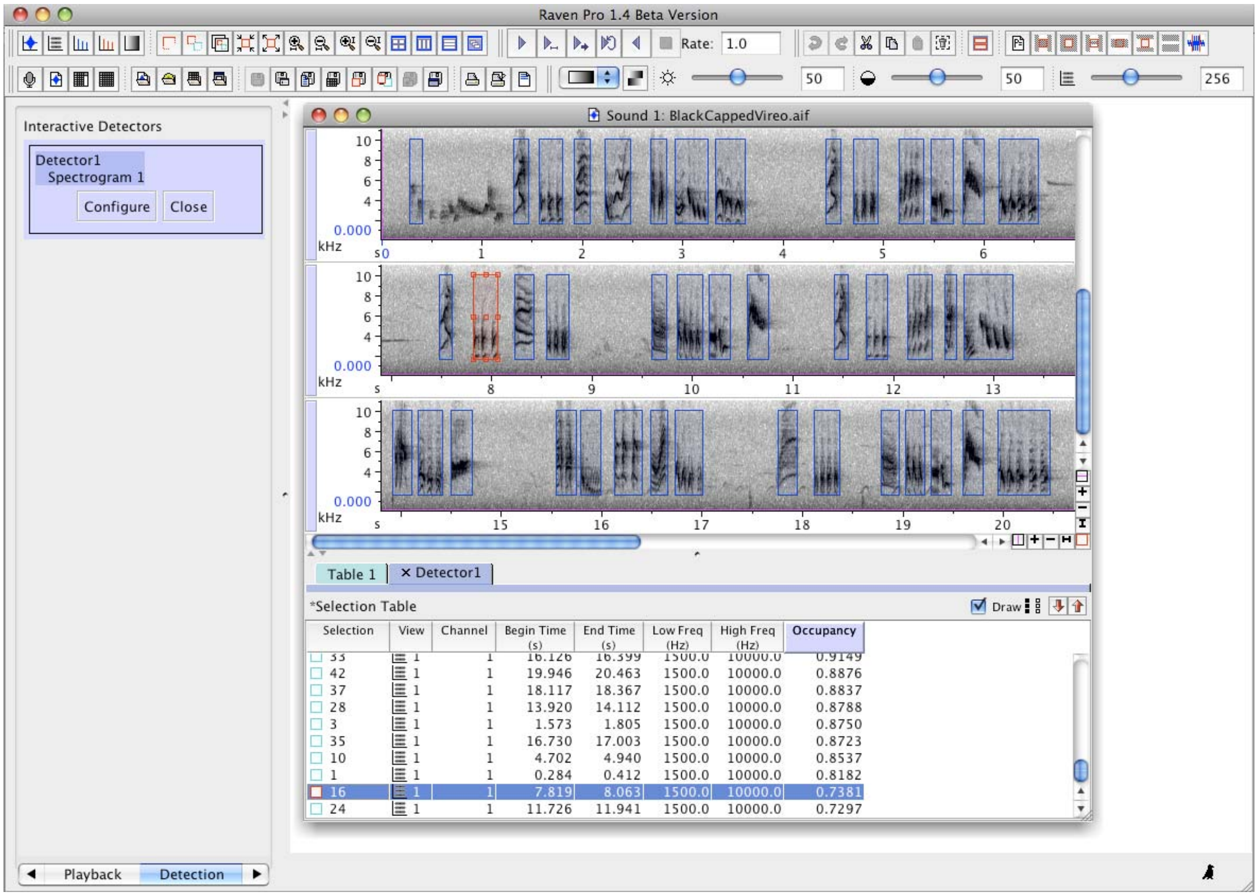
Lt blue vertical line or box – candidate detection, below minimum duration

Figure 5b. Diagnostic tool definitions. Each definition represents a parameter setting in the dialog box to set energy detector algorithm settings for automated detection; however this figure contains an exclusion band setting, which allows the user to exclude signal energy in frequency bands outside of the band of interest for detecting flight-calls.



Spectrogram Cross Correlation in Raven

When searching for calls within long recordings or comparing calls, a common technique for searching is using spectrogram correlation. In Raven Pro 1.3 and 1.4, the Raven developers have added and refined the ability to correlate signals against one another in both waveforms (time series) and spectrograms (time/frequency analysis). The ability to compare individual signals is important because it gives users more power in their ability to classify sounds. Two sounds with a high correlation value are similar in shape, duration, and bandwidth so they should be further analyzed for the possibility that they were made by the same species. Features added to Raven Pro 1.4 include the ability to sort the columns of a batch correlation table to look at the sounds that most highly correlate with a given sound. The correlation cells are also color-coded to allow users to easily identify high values. In the accompanying figure, the column for sel.10.aif is sorted from high to low values. The top row is the autocorrelation of the sound against itself. In row 2 is a correlation of sel.04.aif against sel.10.aif. The correlation value of 0.513 is also shown in the individual correlation plot to the right of the column. The other three windows in the figure show several correlation plots from the same column to show Raven's ability to show multiple plots and their relationships to each other.

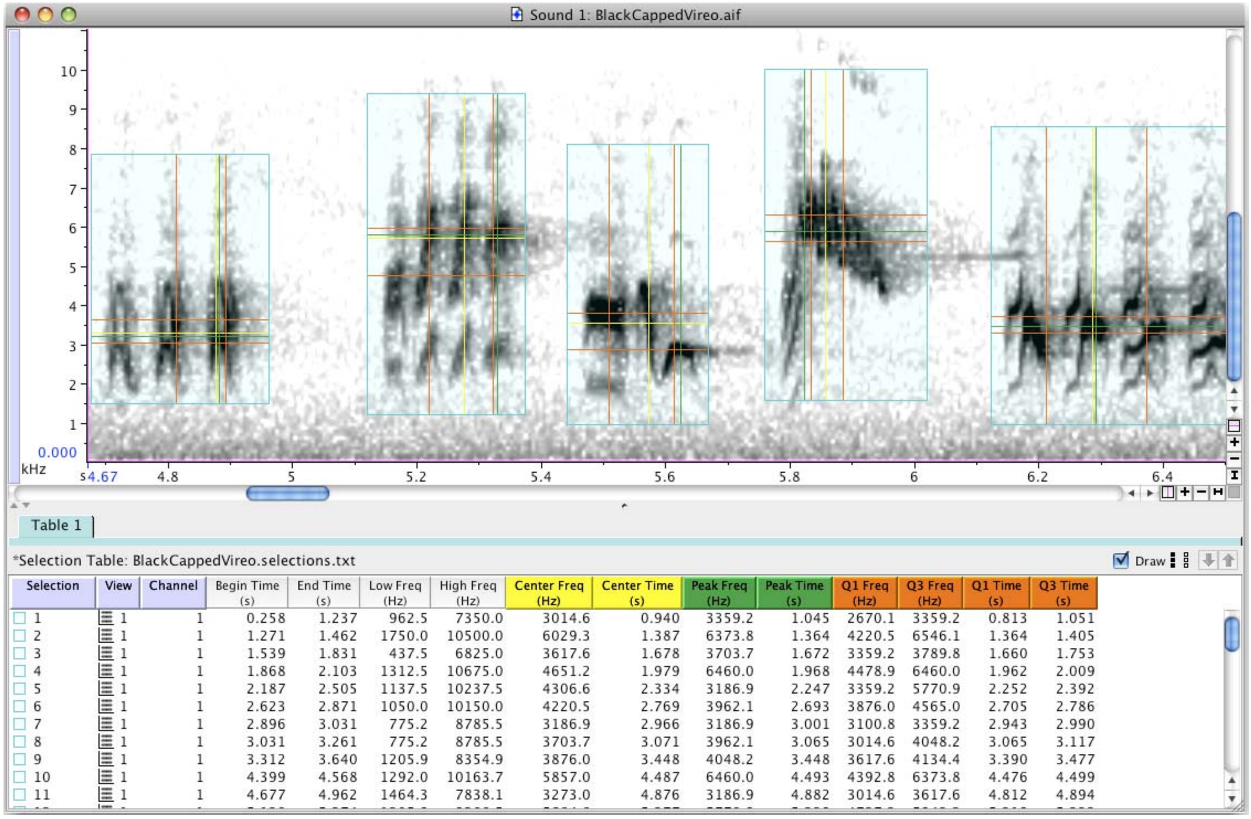


*Selection Table

Selection	View	Channel	Begin Time (s)	End Time (s)	Low Freq (Hz)	High Freq (Hz)	Occupancy
☐ 33	1	1	16.126	16.399	1500.0	10000.0	0.9149
☐ 42	1	1	19.946	20.463	1500.0	10000.0	0.8876
☐ 37	1	1	18.117	18.367	1500.0	10000.0	0.8837
☐ 28	1	1	13.920	14.112	1500.0	10000.0	0.8788
☐ 3	1	1	1.573	1.805	1500.0	10000.0	0.8750
☐ 35	1	1	16.730	17.003	1500.0	10000.0	0.8723
☐ 10	1	1	4.702	4.940	1500.0	10000.0	0.8537
☐ 1	1	1	0.284	0.412	1500.0	10000.0	0.8182
☐ 16	1	1	7.819	8.063	1500.0	10000.0	0.7381
☐ 24	1	1	11.726	11.941	1500.0	10000.0	0.7297

Energy Detection in Raven

The introduction of automatic detection in Raven has led to many advances on the Legacy project. Raven developers made significant breakthroughs in performance and usability starting in December 2007 that allowed the Legacy analysis to move forward in ways that it was unable to previously. Detection runs could now produce output tables with several hundred thousand to over a million detections. Additional tools were created for splitting and consolidating these tables so that analysts could work with the data in a more flexible way. New techniques were introduced within the detector to explore the data by using measurements to classify calls as possible flight calls or not. Shown in the accompanying figure is a detector run that returns the occupancy, or detector score, for each detection. By sorting this column of values, analysts can make decisions about how to set parameters in future detector runs.



*Selection Table: BlackCappedVireo.selections.txt

Selection	View	Channel	Begin Time (s)	End Time (s)	Low Freq (Hz)	High Freq (Hz)	Center Freq (Hz)	Center Time (s)	Peak Freq (Hz)	Peak Time (s)	Q1 Freq (Hz)	Q3 Freq (Hz)	Q1 Time (s)	Q3 Time (s)
☐ 1	1	1	0.258	1.237	962.5	7350.0	3014.6	0.940	3359.2	1.045	2670.1	3359.2	0.813	1.051
☐ 2	1	1	1.271	1.462	1750.0	10500.0	6029.3	1.387	6373.8	1.364	4220.5	6546.1	1.364	1.405
☐ 3	1	1	1.539	1.831	437.5	6825.0	3617.6	1.678	3703.7	1.672	3359.2	3789.8	1.660	1.753
☐ 4	1	1	1.868	2.103	1312.5	10675.0	4651.2	1.979	6460.0	1.968	4478.9	6460.0	1.962	2.009
☐ 5	1	1	2.187	2.505	1137.5	10237.5	4306.6	2.334	3186.9	2.247	3359.2	5770.9	2.252	2.392
☐ 6	1	1	2.623	2.871	1050.0	10150.0	4220.5	2.769	3962.1	2.693	3876.0	4565.0	2.705	2.786
☐ 7	1	1	2.896	3.031	775.2	8785.5	3186.9	2.966	3186.9	3.001	3100.8	3359.2	2.943	2.990
☐ 8	1	1	3.031	3.261	775.2	8785.5	3703.7	3.071	3962.1	3.065	3014.6	4048.2	3.065	3.117
☐ 9	1	1	3.312	3.640	1205.9	8354.9	3876.0	3.448	4048.2	3.448	3617.6	4134.4	3.390	3.477
☐ 10	1	1	4.399	4.568	1292.0	10163.7	5857.0	4.487	6460.0	4.493	4392.8	6373.8	4.476	4.499
☐ 11	1	1	4.677	4.962	1464.3	7838.1	3273.0	4.876	3186.9	4.882	3014.6	3617.6	4.812	4.894

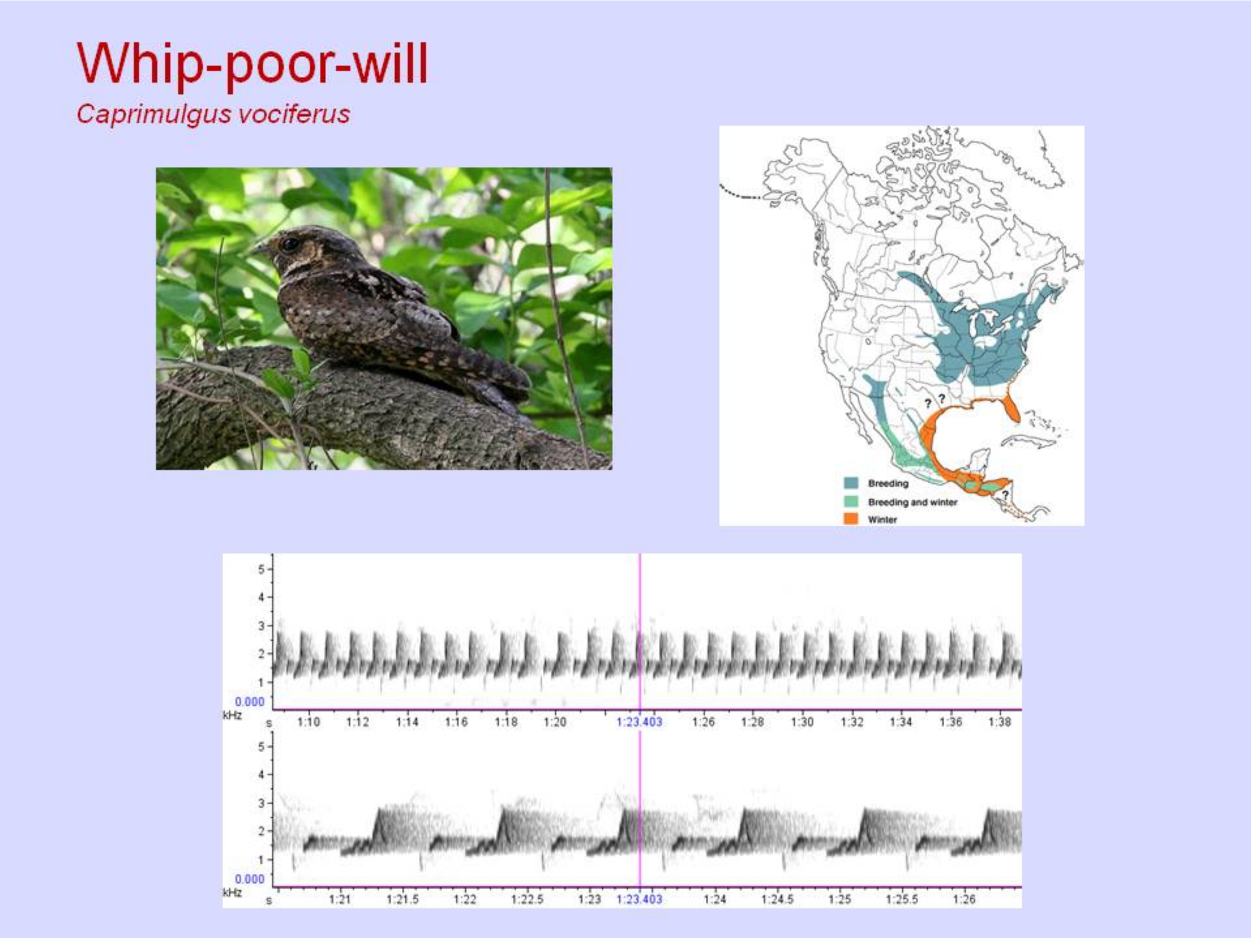
Measurement plotting in Raven

The recent introduction of plottable measurements to Raven opens new doors to analysis. Users have been able to quantify sound characteristics in the past with Raven, but with the ability to see the measurement plots on the signal views, users can gain new insights into ways to classify calls to species. The Raven development team has been receptive to discussions of possible new measurements to add to Raven as well as usability recommendations from the Legacy analysts.

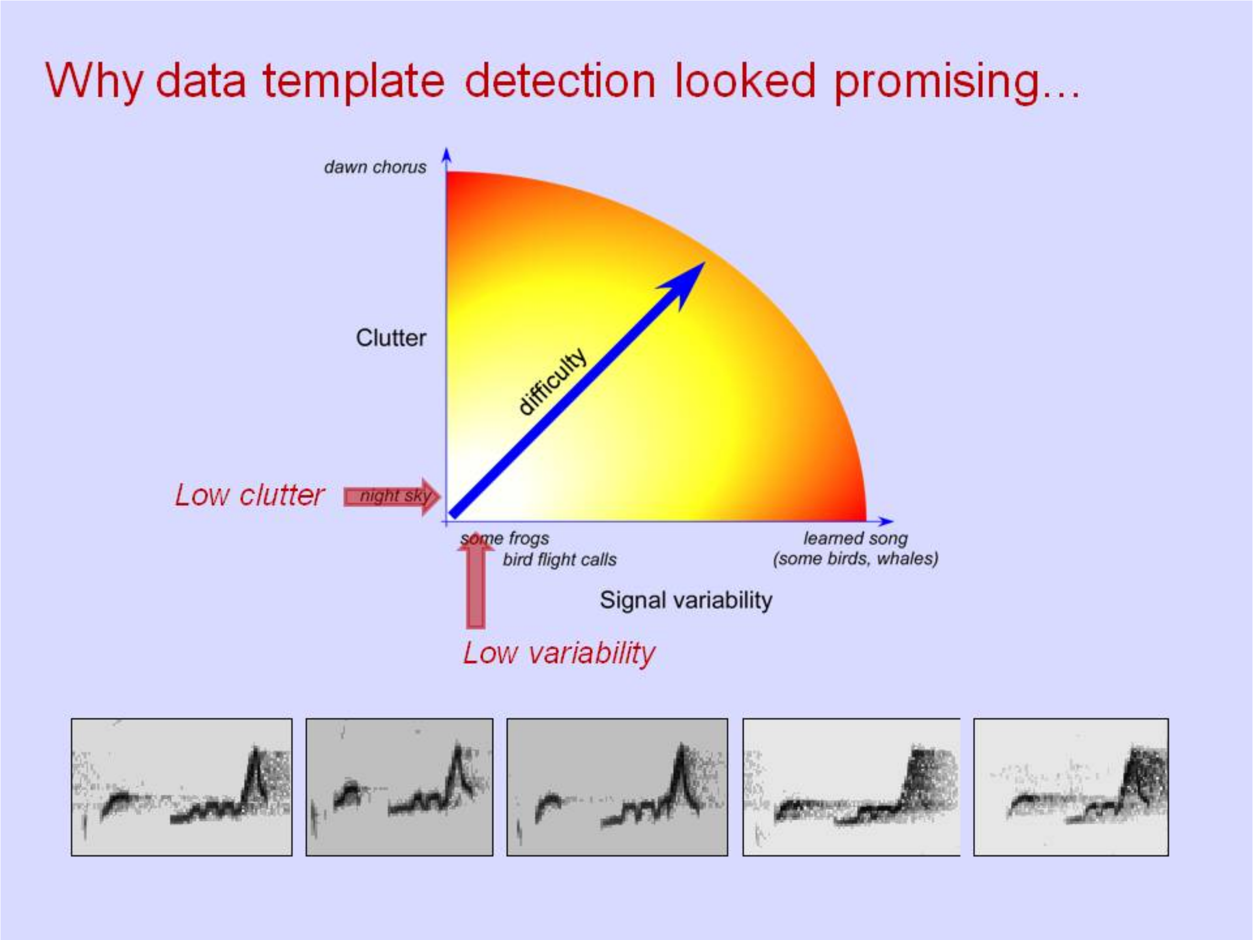
Whip-poor-will recording (Andrew Farnsworth, Russell Charif, Michael Pitzrick)

Whip-poor-will is a vociferous nocturnal caller, occurring in many parts of the eastern US and southern Canada. This species is generally elusive, being one of the least studied members of the North American nightjar family and avifauna in general. In fact, much biology for this species remains poorly known or even unstudied. However, widespread declines have been reported in the species, and despite challenges in estimating populations, many ornithologists and field observers agree that this species in declining across its range. Current Whip-poor-will (WPWI) survey protocols involve surveys performed by observers that listen only during the two-week period centered on the full moon phase, assuming that WPWI calling behavior will exhibit the highest calling rates during this period of time. Generally, observers listen at a given site for six-minute periods, and then move to another site, to determine the presence of this species. We applied acoustic monitoring to this protocol, deploying ARUs a single sites for multi-week periods and deploying "roving" units that recorded at a different site each night and moved as the observer saw fit to deploy the units. We ran these units in coordination with Chris Dobony and Ray Rainbolt at Ft Drum and Nightbird Monitoring Group of the Northeastern Partners in Flight group. We wanted to test the effectiveness of the data template detector for detecting WPWI songs, and in doing soon we sought to obtain quantitative description of WPWI calling behavior relative to lunar illumination, time of night, and season. Our goal was to apply what we learned here to informing protocols for field observers trying to monitor populations of this species and to suggest that protocols for DoD installations seeking to monitor target species would be well served in terms of efficiency, efficacy, and repeatability to pursue these acoustic methods. We also sought to develop protocols for automated acoustic monitoring designed to enhance and to replace the current observer based monitoring schemes.

We recorded civil twilight to civil twilight periods at six northeastern DoD installations with the units deployed to monitor nocturnal migration. We focused on Ft Drum, a known center of abundance for this species, analyzing portions of the 45-night recordings centered around the full moon using a data template detector with five WPWI templates selected from the Macaulay Library's archives. We hand browsed 400 random 60-second pages (screens) and scored for the presence/absence of WPWI sounds. This yielded a ground-truthed log against which we could compare the results of the template detector, quantifying its performance using various threshold of template correlation by comparison with the standard, hand browsed log. We also examined vocalization rates as a function of time of sunrise and sunset, lunar phase, lunar altitude, and lunar illumination.

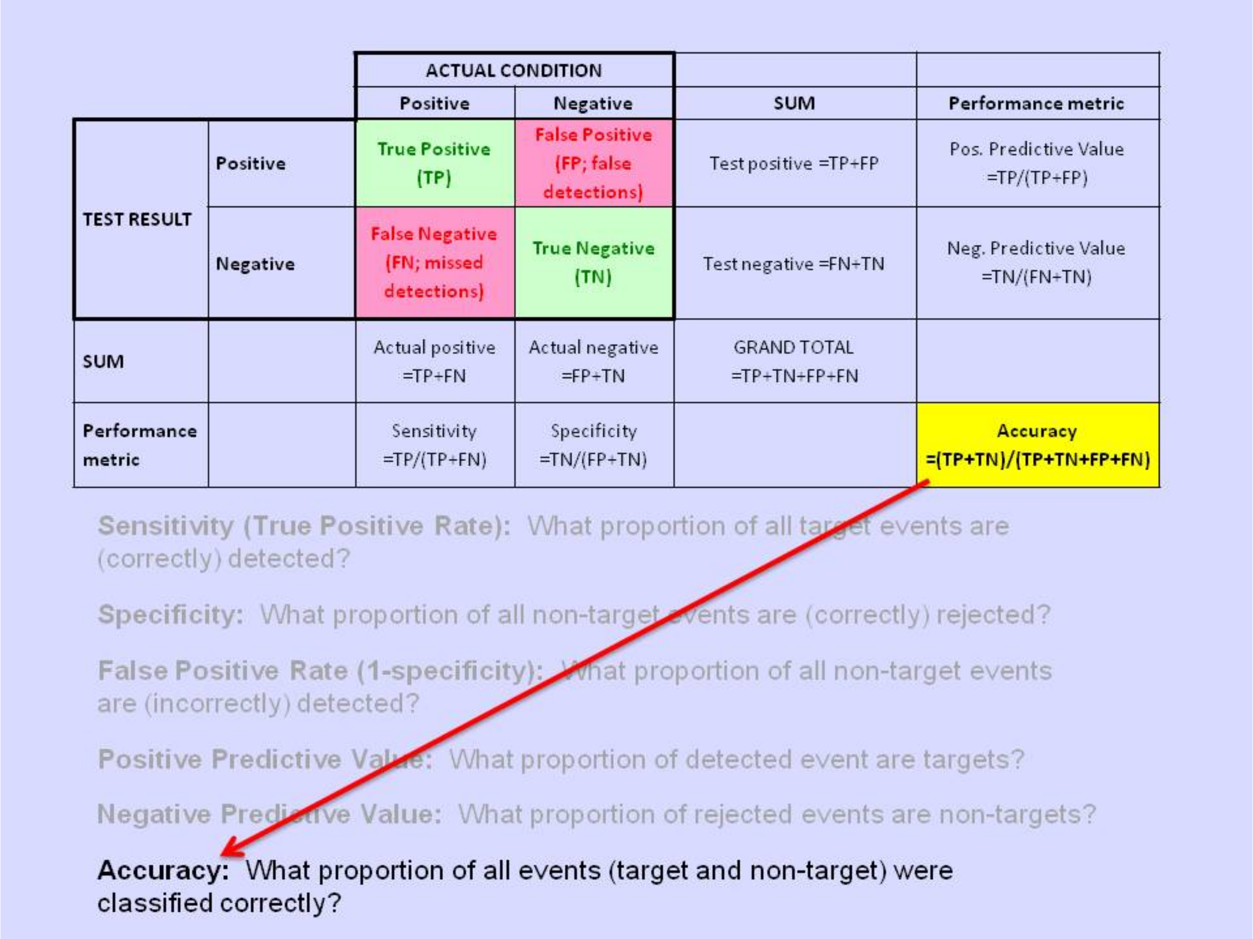


Whip-poor-will is a vocal nightjar that breeds primarily in Eastern North America. The vocalization is distinctive and loud, and phrases generally vary little across the species. These features make template detection an ideal approach for automatically monitoring the species. Additionally, widespread declines have occurred in many areas of its distribution.



Why data template detection looked promising…

Whip-poor-will is a perfect candidate for data template detection. A loud singer producing a song that is largely invariant at a time when external competition from interfering sounds is low is an excellent time to apply template detection. Based on these characteristics, we are confident that a number of species of concern could be monitoring using exactly this approach, including Spotted Owl and Greater Sage-Grouse. Targeted application of this detection strategy does not have near the false detection problem that permissive, band limited energy detection has, negating the need for effort spent to remove non-target signals of interest.



		ACTUAL CONDITION			
		Positive	Negative	SUM	Performance metric
TEST RESULT	Positive	True Positive (TP)	False Positive (FP; false detections)	Test positive =TP+FP	Pos. Predictive Value =TP/(TP+FP)
	Negative	False Negative (FN; missed detections)	True Negative (TN)	Test negative =FN+TN	Neg. Predictive Value =TN/(FN+TN)
SUM		Actual positive =TP+FN	Actual negative =FP+TN	GRAND TOTAL =TP+TN+FP+FN	
Performance metric		Sensitivity =TP/(TP+FN)	Specificity =TN/(FP+TN)		Accuracy =(TP+TN)/(TP+TN+FP+FN)

Sensitivity (True Positive Rate): What proportion of all target events are (correctly) detected?

Specificity: What proportion of all non-target events are (correctly) rejected?

False Positive Rate (1-specificity): What proportion of all non-target events are (incorrectly) detected?

Positive Predictive Value: What proportion of detected event are targets?

Negative Predictive Value: What proportion of rejected events are non-targets?

Accuracy: What proportion of all events (target and non-target) were classified correctly?

There are several ways to evaluate the performance of a detector, and we use all of these performance metrics to describe different features of the detector's behavior.

b. Sample data

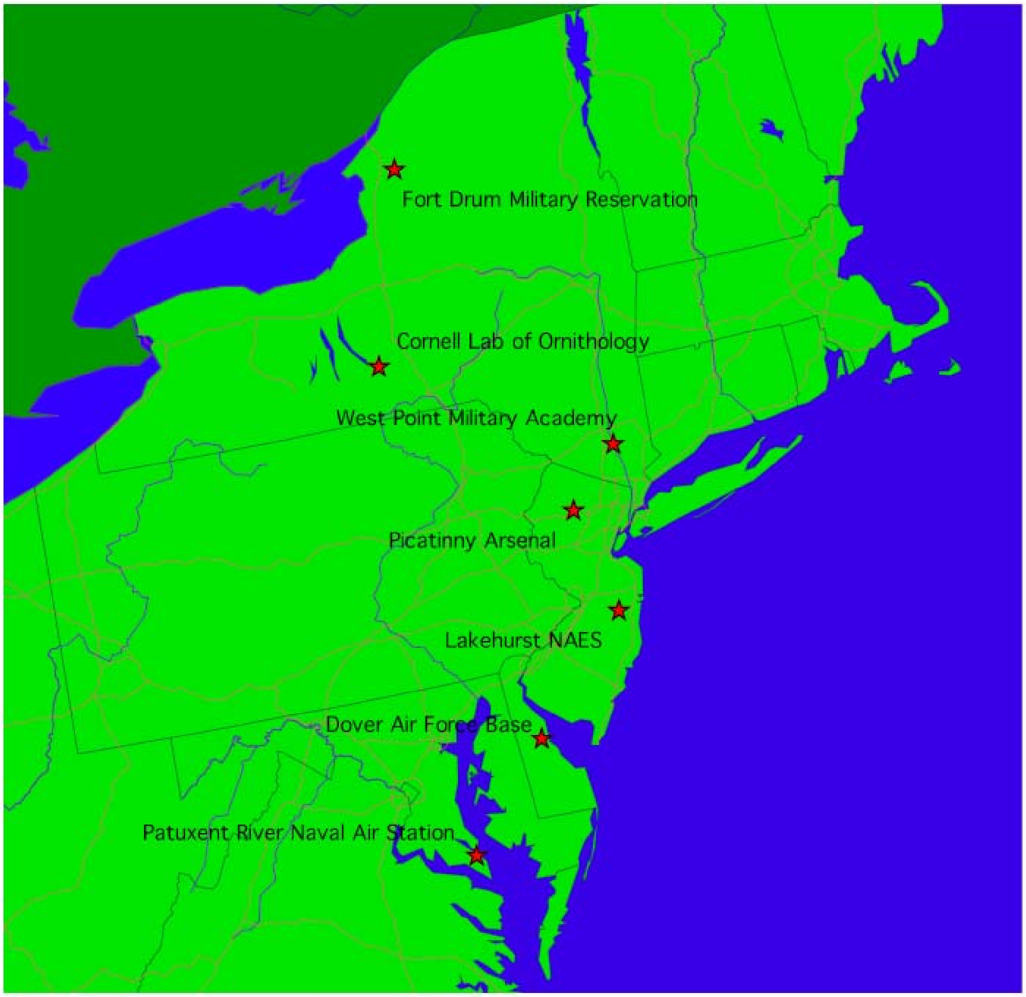
Given the volumes of data we have collected, we have summarized briefly the types of information available to DoD installations based on the automated acoustic monitoring over the past three years. We have archived nearly 60,000 hours of data during the duration of this project, recording at least 210 species (and counting) using automated acoustic monitoring methods on DoD lands. The summary of these species and their recording locations is presented in the accompanying spreadsheet. Highlights of this species list included the occurrence of some Federal - listed bird species on DoD installations, as determined by diurnal and nocturnal acoustic sampling. We highlight a few of these below:

ENDANGERED SPECIES
Black Rail *Laterallus jamaicensis*
"Yuma" Clapper Rail *Rallus longirostris yumanensis*
"Southwestern" Willow Flycatcher *Empidonax traillii extimus*

THREATENED SPECIES
Pied-billed Grebe *Podilymbus podiceps*
Least Bittern *Ixobrychus exilis*
Upland Sandpiper *Bartramia longicauda*
Henslow's Sparrow *Ammodramus henslowii*

SPECIES OF SPECIAL CONCERN
American Bittern *Botaurus lentiginosus*
Red-shouldered Hawk *Buteo lineatus*
Common Nighthawk *Chordeiles minor*
Whip-poor-will *Caprimulgus vociferus*
Red-headed Woodpecker *Melanerpes erythrocephalus*
Horned Lark *Eremophila alpestris*
Bicknell's Thrush *Catharus bicknelli*
Vesper Sparrow *Pooecetes gramineus*
Grasshopper Sparrow *Ammodramus savannarum*

In an effort to examine what types of products we would produce once automated software is fully developed, we quantified the temporal pattern of the number of calls per hour on 8 October 2005 as recorded by an ARU at Dover AFB in Delaware (Figure 2a) and summarized the species composition (Figure 3). We also quantified the pattern of calls per hour without Savannah Sparrow, a species that winters regularly in the area of the sample dataset and likely on DoD land, thus correcting for the presence of possible bias generated by a non-migrating, wintering species (Figures 2b, 3). This temporal pattern is typical of both anecdotal reports of temporal patterns as well as published accounts (Ball 1952, Graber and Cochran 1960, Evans and Mellinger 1999, Evans and Rosenberg 2000, Farnsworth et al. 2004, Farnsworth 2005).



2005 Locations of Autonomous Recording Unit (ARU) arrays for monitoring nocturnal flight-calls and documenting use of airspace above DoD installations in the Northeastern United States by migrating songbirds. In the future ARU arrays will likely aid in documenting use of habitat within the installations for migratory stopovers.

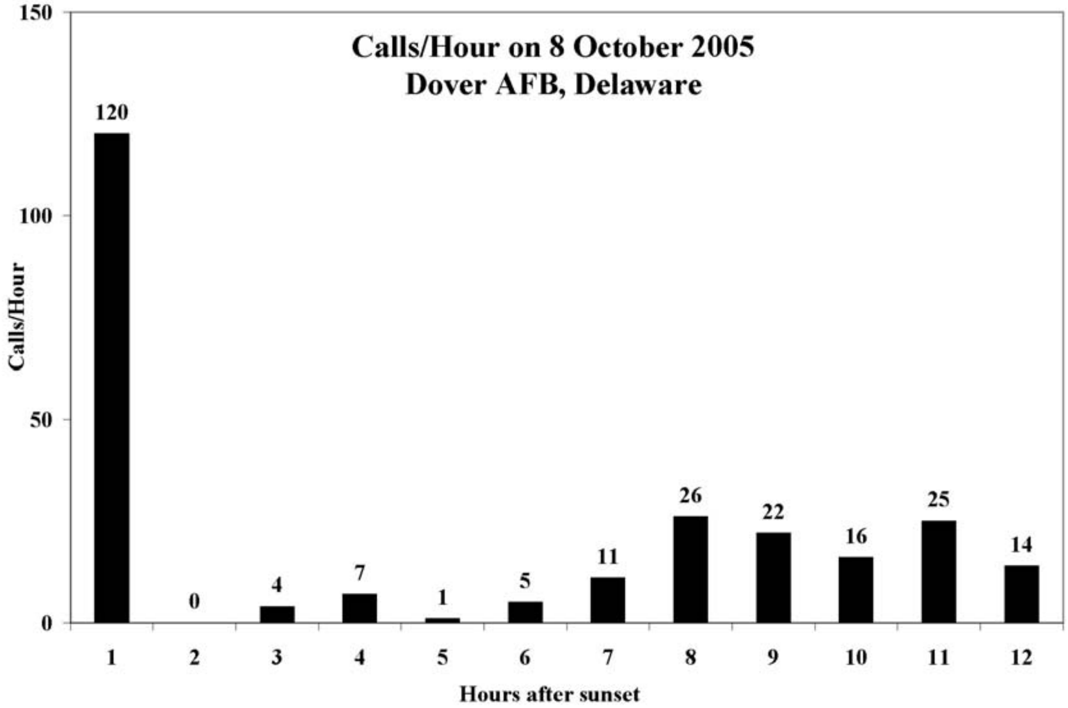


Figure 2a. Calls per hour at Dover AFB, Delaware on the night of 8 October 2005. Note the high call count for the first our after sunset. This represents Savannah Sparrows, and these flight-calls may represent non-migrant individuals, and as such these calls bias the temporal pattern in a substantial way.

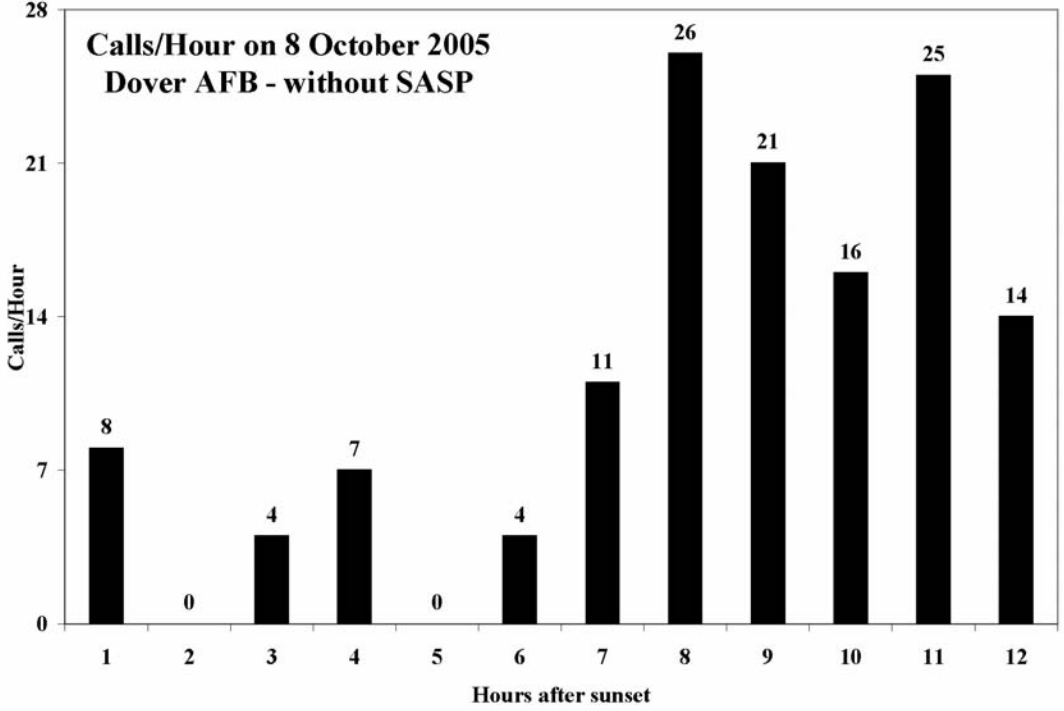


Figure 2b. Calls per hour at Dover AFB, Delaware on the night of 8 October 2005, without Savannah Sparrow flight-calls (SASP). Note the pattern of higher call counts closer to dawn, also observed in anecdotal accounts of flight-call temporal patterns and published accounts.

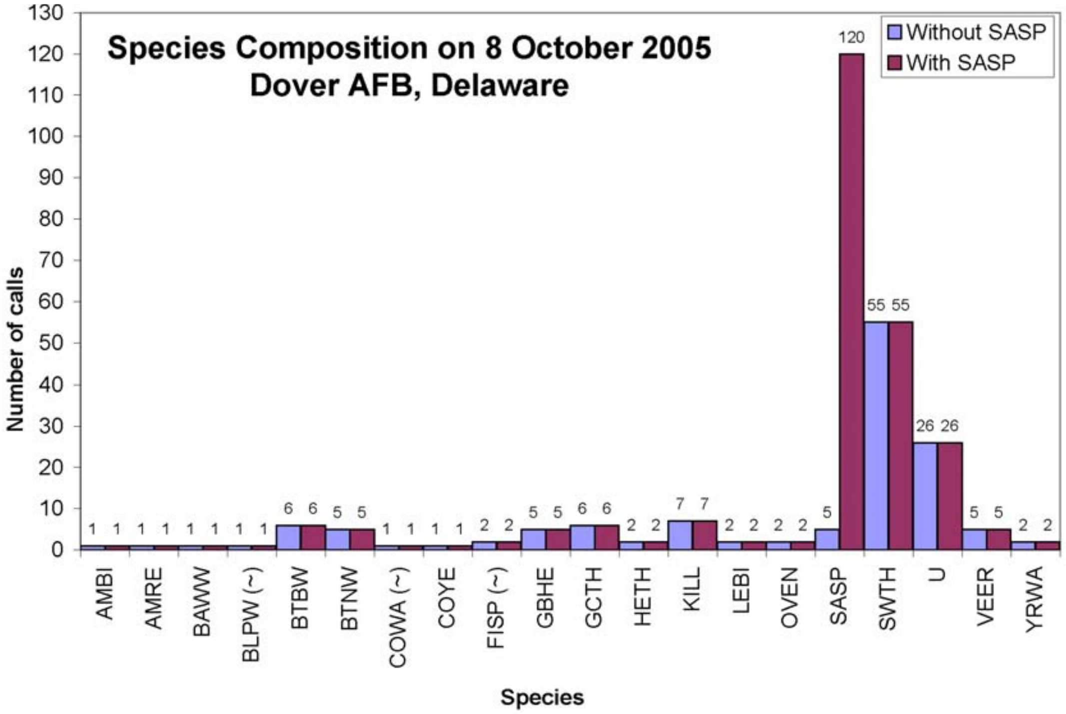
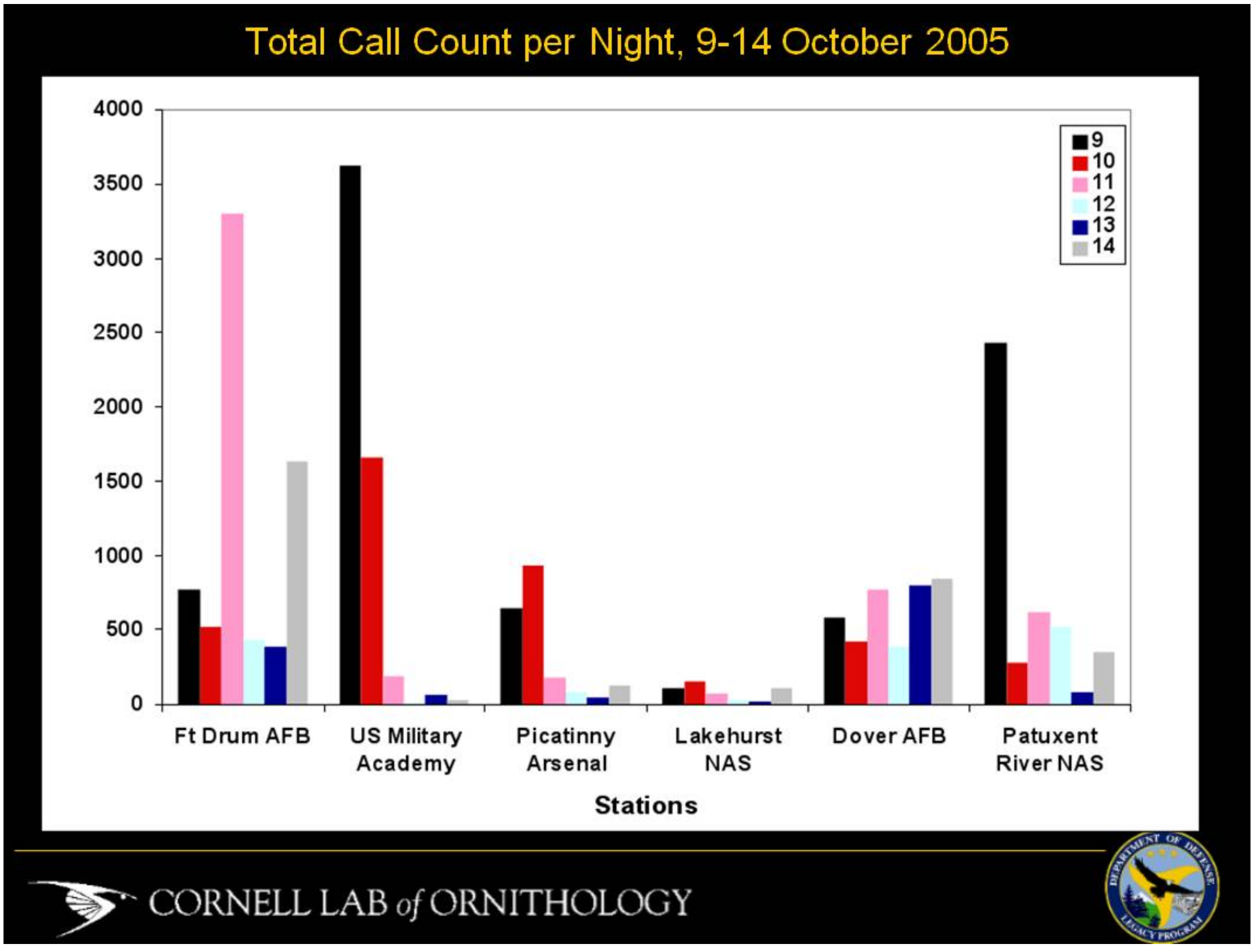


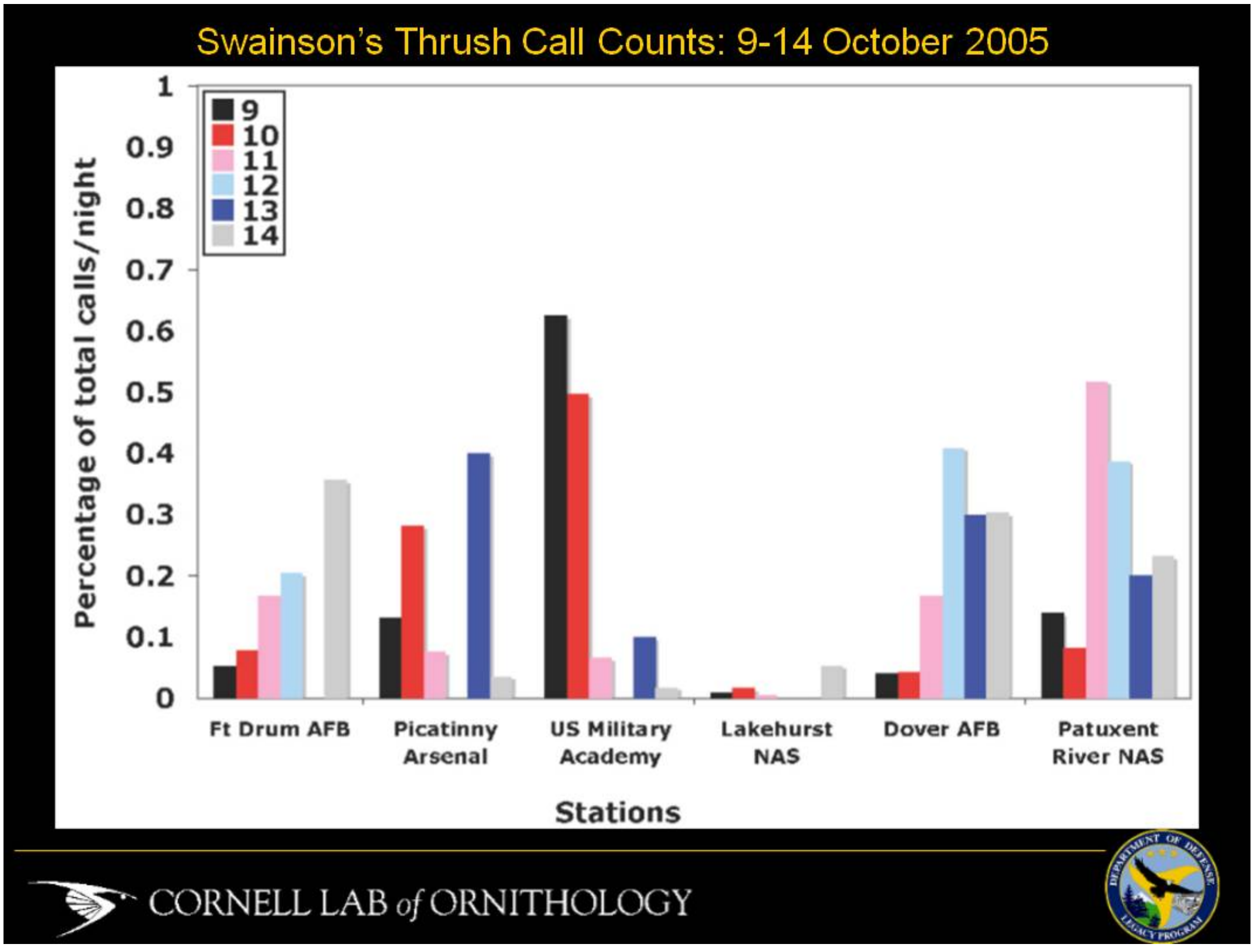
Figure 3. Species composition at Dover AFB, Delaware on the night of 8 October 2005. Note that Savannah Sparrow (SASP) composes a large portion of the total calls. These calls may represent non-migrant birds, hence the representation of "Without SASP" for comparison to represent a potentially less biased examination of the species composition of vocal migrants on this evening. Species abbreviation are: AMBI American Bittern, AMRE American Redstart, BAWW Black-and-white Warbler, BLPW Blackpoll Warbler, BTBW Black-throated Blue Warbler, BTNW Black-throated Green Warbler, COWA Connecticut Warbler, FISP Field Sparrow, GBHE Great Blue Heron, GCTH Gray-cheeked Thrush, HETH Hermit Thrush, KILL Killdeer, LEBI Least Bittern, OVEN Ovenbird, SASP Savannah Sparrow, SWTH Swainson's Thrush, U Unidentifiable, VEER Veery, YRWA Yellow-rumped Warbler. ~ indicates probable identifications due to poor spectrographic resolution of the flight-calls.



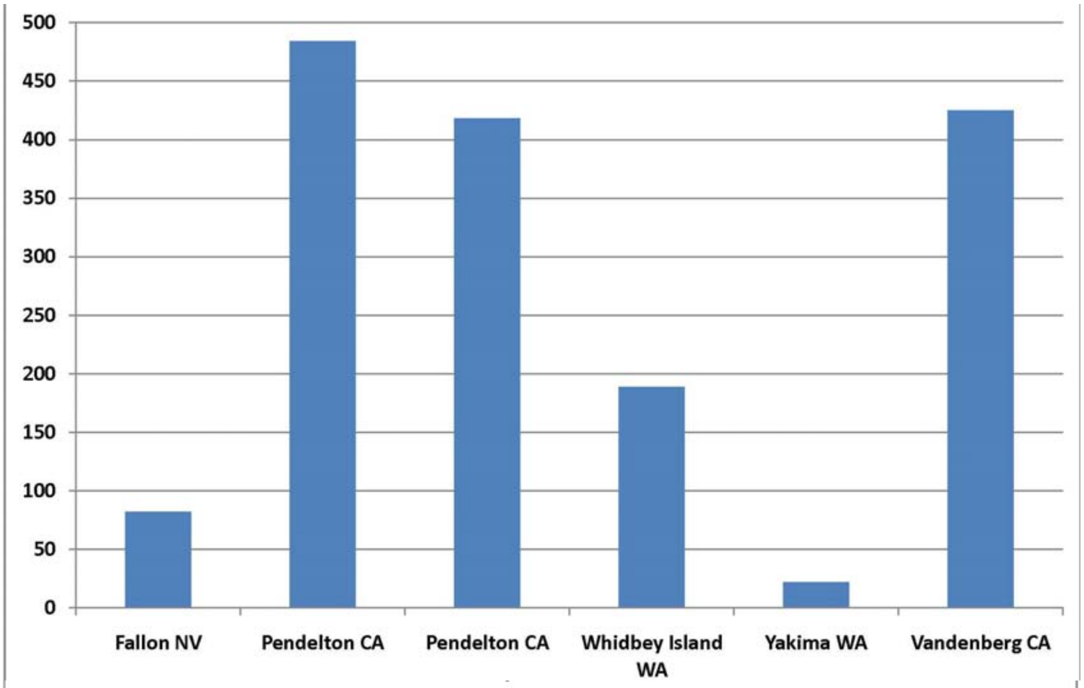
Total Call Count per Night, 9-14 October 2005

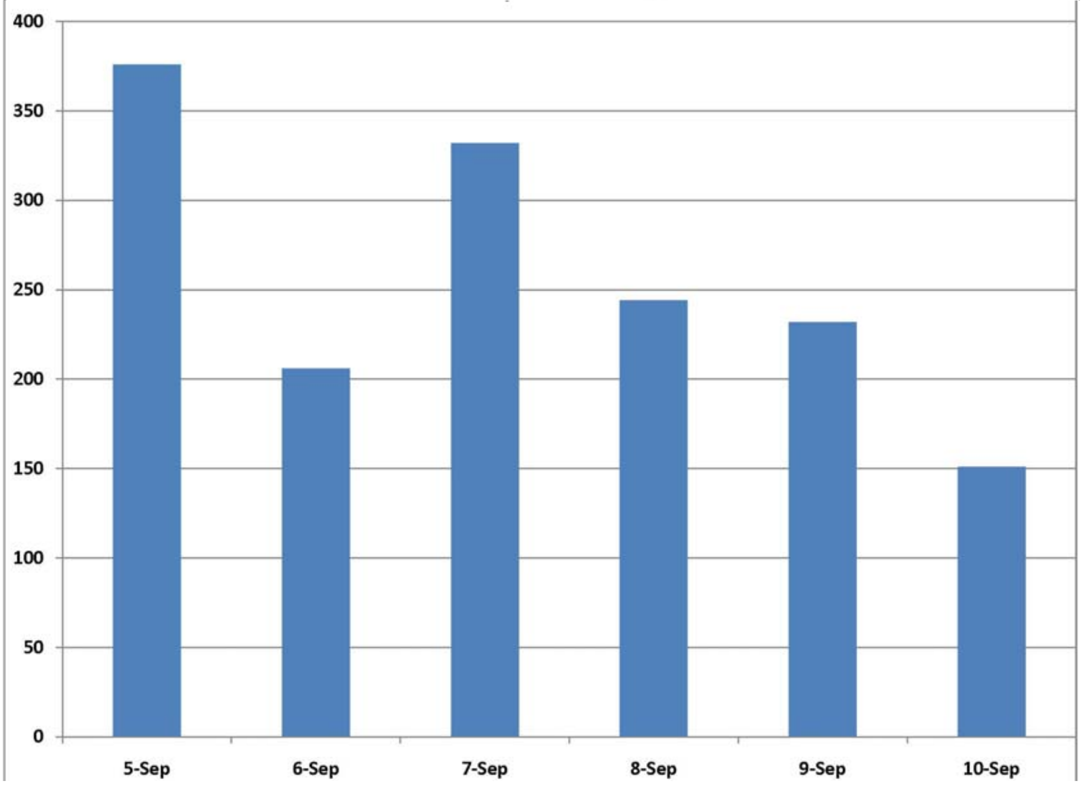
CORNELL LAB of ORNITHOLOGY

Flight calls across six DoD installations in the Northeastern US in October 2005. The total number of calls recorded on each night over the course of a week in the heart of mid-to-late passerine migration shows how variable calling is on a regional basis. US Military Academy in particular exhibits some exceptional nights of call counts. This site is known to have frequent fog and artificial lighting, features that are characteristic of a high-calling location. Although we have not corrected for bird density in this presentation, comparing acoustics and radar is a critical future direction for monitoring. In places like West Point, factoring in bird density will allow for better representation of the true numbers of birds aloft identified by flight calls. For future DoD deployments, the critical information that this approach provides is both the species composition at given installations and the ability to predict passage timing and volume in relation to time of year, environmental factors, and geography.

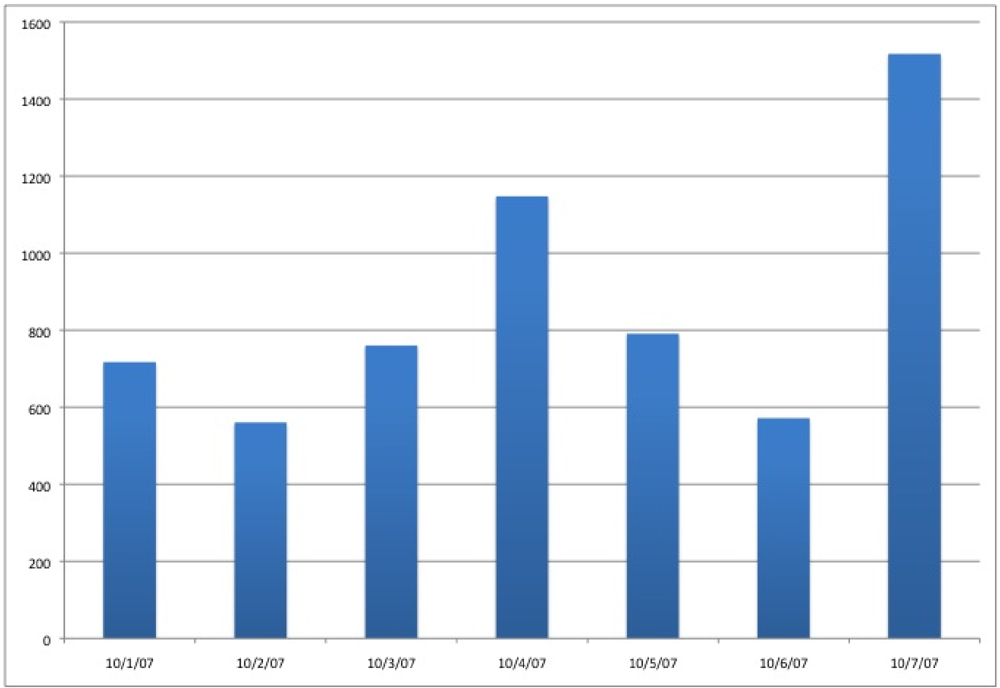


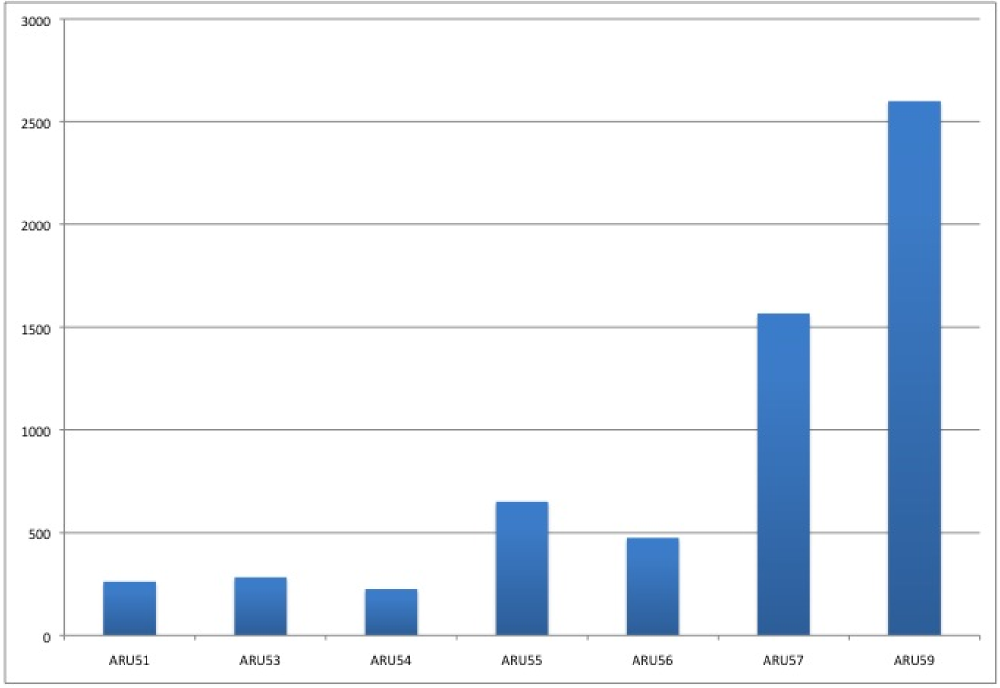
Swainson's Thrush detections across six Northeastern DoD installations in October 2005. Swainson's Thrush is a ubiquitous nocturnal caller, but there is still tremendous variation in the call counts recorded across even a several hundred-kilometer area. This is true also of the relative contribution of this species to the total vocal avifauna passing nocturnally at these sites. Note in particular the small number of Swainson's Thrush calls relative to other calls at Lakehurst Naval Air Station. This site is south of several major urban areas, and it is the largest expanses of open country in the region - these factors, among others, may correlate with the observed patterns. Such information is important for building predictive models of species composition and likelihood of occurrence - these models will be the future of assessing how DoD activities might affect migratory birds, and these may provide information for how to best mitigate activities such as low level training flights.



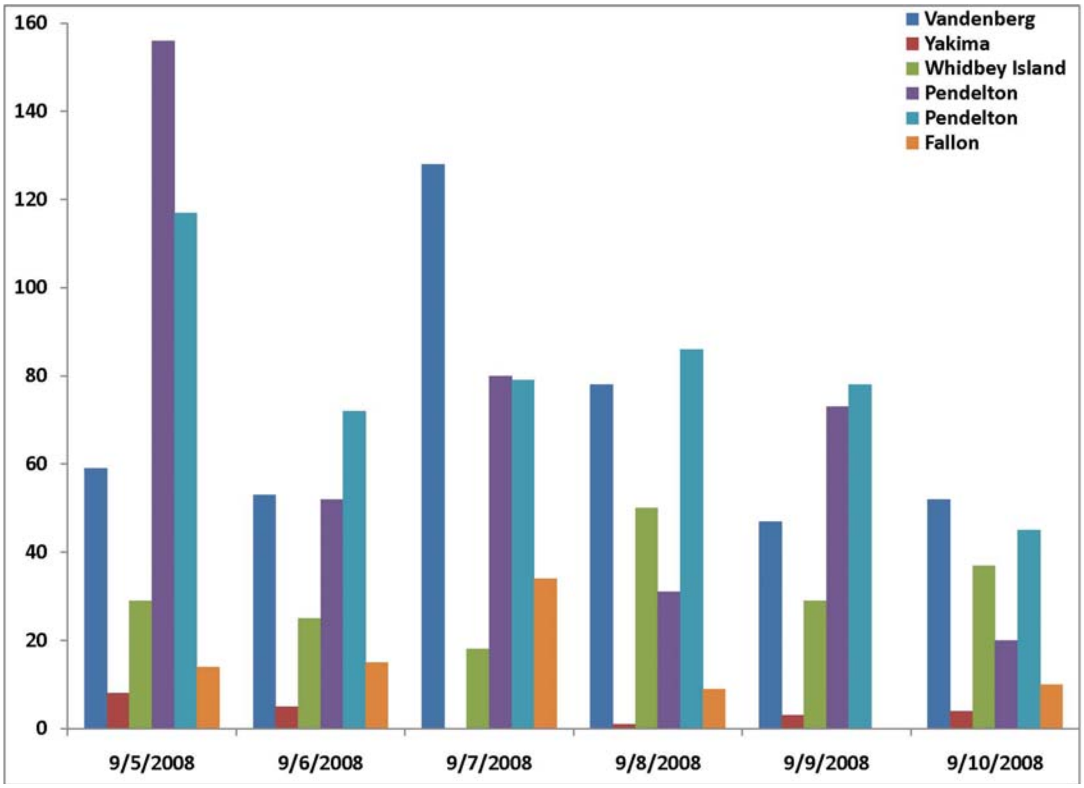


The top graph shows total calls across the "western transect" of Legacy ARU deployments, 5-11 September 2007. Note wide variation in call counts across sites, even at installations in the same regions. This highlights the value of multiple monitoring stations to study amount and type of nocturnal migration passing DoD airspace. The bottom graph shows calls across "western transect" sites in time. Nightly temporal patterns provide the foundation for critical analyses that predictive modeling in DoD airspace will require for assessing likelihood of bird strikes, patterns of usage and potential stopover value of local DoD habitat resources.

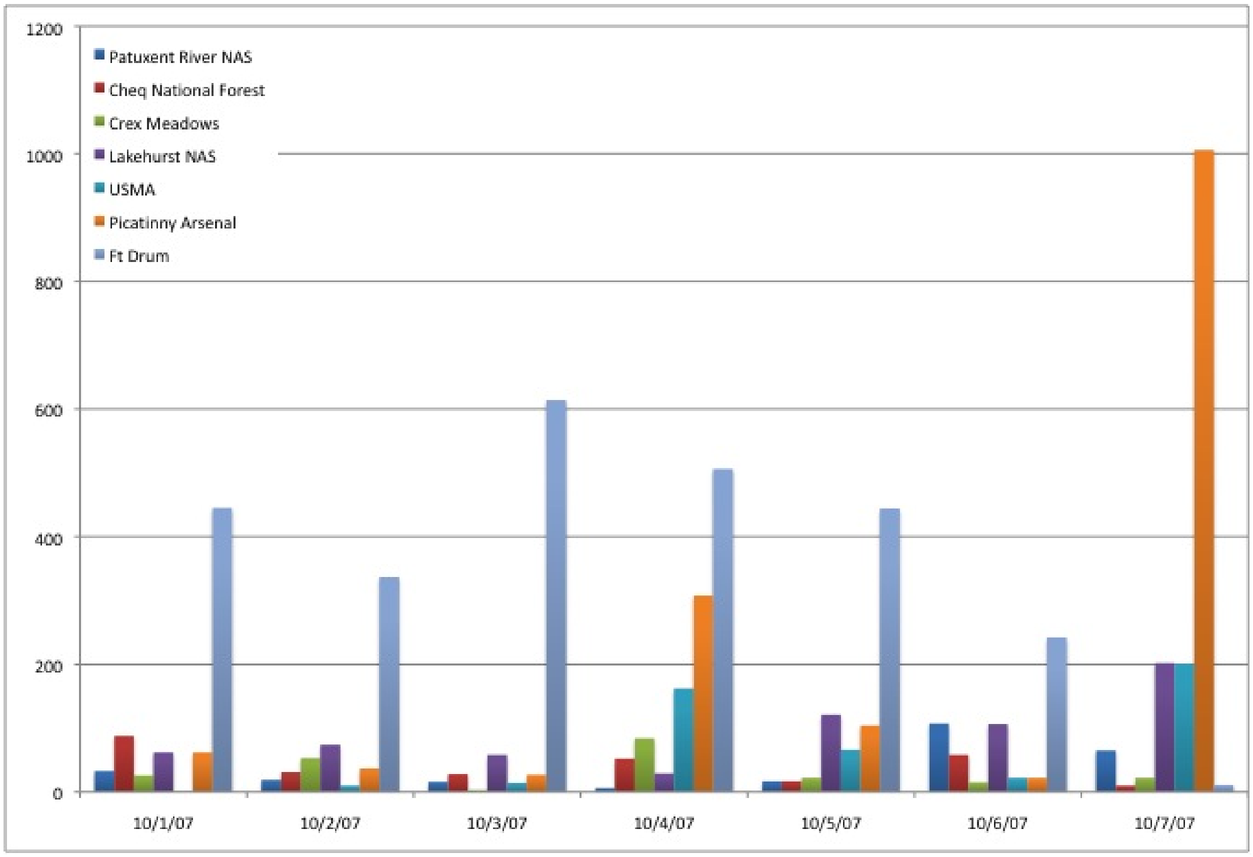




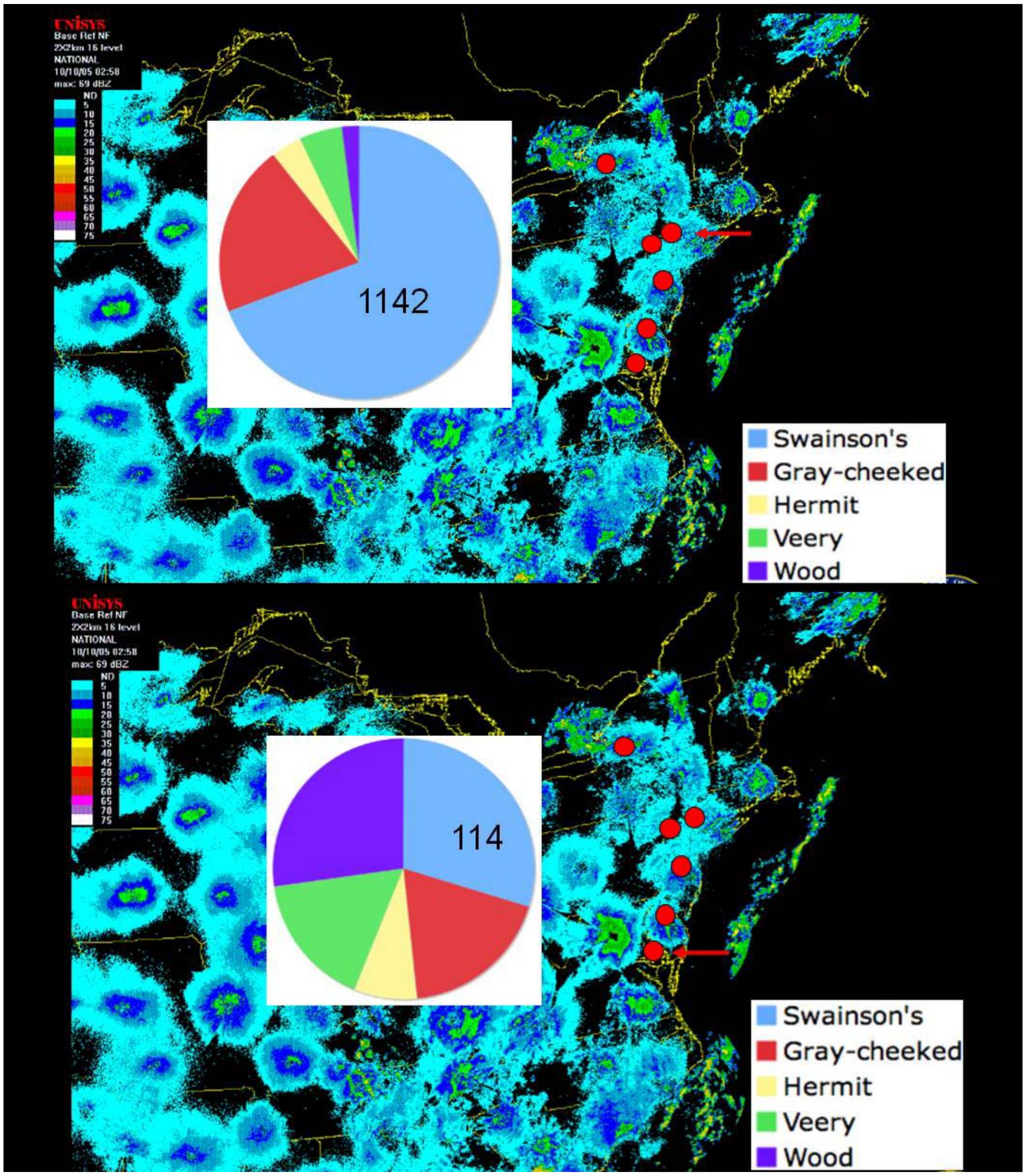
The top graph shows calls across "western transect" sites in time, 1-8 October 2007. Nightly temporal patterns provide the foundation for critical analyses that predictive modeling in DoD airspace will require for assessing likelihood of bird strikes, patterns of usage and potential stopover value of local DoD habitat resources. The bottom graph shows total calls across the "eastern transect" of Legacy ARU deployments. This represents 7 ARUs: 51 – Patuxent Naval Air Station, NJ; 53 (non-DoD) – Cheq National Forest, WI; 54 (non-DoD) – Crex Meadows, WI; 55 – Lakehurst Naval Air Station; 56 – USMA, West Point, NY; 57 – Picatinny Arsenal, NJ; 59 – Fort Drum AFB. Note wide variation in call counts across sites, even at installations in the same regions; generally call counts are higher than almost all western recording sites.



Call counts by date and location for the nights of 5-11 September 2007. This geographic "slice" analysis is the first of its kind performed for the western United States, and it provides insight into the species passage over western DoD installations at a coarse level. However, the level of detail possible is evidenced from the basic data presented in the summary species list. There is extensive variation among sites and nights for our western DoD installation monitoring. The coastal Pendelton site had consistently high call counts, composed of numerous small passerines including Savannah Sparrow, White-crowned Sparrow, Common Yellowthroat, Orange-crowned Warbler, and various other small Emberizid and Parulid species. The species composition at other locations on these nights largely mirrored the species composition detected at Pendelton.



Call counts by date and location for the nights of 1-8 October 2007. This geographic "slice" analysis is one of the few of its kind performed for the eastern United States, and it provides insight into the species passage over DoD installations and nearby locations at a coarse level. However, the level of detail possible is evidenced from the basic data presented in the summary species list. There is extensive variation among sites and nights for our eastern DoD installation monitoring. Whereas species composition at these sites was largely similar for this time period (highlighted by large numbers of White-throated and Savannah Sparrows as well as smaller numbers of Common Yellowthroat, American Redstart, Yellow-rumped Warbler), the total call counts vary widely. Note the large number of a calls recorded at Picatinny Arsenal on the night of 7-8 October, evidence of a larger scale, low altitude movement of birds associated with frontal passage in the area in conjunction with artificial lighting conditions in the vicinity. This type of dataset has great utility for understanding the species composition passing DoD sites as well as comparative research using this dataset with weather variables, flight paths of aircraft/training missions, etc.

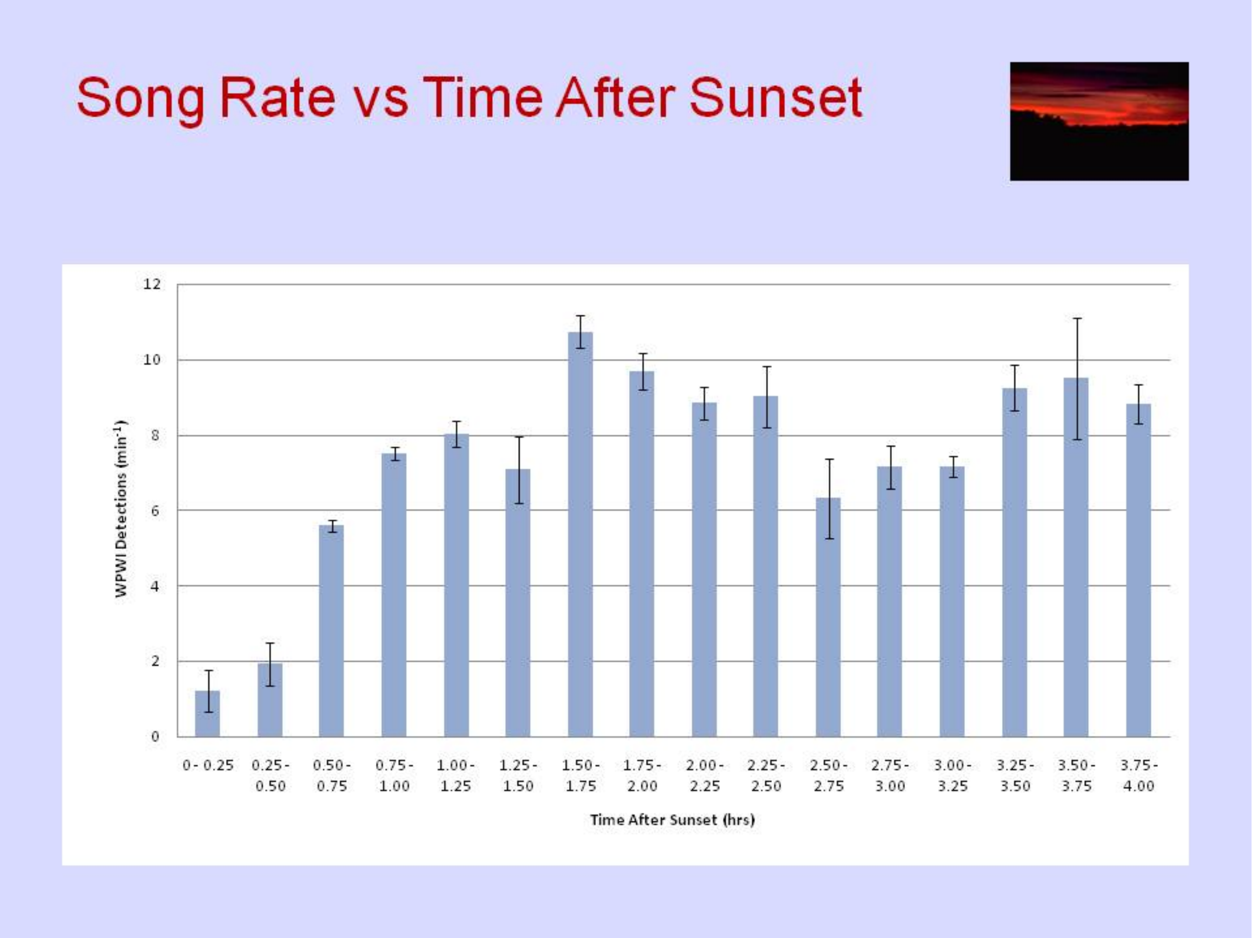


WSR-88D mosaic (courtesy of Dr. Sidney A. Gauthreaux, CUROL) and acoustic detection of thrush flight calls at six DoD installations in the Northeastern US. Assessing variation in species composition across sites is an important product for DoD installations in terms of understanding what species are using their facilities and the airspace over their facilities on a nightly and seasonal basis. Analysis of the 2005 dataset in the Northeastern United States shows a marked difference between the call counts and species composition as detected automatically at US Military Academy at West Point (top) and Patuxent River Naval Air Station (bottom). Although Swainson's Thrush composes the bulk of the calls at both locations, a higher relative number of Wood Thrushes occurs farther south. These data illustrate the biological and applied value of this method of monitoring: one can assess species-specific attributes relative to stopover habitat and to the potential to occur at DoD installations; no other monitoring method can provide these details on nocturnal migrants passing overhead.

c. Whip-poor-will Analyses

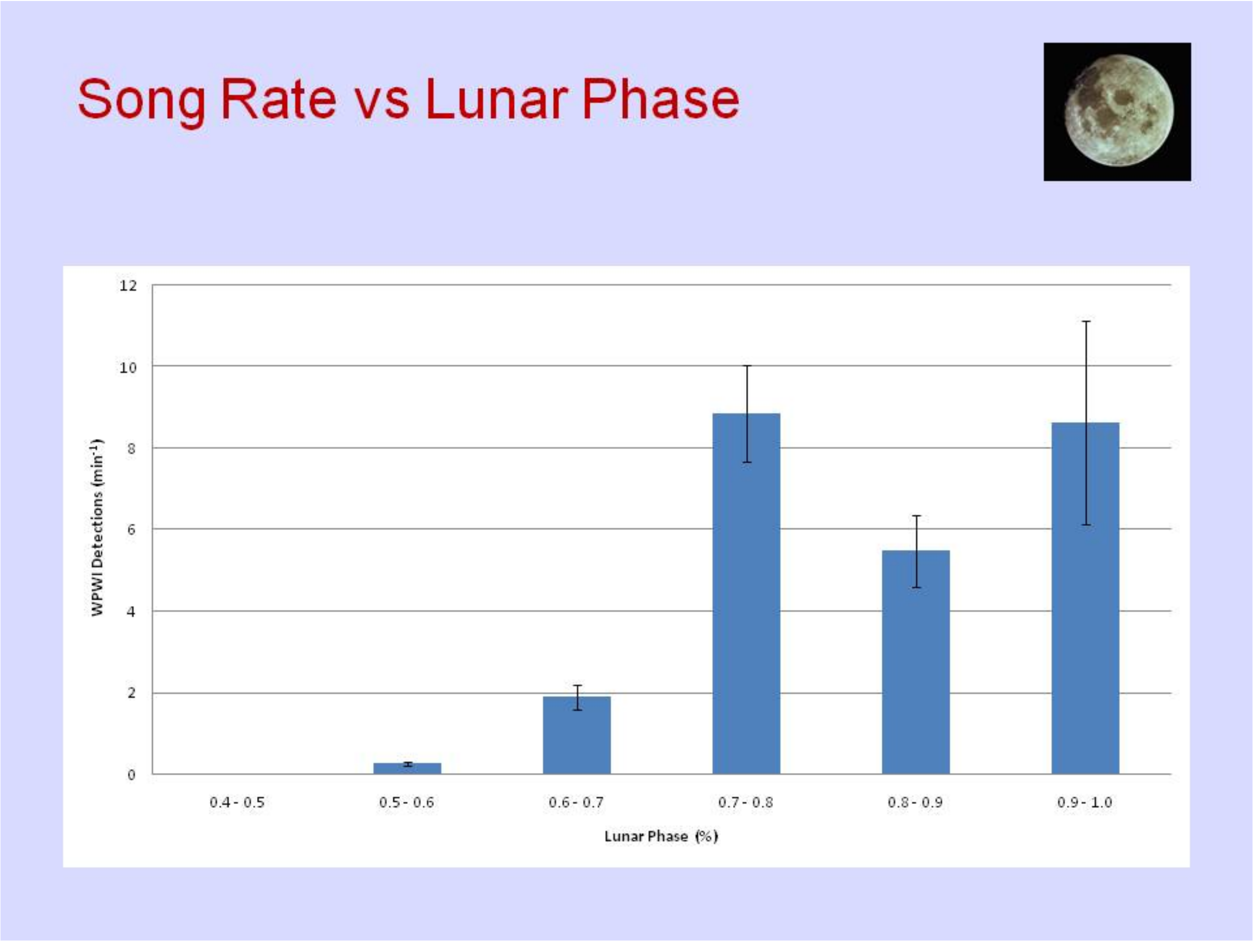
(Michael Pitzrick, Russell Charif, Andrew Farnsworth)

The data template detector found 68,995 WPWI phrases in 15 nights of recording around the full moon with extremely low rates of false detection. The detector found even distant and poorly recorded WPWI. More importantly, the detector found WPWI even on the darkest nights of the lunar cycle, detecting 3514 WPWI phrases in the new moon period. Figures (XXX) show the results of these analyses. The detector performed very well at detecting WPWI at Ft Drum and several other sites at which we deployed ARUs. Additionally, this detector allowed us to examine relationships between vocal behavior and lunar attributes with a precision not otherwise obtainable from human observations alone. These data will yield a quantitative basis for refining field protocols for observers surveying this species, and the combination of ARUs and template detection likely provides a cost effective means for expanding WPWI survey efforts on DoD lands. Furthermore, this model of monitoring is directly applicable to other target species recording, and the likelihood of cost savings and increased monitoring benefits is very high.



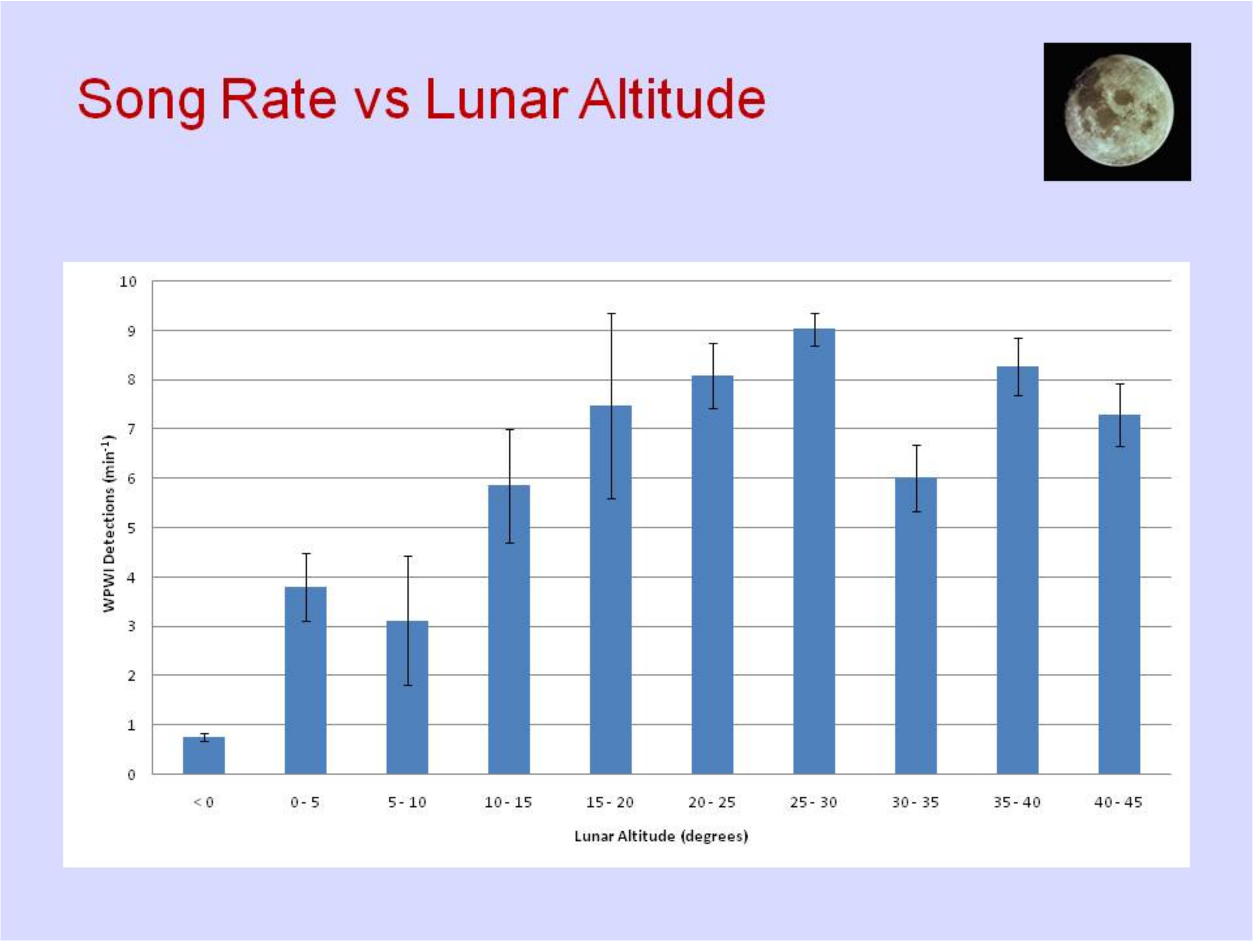
Song Rate vs Time After Sunset

Traditional monitoring methods have focused on timing surveying Whip-poor-will close to sunset. Our data collected automatically with ARUs and processed automatically using a template detector show that birds continue singing even four hours after sunset. However, these data do not control for lunar characteristics.



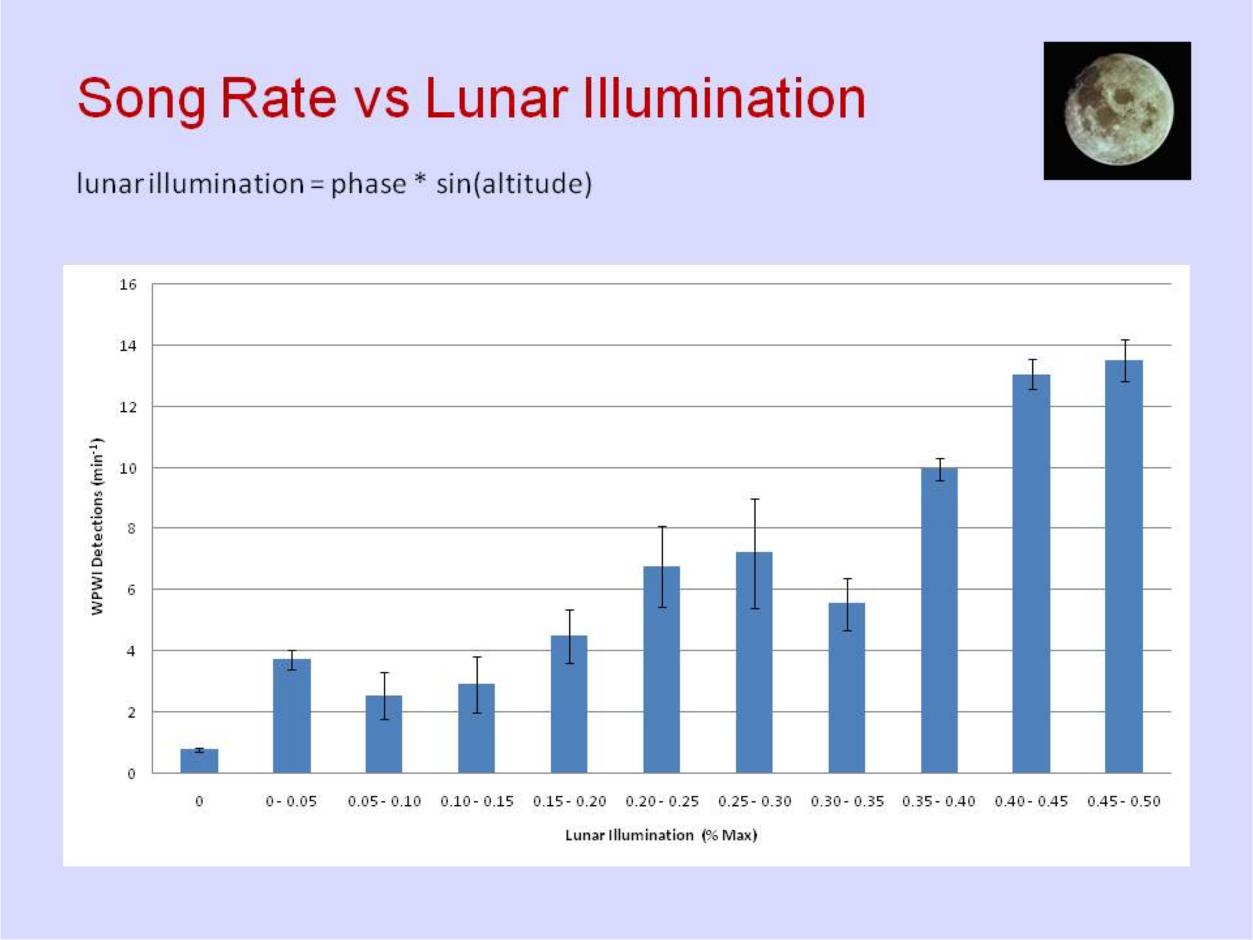
Song Rate vs Lunar Phase

Lunar phase appears to correlate strongly with Whip-poor-will song rates. Once the moon is nearly three quarters full, calling rates increased dramatically.



Song Rate vs Lunar Altitude

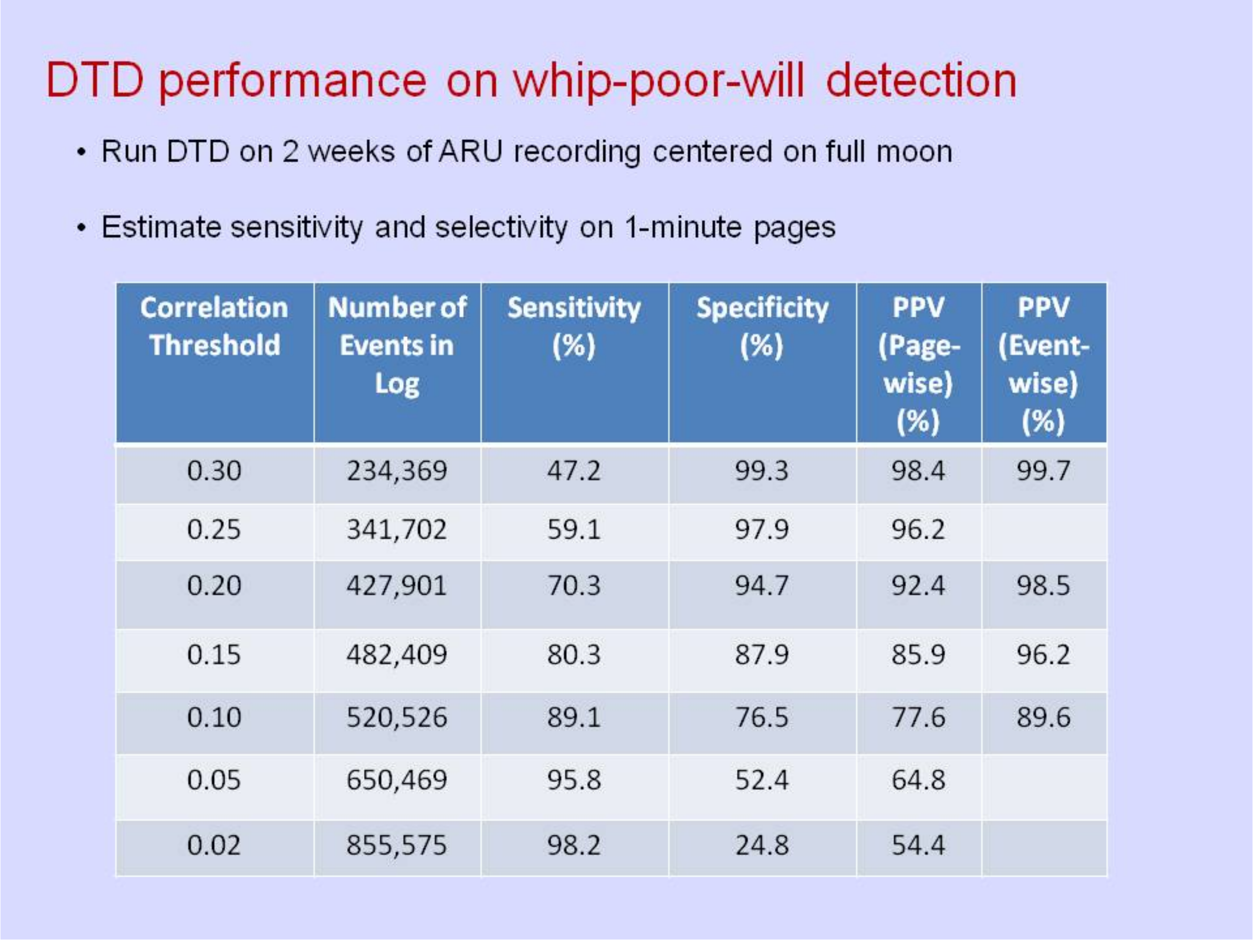
Lunar altitude also plays a role in calling of Whip-poor-wills. Although there is substantial variation at low altitudes (close to the horizon), calling rates are generally highest once the moon has risen above 15-20 degrees over the horizon.



Song Rate vs Lunar Illumination

lunar illumination = phase * sin(altitude)

To correct for the effects of both phase and altitude of the moon, we modeled calling rates against lunar illumination. This metric factors the two attributes to calculate a metric of how bright are the conditions under which calling occurs. This graphic depicts the pattern hinted in the previous graphs - Whop-poor-will singing is probably most strongly correlated to the brightness of the moon, factoring both altitude and phase. Note, however, that this does not attempt to model the effects of lunar illumination and cloud cover. This is a feature we still need to explore in future studies.

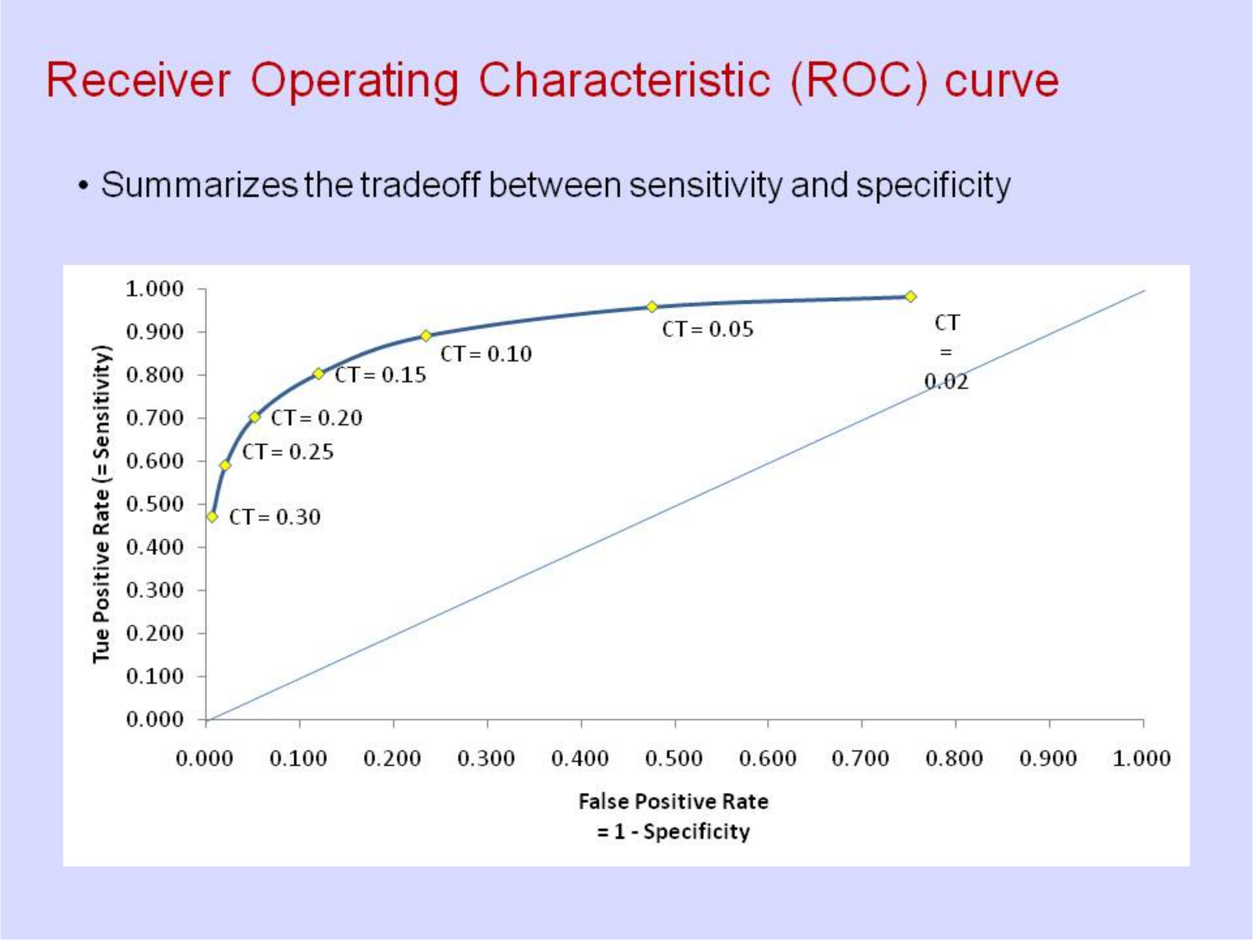


DTD performance on whip-poor-will detection

- Run DTD on 2 weeks of ARU recording centered on full moon
- Estimate sensitivity and selectivity on 1-minute pages

Correlation Threshold	Number of Events in Log	Sensitivity (%)	Specificity (%)	PPV (Page-wise) (%)	PPV (Event-wise) (%)
0.30	234,369	47.2	99.3	98.4	99.7
0.25	341,702	59.1	97.9	96.2	
0.20	427,901	70.3	94.7	92.4	98.5
0.15	482,409	80.3	87.9	85.9	96.2
0.10	520,526	89.1	76.5	77.6	89.6
0.05	650,469	95.8	52.4	64.8	
0.02	855,575	98.2	24.8	54.4	

When one surveys a species of concern, a key piece of information is the correct detection of the target signal of all of that type of target signal in a sound stream. In the case of Whip-poor-will, the data template detector does an exceptional job of maximizing this value. Correlation threshold in this table refers to the spectral cross correlation value between the target signal of interest and the example Whip-poor-will phrase template. The lower the value, the lower the similarity required between the target and the template to qualify as a match.



Receiver Operating Characteristic (ROC) curve

- Summarizes the tradeoff between sensitivity and specificity

Although the approach to maximizing the true positive rate for Whip-poor-will detections increases the number of false positives (non-Whip-poor-will signals), the trade off is worth it given the high value of correct detection relative to the false positive rate. ROC curves are typical graphical displays of this tradeoff.

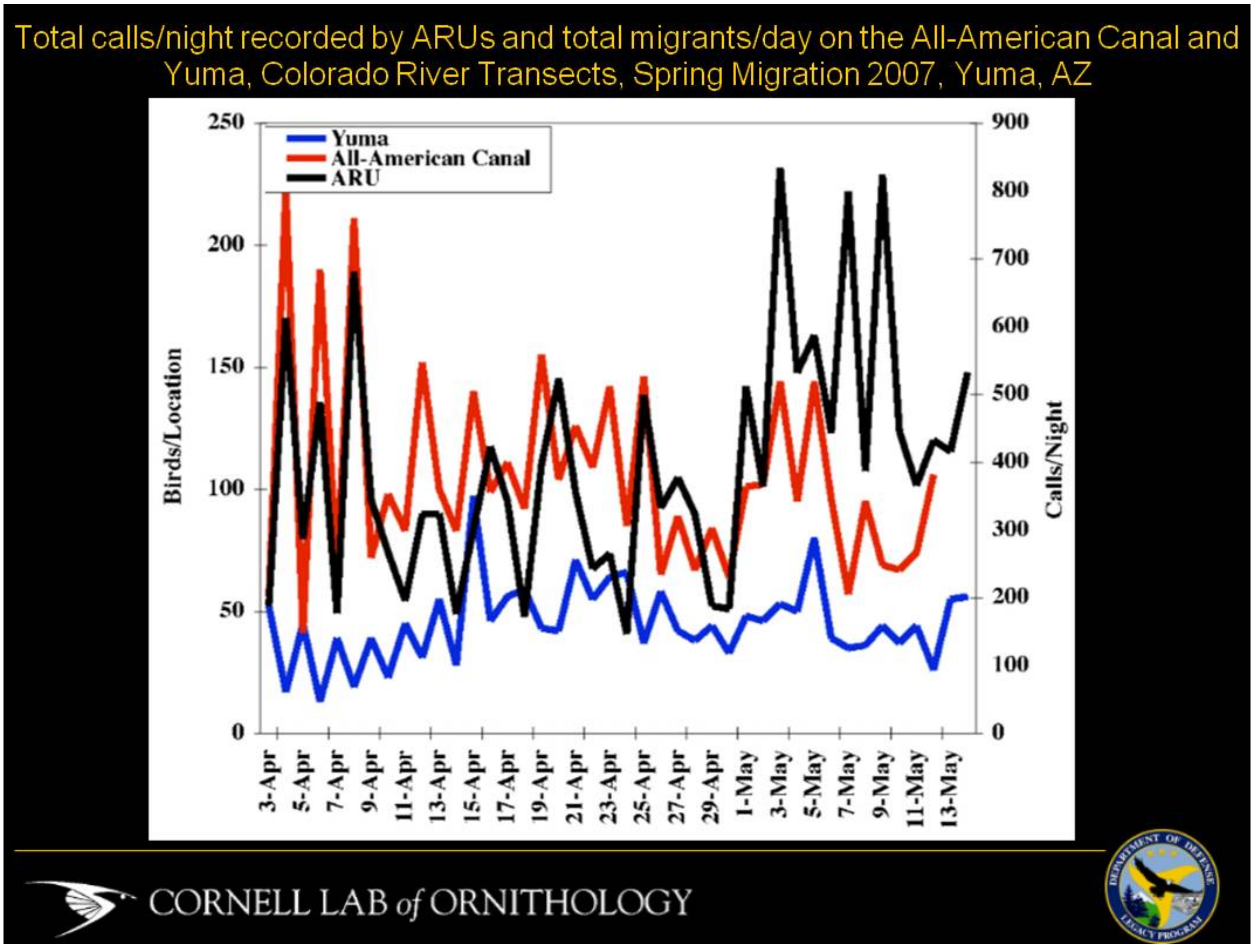
Correlation Threshold	TP	FN	FP	TN	Accuracy
0.3	895	1000	15	2059	0.744
0.25	1120	775	44	2030	0.794
0.2	1332	563	109	1965	0.831
0.15	1522	373	250	1824	0.843
0.1	1688	207	488	1586	0.825
0.05	1815	80	987	1087	0.731
0.02	1860	35	1559	515	0.598

This table shows the performance of the data template detector for detecting Whip-poor-will phrases given a suite of different correlation values between the detected signals and the exemplar templates used to detect them. The following legend applies to the abbreviations: TP - true positive, FN - false negative, FP - false positive, and TN - true negative. Accuracy: What proportion of all events (target and non-target) were classified correctly? This equals (TP+TN)/(TP+TN+FP+FN).

d. Yuma Datasets

(Rich Fischer, Sidney Gauthreaux, Andrew Farnsworth)

Results from this analysis were promising. Species composition recorded by flight-calls is similar to that observed during diurnal point counts. However, certain species detected by voice (e.g. Clapper Rail, Swainson's Thrush) were not apparent in diurnal visual observations. We also found that there was tremendous local variation in calling patterns, likely due to habitat, topography and environmental noise patterns as well as differences among species and individuals. Furthermore, these data on variation and the data on calling phenology of resident and migrant species is a primary source for information on migration patterns and behaviors of many species of interest for monitoring purposes. With the successful monitoring at these sites, we showed that acoustic monitoring has many useful applications in the western United States, an area that had previously received almost no attention from an acoustic monitoring perspective.



Total calls/night recorded by ARUs and total migrants/day on the All-American Canal and Yuma, Colorado River Transects, Spring Migration 2007, Yuma, AZ

The Yuma recordings exemplify the variation across local sites with observation transects. Daily variation is likely a functional of the input and exodus of migrants in these stopover areas. Note that the highest call counts tended to mirror the observation data collected at the All American Canal transect. This dataset is unique in that we have radar, acoustic, and observational data available to us. We plan to begin the next level of analysis on these data in the spring of 2009 with Rich Fischer and Sidney Gauthreaux.

Sound analysis: Improved speed and consistency in analyzing data

We explored the use of automatic detection algorithms to facilitate faster analysis of sound files containing flight-calls. Often these files are large, with single sound files containing tens of hours of data. Automatic detection using algorithms designed to detect specific signal energy parameters is a useful way to begin to speed this process. Our results and experiences show that it is exceptionally more efficient to use this approach for analyzing sounds than to use an approach that relies solely on real time listening or spectrographic evaluation. A single researcher can process up to 20 sites in the time it previously took to examine a single site. However, choosing the parameters and defining the bounds of detection software is a challenging process, requiring extensive research in some cases (XBAT) and some trial and error in other cases (Raven - diagnostics not yet implemented). We have tested energy detection algorithms extensively in XBAT during the past three years, and we are beginning to develop the parameters that detect 150-200X faster than real time. This success of these detectors varies extensively, but some test parameters detected 90-100% of the flight calls in a sound stream. However, the cost of reaching these levels of detection success is high - tens of thousands to millions of false (non flight call) detections are possible when applying such methods to an entire season of recording, with some single nights in the tens of thousands of false detections.

Our initial attempts to analyze recordings used two software packages, Raven 1.2 and XBAT 0.7. Neither program supported mp3 file analysis during the bulk of the first year of our data collection, so analyzing data in spectrographic form was impossible; because of the quantities of data we collected, real-time aural analysis of all the data was also impossible. In our first attempts at data processing and analysis, we needed to split all the mp3 files into segments, determine which of these segments corresponded to nocturnal and diurnal recordings, and then convert these files to .aif sound files that could be opened in Raven and XBAT. In addition, without energy detection browsing these files for flight-calls required longer than real-time analysis, meaning that for each hour of recordings, sometimes 2-3 hours was needed to analyze flight-call data. This number is faster than real time for a trained flight-call analyst, perhaps approaching 3-5 times faster than real time. However, such tasks are clearly at the expense of analyzing flight-calls themselves and classifying them to species. Even a trained flight-call analyst could not sustain thousands of hours of analysis to detect flight-calls. However, these software platforms improved during 2006 and eventually facilitated direct (visual inspection and algorithm based “inspection” such as energy detection), faster-than-real-time analysis of mp3 files by late 2006. We overcame a number of problems associated with reading mp3 data, and are now able to load, visualize, play, and analyze these files. In addition, whereas it was not possible to open a single file in previous versions, we could view and analyze an entire deployment's files in a single session of XBAT by late 2006.

Toward the end of the first year, we began to make drastic improvements toward the proposed goal of automatic detection technology. We employed an energy detector that uses a series of adjustable parameters to locate signals of interest in a sound file and log those by time and frequency (Figure 4a, b, c). This procedure iteratively succeeded and failed, confirmed primarily by comparing logs of flight-calls flagged by an expert visually inspecting the sound file spectrograms with the logs generated automatically by the energy detection algorithms. However, this exercise greatly improved our abilities to detect flight-calls using parameter-based automatic detection algorithms, producing successful classifications at first in the 0-20% match range then successively up to 45-60% success. With continuing iterative research, we believe we will attain success as high as 80-90% detection of all calls in audio files classified visually and aurally by human flight-call experts. This will substantially reduce the time required to analyze flight-call data because automatic detectors are now working at speeds 10-20 times faster than real time.

We faced additional challenges in early stages of our sound analyses; we did not have diagnostic tools to streamline the use of the energy detector, thus necessitating the trial and error approach. Once we incorporated diagnostic tools into our use of the energy detection algorithms, we were able not only to understand the exact functions of the parameter settings and their affect in modifying the algorithm but also to determine easily the effects of changing each parameter, singly or in concert with other parameters, across sound recordings (Figure 5 a, b). Such diagnostic tools are vitally important for understanding the effects of different levels of background noise on the detection capabilities of the automatic algorithms.

e. Flight call classification project

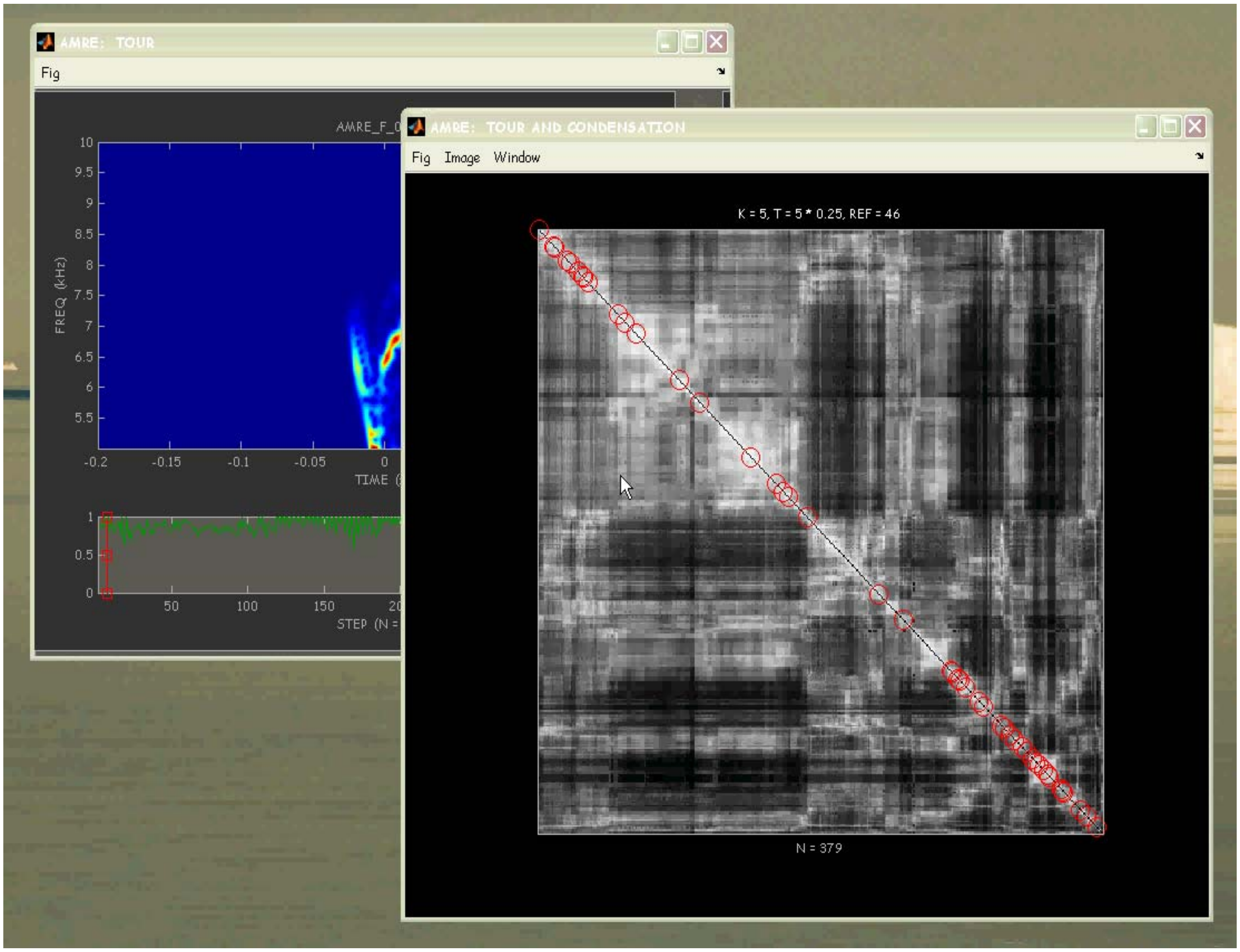
(Andrew Farnsworth, Kathryn Cortopassi - bioacoustician in Bioacoustics Research Program, Harold Figueroa - bioacoustician in Bioacoustics Researcher Program; funded by private donation to CLO, with partial support for Farnsworth's salary on Legacy)

Although SERDP did not fully develop the classification algorithms that Legacy required, several of the researchers working on classification issues collaborated with the Legacy project team to pursue the end goal of developing an automated classification system for flight calls. Essential to the task of rapidly and reliably analyzing vast quantities of nocturnal audio recordings for migrant activity are a suite of tools for automatically detecting and classifying night flight calls. Such automatic processing would free human operators from having to review long streams of recorded sound, and would make the entire analysis procedure repeatable and quantifiable. In this project, we sought to develop methods for detecting and classifying the night flight calls of six species of "*Catharus*" thrushes. Our primary goal was to maximize the rate of call detection and correct identification, while simultaneously minimizing the number of missed calls and false detections. Our initial objectives were:

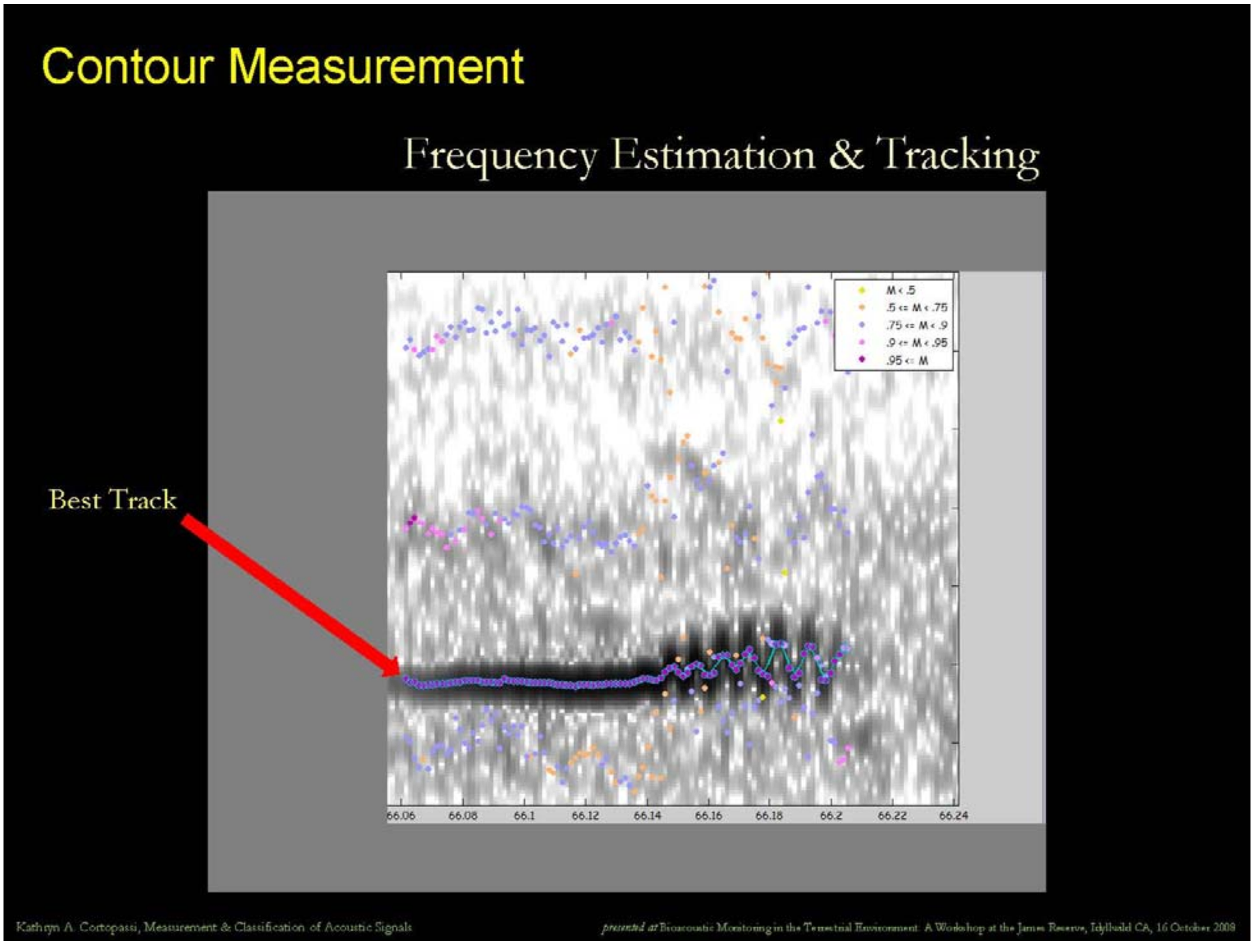
1) to develop a comprehensive training and testing dataset of sound clips consisting of expertly labeled flight calls from six thrush species (Bicknell's, Gray-Cheeked, Hermit, Swainson's, Veery, and Wood Thrush) and four other species (Green Heron, Rose-breasted Grosbeak, Scarlet Tanager, and spring peeper) with similar vocalizations to provide a realistic challenge for discrimination tasks;
2) to accumulate a training and testing dataset of long sound streams consisting of expertly labeled calling events from the ten species mentioned above;
3) to explore variation in flight call samples using spectrogram cross correlation and to condense large training sets into smaller sets completely representative of the larger set for use in nearest-neighbor based detection and classification;
4) to explore signal measurement and feature extraction for use in model-based classifiers as a means to label and screen sound events generated by a permissive energy (or other) detection process; and
5), to do the above with the ultimate goal of automatically processing long term data from passive acoustic recording devices-- that is, to extract (detect) migrant flight calls and to classify those calls to species with high accuracy (minimizing false positives and false negatives).

We explored two distinct approaches to the problem of automatic detection and classification: one is a nearest-neighbor-based approach that begins by condensing a large library of target exemplars into a small, manageable set that performs as well as the original library; another is a measurement-based approached that uses a novel method of frequency modulated (FM) contour extraction (incorporating parametric frequency estimation and dynamic track building) to characterize the structure of signals extracted via a permissive energy detection process. Both approaches showed promising results. The nearest-neighbor condensation method reduced a 1500-Magnolia Warbler flight call exemplar library down to only 17 calls with equivalent classification performance, and a random forest classification model built using the extracted FM contour measurements correctly classified more than 80% of the thrush vocalizations from an expertly labeled training set. At present we have:

1) developed an expertly labeled dataset of call clips from ten target and clutter species for training and testing purposes that includes maximum biological signal variation;
2) stabilized basic operations in a development version of XBAT to use as a data review and algorithm prototyping environment, including establishment of a programming interface (API) for measurement extensions;
3) developed quantitatively-based clip visualization tools that provide a tour of the range of signal variation in flight call exemplar libraries;
4) developed nearest-neighbor-based library condensation algorithms for thrush and warbler exemplar data (Fig. _); presented preliminary findings at the Acoustics08 conference in Paris, France;
5) created a consistent set of 17 example warbler calls from the full set of 1500 calls, an order of magnitude decrease in library size that still correctly classifies the entire set of thrush training data, for use with a matched-filter detector-classifier process;
6) expanded development of existing energy detection algorithm to process sound streams over arbitrarily long or short time scales, allowing for rapid scanning of streams to identify areas of high vocal activity;
7) developed a variety of contour extraction and summarization algorithms (including both modern frequency estimation and Fourier transform based approaches) for signal feature measurement (Fig. _); presented preliminary findings at the October 2008 NSF workshop on Bioacoustic Monitoring in the Terrestrial Environment held at the James Reserve, CA;
8) applied arbitrary scale energy detector to long sound stream data; rapidly processed streams to identify gross areas of interest, followed by finer-scale processing to extract single calling events; rough estimates show a two-fold reduction in processing time and an order of magnitude reduction in unwanted detections as compared to previous methods;
9) generated signal feature measurement sets for the expertly labeled thrush clip data using contour extraction and summarization algorithms based on parametric frequency estimation and dynamic track building; and
10) built a random forest classifier using the extracted contour measurements; preliminary results show good classifier recall and precision rates for the target thrush species.



Using the nearest neighbor rules defined by statistics of distance metrics and association, we have identified the mechanics of functioning of the data template detector. In this case, Figueroa has generalized the rule to apply to any number of sample exemplars to generate a consistent training set that classifies all members of the initial sample correctly. This condensation process has great potential for rapidly incorporating variation in species' signals and reducing this variation into a manageable subset. Sample condensation matrix for American Redstart (*Setophaga ruticilla*.) This figure shows a representation of the best example flight calls (n=46, red circles) that correctly classify all members of the Redstart training dataset (n=379), plotted as points along the diagonal through the matrix of spectral cross-correlations values.



Contour Measurement

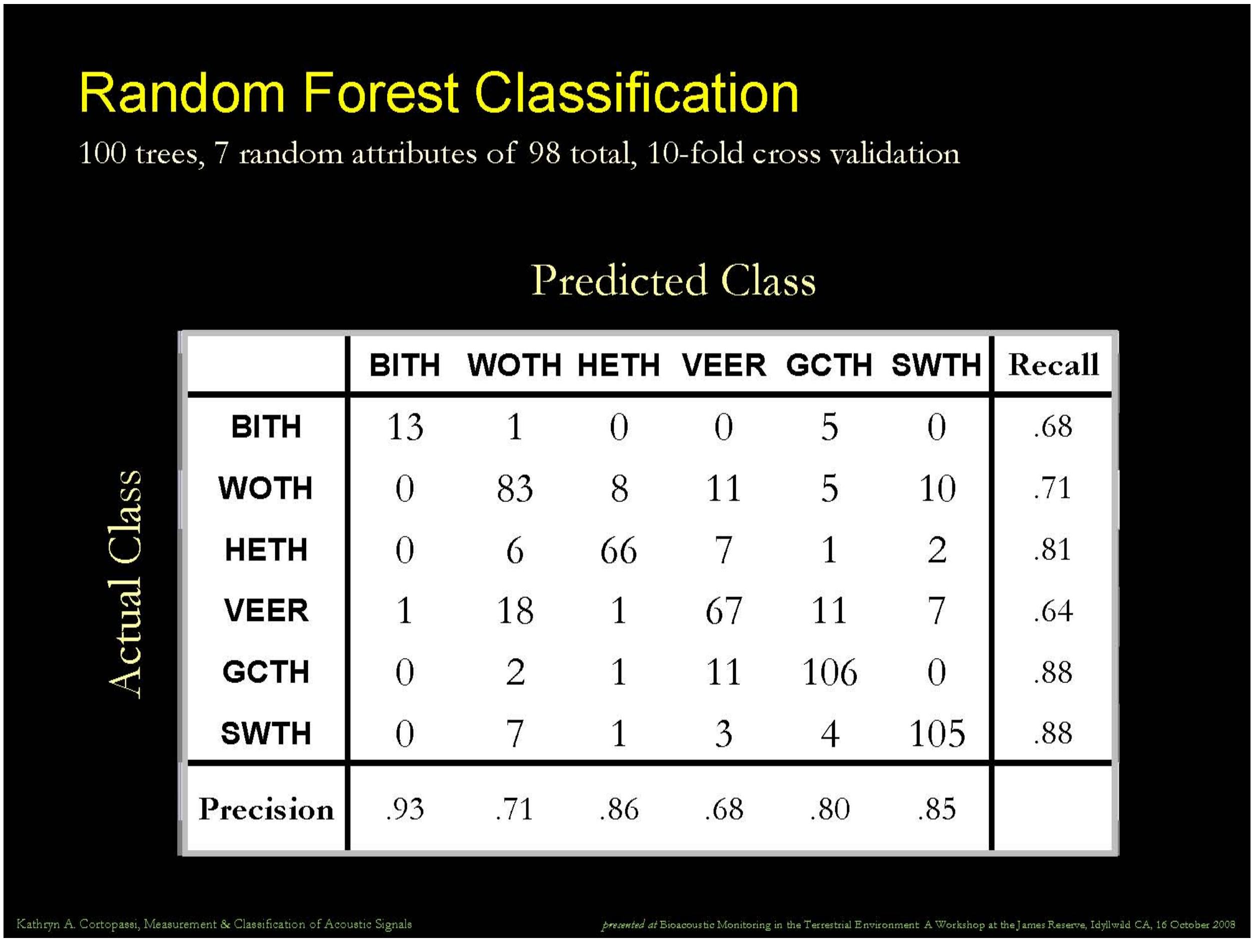
Frequency Estimation & Tracking

Best Track

Kathryn A. Cortopassi, Measurement & Classification of Acoustic Signals

presented at Bioacoustic Monitoring in the Terrestrial Environment: A Workshop at the James Reserve, Idyllwild CA, 16 October 2008

Frequency contour for a gray-cheeked thrush (*Catharus minimus*) flight call. Colored dots show signal frequency content made using a parametric estimation technique; frequency estimates are color-coded by their magnitude, or “quality”. Estimates are connected into contour tracks using a dynamic programming approach. Note that the spectrogram is shown only as a visualization aid and is not part of the frequency estimation process.



Random Forest Classification

100 trees, 7 random attributes of 98 total, 10-fold cross validation

Predicted Class

Actual Class

	BITH	WOTH	HETH	VEER	GCTH	SWTH	Recall
BITH	13	1	0	0	5	0	.68
WOTH	0	83	8	11	5	10	.71
HETH	0	6	66	7	1	2	.81
VEER	1	18	1	67	11	7	.64
GCTH	0	2	1	11	106	0	.88
SWTH	0	7	1	3	4	105	.88
Precision	.93	.71	.86	.68	.80	.85	

Kathryn A. Cortopassi, Measurement & Classification of Acoustic Signals

presented at Bioacoustic Monitoring in the Terrestrial Environment: A Workshop at the James Reserve, Idyllwild CA, 16 October 2008

Classification of flight calls by statistical modeling of contour measurement used Legacy data as training data. Results of a random forest (RF) classification of six thrush species built using 98 extracted frequency contour measurements (RF model: 100 trees, 7 random features considered, 10-fold cross validation); overall classification accuracy is 82.2%, with individual recall values (true positives over total actual) for four of the six classes ranging from ~85-90%, with recalls for the other two classes between 60-65%; precision rates (true positives over total predicted) for all classes are from ~80-90%. Precision is the number of true positives (i.e. the number of thrush calls correctly labeled as belonging to a species class) divided by the total number of calls labeled as belonging to the class (i.e. the sum of true positives and false positives, which are calls incorrectly labeled as belonging to a species class). Recall is the number of true positives divided by the total number of calls that actually belong to a species class (i.e. the sum of true positives and false negatives, which are calls which were not labeled as belonging to that species class but should have been). In this classification task, a Precision score of 1.0 for a species class means that every call labeled as belonging to that species class does indeed belong there (but says nothing about the number of calls from that class that were not labeled correctly) whereas a Recall of 1.0 means that every call from the species class was labeled as belonging to that class (but says nothing about how many other calls were incorrectly also labeled as belonging to that class). This technique showed great promise for this technique to be the long awaited automated classification algorithm for flight call monitoring that we had hoped would develop from SERDP research.

f. Development of DoD-customized eBird Application

(Steve Kelling, Information Science)

To facilitate the year-round inventory of bird populations, both on and surrounding DoD facilities, we developed a DoD-specific version of the eBird application, customized to accommodate the data management and security needs of DoD resource managers. Cornell Lab of Ornithology and its partners have developed eBird (http://www.ebird.org), an online database system for gathering, storing, and displaying bird monitoring information from across North America. The DoD eBird application, developed in consultation with DoD resource managers (Chris Eberly, Rich Fischer, Kyle Rambo) will have the ability to integrate the monitoring projects across all DoD sites into a single DoD bird-monitoring database containing historical and current data. This application will allow DoD officials to recruit individuals to do bird surveys at specific predefined sites following point count, transect, or area search protocols, fostering partnerships with public groups such as bird clubs and ornithological societies. The results of these surveys can be restricted from general public access, but allow an across-sites analysis of survey results. DoD eBird will be the first step in a complete data management system through the Avian Knowledge Network (http://avianknowledge.net) that will allow the compilation of all bird-observational data on and around installations, including records from visiting birders, organized field trips, Christmas Bird Counts, as well as professional surveys. The primary challenge for DoD at present is to populate this database with actual information now that the structure and storage architecture is complete. We hope that in the coming years, DoD will take full advantage of this structure for organizing its data for use to the fullest extent in the spirit and letter of the Coordinated Bird Monitoring plan.

eBird Summary

The Department of Defense eBird site was released with two mechanisms to collect data. First, is to use the Submit Data tab on the eBird page. This works well for observations made outside of any specific monitoring protocol and for new projects that do not record distance or break down time intervals. Exiting datasets may be brought in using the Avian Knowledge by using the Dataset Archive Upload <http://ebird.org/ebird/dod/ebird_upload> . Those projects dataset will be archived in its original Access/Excel/CSV or other file format. Data will be stored in the AKN with the associated metadata describing your project.

General Description of eBird

A real-time, online checklist program, eBird has revolutionized the way that the birding community reports and accesses information about birds. Launched in 2002 by the Cornell Lab of Ornithology and National Audubon Society, eBird provides basic information on bird abundance and distribution at a variety of spatial and temporal scales. eBird's goal is to maximize the utility and accessibility of the vast numbers of bird observations made each year by recreational and professional bird watchers. It is amassing one of the largest and fastest growing biodiversity data resources in existence. For example, in 2006, participants reported more than 4.3 million bird observations across North America. eBird enables the use of these observations by a global community of educators, land managers, ornithologists, and conservation biologists. In time these data will become the foundation for a better understanding of bird distribution across the western hemisphere and beyond.

eBird documents the presence or absence of species, as well as bird abundance through checklist data. A simple and intuitive web-interface engages tens of thousands of participants to submit their observations or view results via interactive queries into the eBird database. eBird encourages users to participate by providing Internet tools that maintain their personal bird records and enable them to visualize data with interactive maps, graphs, and bar charts. A birder simply enters when, where, and how they went birding, then fills out a checklist of all the birds seen and heard during the outing. eBird provides various options for data gathering including point counts, transects, and area searches. Results from more standardized or professional surveys using these basic protocols are also easily accommodated by eBird. Automated data quality filters developed by regional bird experts review all submissions before they enter the database. Local experts review unusual records that are flagged by the filters.

As eBird has grown, we have developed customized portals that are managed and maintained by local partner organizations. In this way eBird targets specific audiences with the highest level of local expertise, promotion, data quality, and project ownership. Portals may have a regional focus (aVerAves, eBird Puerto Rico) or they may have more specific goals and/or specific methodologies (Louisiana Winter Bird Atlas, Bird Conservation Network eBird). As part of this Legacy project, we worked with DoD resource managers to develop a phase-1 prototype of a DoD-customized eBird portal.

Features of the DoD eBird portal: A primary feature of the DoD portal is the addition of access restrictions based on user/password. Approved DoD users will create their own login name and password, which they will then use to securely access the Department of Defense eBird. This feature will allow DoD resource managers to control which bird-monitoring data are entered from DoD lands, and which data may be viewed by authorized users. DoD users will be able to access and view bird data from all public locations in eBird, including sites on and around publicly accessible DoD facilities, but public users will not be able to access or view restricted data entered into the DoD-specific eBird application. The Phase 1 release, which is currently available for review, includes the secure access to the data entry and report portions of the application, utilizing the existing DoD user accounts for the Birds of North America project at the Cornell Lab of Ornithology. Phase 2 will include data visualizations and reports from DoD lands, based on polygon coverages being developed by eBird and DoD managers. Registered users with access to the DoD portal will have the ability to select specific DoD lands and view data reports and maps from those lands. The phase 1 version is available at http://ebird.org/DoD (Fig. _).

Example of eBird data output

As an example of the powerful outputs available from eBird, we provide a portion of a seasonal bar graph, depicting bird-species' abundances from publicly accessible sites on Fort Huachuca, AZ (a popular birding destination), as well as nearby sites in the Huachuca Mountains. This output was generated via eBird's public application web site, based on 199 checklists submitted by birders visiting that area through March, 2007. As DoD managers enter data from monitoring projects on Fort Huachuca, and visiting birders are encouraged to enter observation from publicly accessible and nearby sites, a more complete picture of year-round abundance and distribution of bird species will emerge. Meanwhile, DoD managers will be able to restrict public access to sensitive data on threatened species or from restricted sites.

Because eBirders submitted more checklists and observations than in any previous year, including over 1,000,000 observations in a single month, and more effort-based observations (traveling, stationary and area counts) than ever before, which greatly increases the utility of their data from a scientific standpoint, eBird is truly coming into its own as a source for information on birds and their distributions. DoD has only to tap into this source and to begin entering its datasets to begin to realize its full potential. During 2008 and there were a number of additional enhancements to the overall eBird site that were implemented as a result of additional support and research. However, all of these are applicable to the use and application of eBird to any and all DoD installations and datasets. These advances include:

- release of bulk data upload procedures that allow users to import data from Excel and personal birding software. Several commercial birding software companies (Avisys, BirdBase and Pocket Bird Recorder) have written code to use this upload process to allow their users to contribute data to eBird;
- the launch of 'checklist sharing', a feature that allows a group of birders to 'share' a single checklist for a birding outing. This will greatly expand the eBird audience by allowing field trip leaders and others to share checklists with people who do not yet use eBird. This will also increase the quality of eBird data by avoiding duplication of data entry;
- the development of new mapping tools that allow people to better manage personal locations and hotspots;
- the development of a way for users to document sightings of rare species by uploading photographs to Flickr. These then show up on the eBird home page and can be searched by anyone; and

the launch of several 'data feeds' that resulted in neat applications like the 'Rare Bird Google Gadget ' and Jack Siler's Birding on the Net 'eBird Rarity Map.'

Welcome to Department of Defense eBird

Where your bird sightings make a difference!

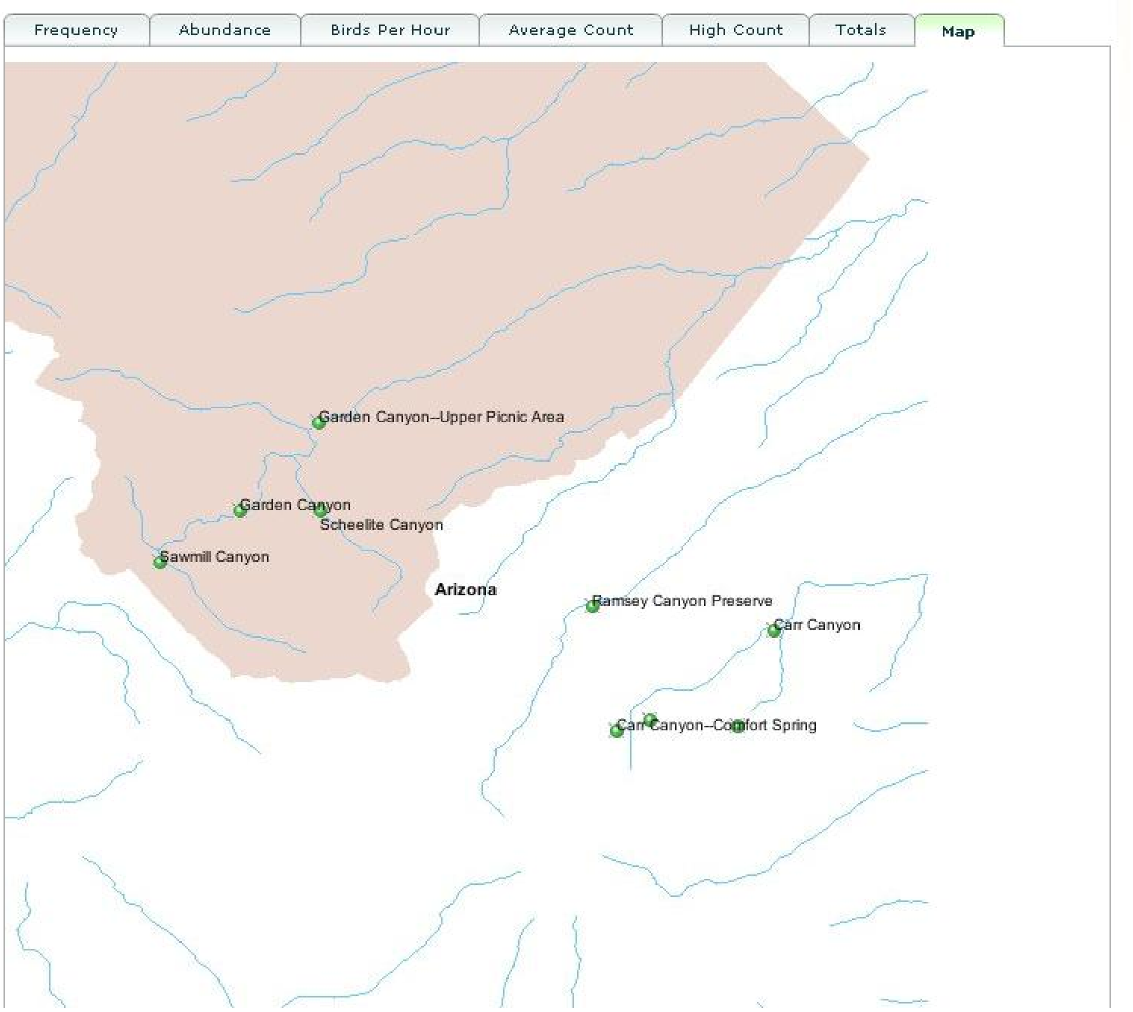
eBird Resources:

Birding News and Features

Screen capture of DoD eBird Home Page

Common Nighthawk (*Chordeiles minor*)
Common Poorwill (*Phalaenoptilus nuttallii*)
Whip-poor-will (*Caprimulgus vociferus*)
White-throated Swift (*Aeronautes saxatalis*)
Broad-billed Hummingbird (*Cynanthus latirostris*)
White-eared Hummingbird (*Hylocharis leucotis*)
Berylline Hummingbird (*Amazilia beryllina*)
Violet-crowned Hummingbird (*Amazilia violiceps*)
Blue-throated Hummingbird (*Lampornis clemenciae*)
Magnificent Hummingbird (*Eugenes fulgens*)
Black-chinned Hummingbird (*Archilochus alexandri*)
Anna's Hummingbird (*Calypte anna*)
Costa's Hummingbird (*Calypte costae*)
Calliope Hummingbird (*Stellula calliope*)
Broad-tailed Hummingbird (*Selasphorus platycercus*)
Rufous Hummingbird (*Selasphorus rufus*)
Allen's Hummingbird (*Selasphorus sasin*)
Rufous/Allen's Hummingbird (*Selasphorus rufus/sasin*)
Elegant Trogon (*Trogon elegans*)
Eared Quetzal (*Euptilotis neoxenus*)
Belted Kingfisher (*Ceryle alcyon*)
Green Kingfisher (*Chloroceryle americana*)
Lewis's Woodpecker (*Melanerpes lewis*)
Acorn Woodpecker (*Melanerpes formicivorus*)
Gila Woodpecker (*Melanerpes uropygialis*)

Screen-capture of eBird output, showing seasonal abundance of bird species on and around Fort Huachuca, AZ, based on 199 checklists submitted to eBird.org through March, 2007.



Map of locations on and around Fort Huachuca, where birders have submitted checklists to www.eBird.org.

3. Challenges

We faced numerous difficulties in the course of this three year project, some of which we have overcome; however, some of these difficulties are inherent in the collection and analysis of acoustic data or inherent in the biology of avian vocalization. However, year by year, we are improving our abilities to meet these challenges, in particular redesigning microphones and microphone housings for better all-weather performance and improving the speed and accuracy of automatic detection algorithms. These challenges and solutions, as well as the challenges of handling large quantities of acoustic data, are all milestones we address in reaching our goals for this project.

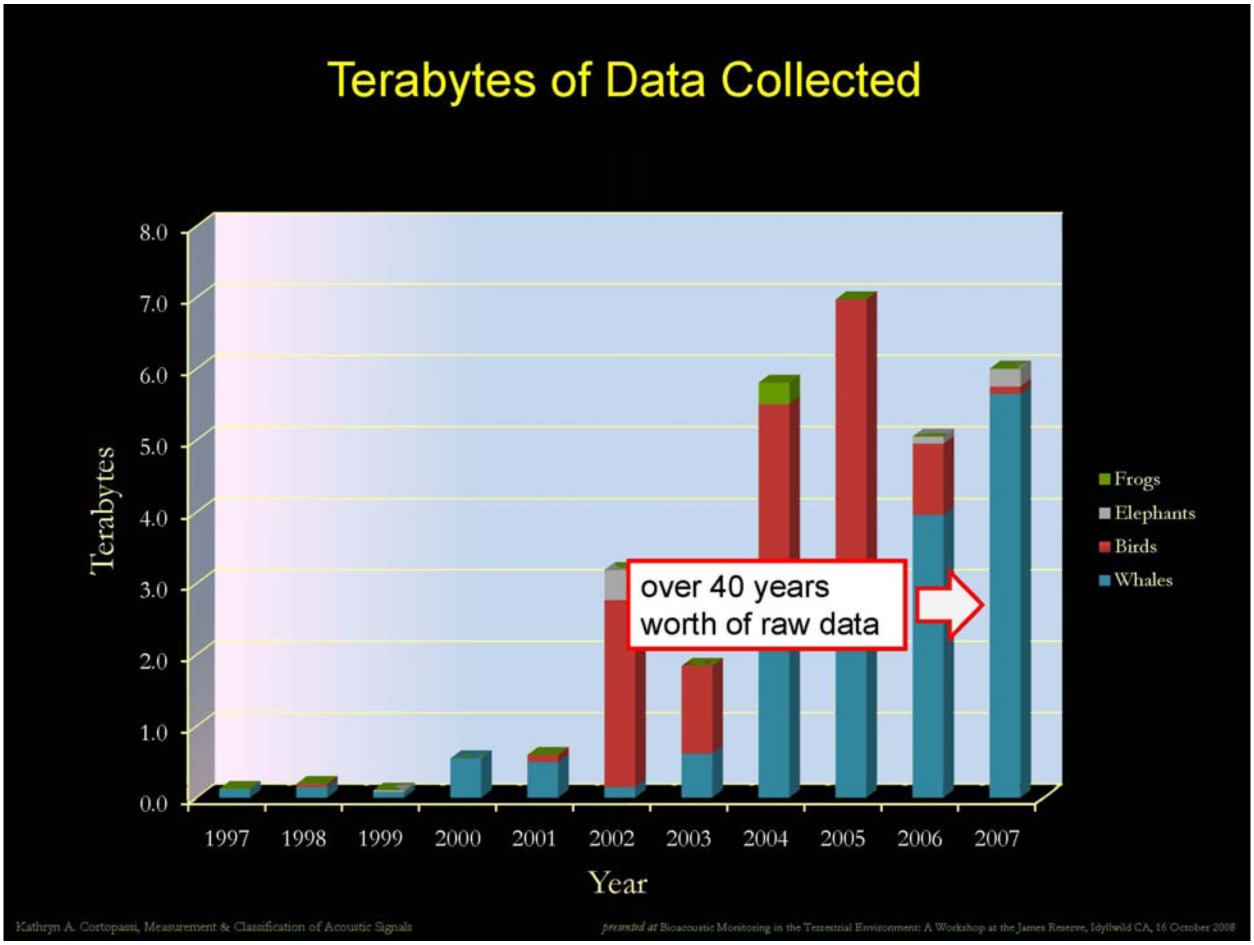
Due to some problems in completion and funding for SERDP SI-1185 and SI-1461, we experienced a suite of delays that manifest as delays in completing the scope of work for year-1 (2005) of this project; this cascaded across years, and we were slightly behind schedule in implementing work for year-2 (2006). This was the case for previous progress reports, but we continued to make strides in breaking new ground despite lacking some of the critical deliverables due for us and to us from SERDP. We requested and received an extension for delivery dates for expected products for 2006 from Legacy. However, we did not anticipate any or many changes in the overall scope of this project by the anticipated end date in 2008.

a. Data storage, file-naming, and file compression

Each recording unit can record 10 or more weeks of data, depending on available battery power and recording attributes such as sampling rate and sample size (converting incoming sound to digital data). There are large quantities of data to analyze, and processing, handling, and analysis capabilities are not keeping pace with collection capabilities. A single season worth of nocturnal migration recording with one microphone, with a 22,050 kHz sampling rate and 16-bit sample size, could lead to approximately 120 GB of data. 10 microphones recording during a season scales this number to 1.2TB. This value quickly approaches a major constraint: storage and access for these data represent a critical need that must be addressed, but deploying tens or hundreds of units would require substantial storage and data management effort. We initially planned for 5 TB of storage for the data we collected, but 2 years into the three year project we exceeded this limit.

Given this quantity of information, data management is critical. Storage for these data quickly becomes an issue in terms of how to access this information easily and where to keep it such that it is organized. We needed to acquire substantial space for storing these files such that they could be easily accessed (a server) as well for creating copies to duplicate data to avoid loss of original data. Additionally, naming the files such that they can be easily located and identified requires explicit attention. Each unit writes files with different naming conventions, sometimes with conventions that do not allow for explicit identification of recording date, location, and timing; therefore, creating informative but relevant names for these files is important.

Sound files recorded by ARUs are compressed (mp3 files rather than aif or wav files) and require smaller amounts of storage space than do non-compressed data (Table 4). Compressed data may represent a viable solution to storage space issues, although access to larger and less expensive drives may make this problem obsolete. Mp3 files are convenient because compression reduces their file size and as a result expands the recording capacity of a hard drive or storage environment by several times. However, compression poses a potential problem for these data - higher frequencies are more prone to compression related artifacts than lower frequencies (such as creating spurious frequencies that are not actually present), and many species of birds have flight-calls in this problematic zone. Although species identification is still possible with these data, no information exists as of yet regarding the extent of potential problems for classification using mp3 or other types of files. Binary files are uncompressed, and as a result take up larger quantities of space that do the same length mp3 files. However, these uncompressed data represent a more accurate representation of the actual sounds recorded, their accuracy compromised only by the choice of sampling size and rate rather than compression attributes and sampling specifications.


Terabytes of Data Collected

over 40 years worth of raw data

Kathryn A. Cortopassi, Measurement & Classification of Acoustic Signals

presented at Bioacoustic Monitoring in the Terrestrial Environment: A Workshop at the James Reserve, Idyllwild CA, 16 October 2008

In the past 10 years, CLO has collected more 220 years worth of acoustic data by time. 30TB is a gross underestimate, but it illustrates the point that software must keep pace with our ability to deploy hardware that can record acoustic information. Additionally, we must keep capacities to store these data. DoD will face a similar problem were it to begin a robust program of acoustic monitoring. However, the opposite side of this continuum is the mountains of paper, effort, and money spent on traditional monitoring that does not accumulate even a fraction of the information collected using acoustic methods.

b. Arrays

We encountered challenges while trying to localize birds in time and space. Array recordings to localize birds in space require absolute time synchronization to determine when sounds reach given portions of an array. Such delays are critically important for determining the origin point of the sound. However, additional problems relating to the resolving power of altitudinal arrays pose concerns as well. Determining the proper distance to position microphones relative to the frequency of the bird vocalizations and relative to the expected heights of migration is critical for implementing the array technology. We feel that much further research is necessary before such a system could precisely and accurately locate birds by their flight-calls. However, we are continuing to investigate new ways of doing exactly this, and in second and third year funding we will be devoting a portion of our recording season to developing these ideas on paper with the goal of trying to test them in the field in the final year of the project.

c. Accelerating pace of software for detection and classification

The processing power and time associated with acoustic data analysis is not a trivial issue. Automating the software to analyze efficiently and effectively the tens of thousands of hours of data we have collected has been a substantially greater challenge than we anticipated. Although we have made great strides, there is still a time constraint that we need to address before widespread application of this approach can reach its most efficient levels. Before beginning this project, analyzing an entire season's (800-1000 hours from a single station) worth of data could not proceed in anything but near-real-time, taking weeks to extract signals of interest and then days to classify them; by the end of Year two, we reduced this time such that it took days to analyze the sound for signals of interest. However, the increasing speed of analysis for signals of interest did not beget a similar reduction to hours of classifying. This process can still take days, although the reduction in time was nearly half of the previous. Although these numbers are two orders of magnitude of improvement from the prior analysis efforts, software speeds, computer processing power, and processing time must improve. We continue to improve these applications, but any future projects should budget substantial funds for software, processing, and storage if possible. In the final year of the project, we began to see a crack in this ceiling, in that processing speeds reached levels of 150-200X faster than real time to extract signals of interest, taking less than a day on a powerful, commercially available Windows XP computer. With this increase we also saw a substantial savings in time for classifying these sounds. However, because of the limitations of the SERDP grant in previous years, the automation of classification did not keep pace with the abilities of detection. Hence, the challenge of dealing with exceptionally large detection datasets from permissive energy detection processes.

A related issue is one of the unwieldiness of large logs, directly related to the energy detection and template detection processes and how permissive each of these approaches is defined by the user. With very permissive detectors, and resultant high likelihood of capturing every event of interest at a cost of massive numbers of false positives, logs of these events of interest and false positives grow extremely rapidly. It is not uncommon, as we have shown in the datasets we have sent on DVD, to have a single station worth of energy detections for a single season reach into the tens of millions. The current file formats available in XBAT could not handle this level of data. Raven, however, was substantially better. Yet in both cases, progress was needed to attempt to eliminate this issue. Progress on this has occurred in the development version of XBAT, such that this platform will take advantage of database management tools such as SQLite to rapidly handle such large management tasks. Raven handles the logging events differently, and this platform has realized some improvements of its own to these ends. For example, Raven selection tables have reached 1.5 million events in current Raven builds and releases, although there are some issues that deal with latency of various actions at this size of log. We have applied Raven to some huge logs, and things are generally working MUCH more smoothly. With the implementation of the new Bioacoustic

Resource Network in early 2009, we hope that some of the lingering problems that remain in accessing logs through Raven and/or XBAT and back again will begin to disappear.

Multiple band energy detection is critical for saving time, because at present we use a single, 1500 Hz bandwidth for detection requiring six different passes through a given data stream to collect flight-call data. This approach was functional but time consuming in XBAT. In Raven, we had comparable success using only two, 4500 Hz bandwidths. However, the problem remains the same - multiple simultaneous bandwidth detection does not yet exist. Pursuing its development would be a big time saver, reducing analysis time by at least 50% and at most 75-85%. We explored fixes to this in Raven, including allowing for multiple detectors running at once. However, this approach quickly reached the limit of typical processor power on an average computer - with a high speed, 64 bit computer, multi-threading could make this more feasible. However, success in reducing time as a function of multiple bandwidth detection will not be realized until true multi-band detectors exist.

d. Contamination and Detectability Issues

We found extensive contamination in sound files from non-avian noises such as insects and non-biological sources such as aircraft, gunfire, and automobiles. Placement of recording units in quiet areas is critical for recording bird vocalizations. However, non-biological noise is relatively easy to filter; it sounds and looks distinct from bird vocalizations, and it is possible to create some algorithms to remove effects of this noise. Insect noise is a greater problem, particularly in that many species of grasshoppers and crickets produce sounds in the range of many flight-calls. As such, positioning microphones away from trees will minimize effects of katydids and some other insects. Positioning microphones away from grassy areas, if possible in paved locations or on top of buildings, will greatly minimize effects of insect noise. Although non-biological noise is relatively easy to filter by eye, by ear, and by machine, it still poses a problem. During periods in which aircraft pass over microphones, no flight-calls can be recorded. The amount of noise from these sounds relative to the volume of flight-calls differs by orders of magnitude. This problem also occurs for other sounds such as gunfire and exploding ordnance. However, all of these are sporadic sources of noise, not continuous, and therefore simply pose problems when they occur. Wind and road noise, particularly noise from Interstates or heavily traveled roads, could pose more of a problem. However, most of this noise, though continuous, is low frequency noise below the range of most flight-calls. The most likely species with which such noise would interfere, however, are larger migrant herons and waterfowl, species that could pose significant threats for bird strike hazard. With this in mind, positioning units to minimize continuous low frequency noise and sporadic high energy noise is a must.

Our lack of understanding of detectability still proves to be a major hindrance in widespread application of acoustic monitoring for quantification purposes. Although we have shown that acoustic monitoring is an invaluable tool for assessing species composition and for understanding calling phenology, it can be much more powerful if we can understand detection functions. This type of work requires the application of ARUs at a much higher density and greater scale than we have been able to do with funding limitations, but this is critical for advancing the technology of detectability. Additionally, there are still problems that relate to the vocalizations themselves - some species do not vocalize frequently or at all during local or migratory movements, so surveying them bioacoustically is not a realistic option. This is especially true if we do not understand their calling rates, the detectability of these calls, and even the identification of these calls.

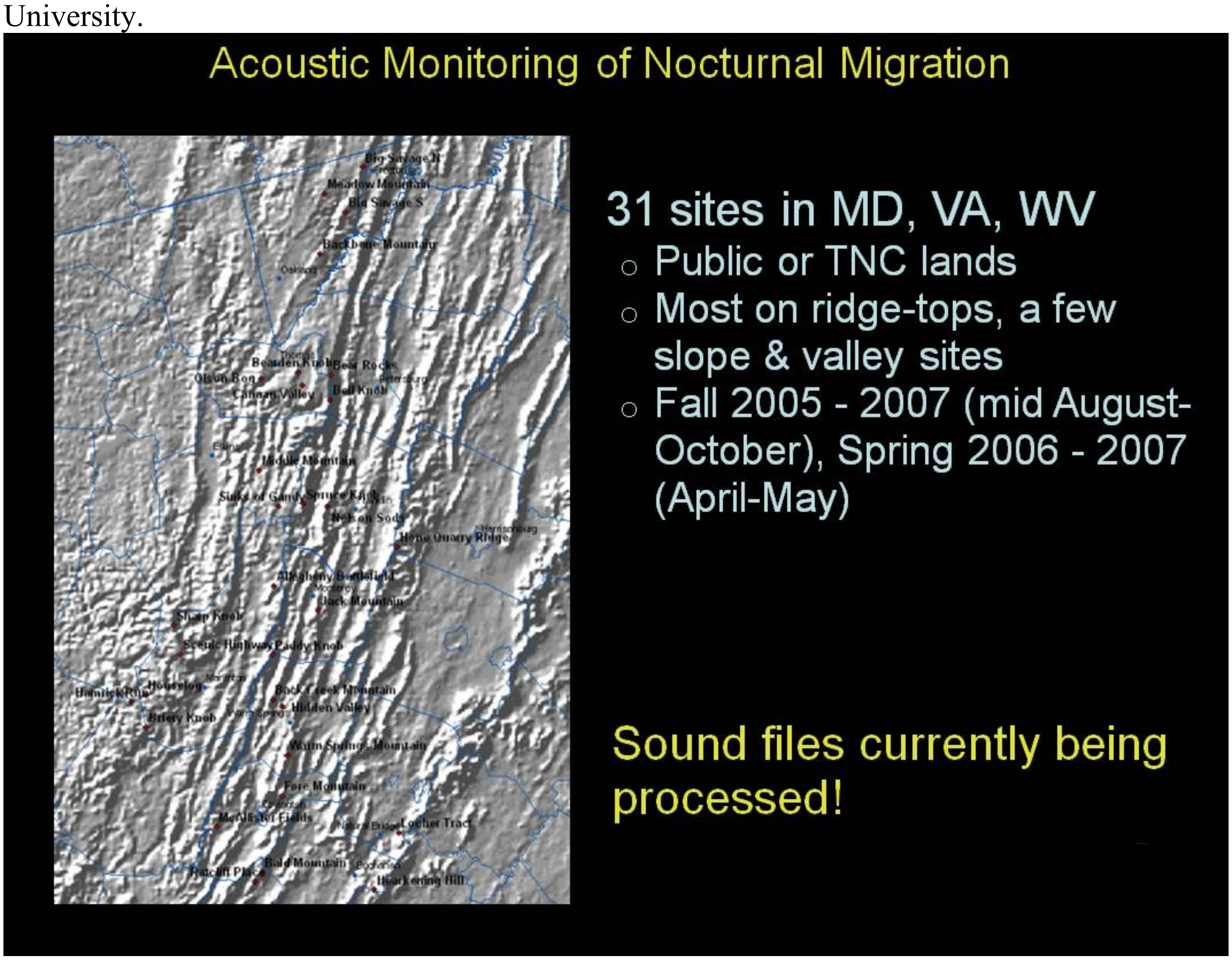
4. Additional monitoring and partnerships

The three components of this proposal are part of a long-term effort to enhance bird-monitoring capabilities through innovative acoustic and internet technologies. We are expanding the field testing and deployment of autonomous recording units from the first year to include additional DoD and non-DoD installations in future years, with the plan to provide eventually the capacity to serve all DoD lands as well as adjacent regions. As such, the local networks of FC monitoring stations on and around DoD bases would form the start of what will eventually be a continent-wide network that would provide measures of species migration traffic on regional and continental scales. Additionally, we will be expanding our acoustic monitoring in spring 2007 to develop and to test protocols to monitor species that vocalize infrequently by deploying ARUs over periods of weeks or months to document changes in vocalization rates in relation to environmental factors at breeding sites where the local density is known. In particular, we are planning to deploy units to monitor rare species (Black Rail) and species that vocalize infrequently (Whip-poor-will).

The innovative monitoring network we proposed and the data we have begun to collect provides the tools and the information to monitor migratory activity by species, contribute towards more accurate population estimates for these species, and provide information for more accurate environmental risk assessments (Migratory Bird Treaty Act and Endangered Species Act) and Integrated Natural Resource Management Plans. The proposed migratory bird network documents migratory phenomena that are unobservable by other means, and enable studies that extend beyond the boundaries of DoD installations, addressing three challenges confronting DoD: acquiring more detailed information to reduce bird strike hazards, meeting environmental stewardship obligations while managing the ongoing financial and operational costs, and engaging broader societal support and solutions for environmental problems.

We are facilitating increased partnerships through our monitoring efforts from the first year of this project. An important collaborative adjunct to this work is the extensive nocturnal flight-call monitoring project headed by Deanna Dawson (USGS) and Tim Jones (USFWS) as part of the Atlantic Coast. Beginning in spring 2007, we collaborated explicitly with this group to expand our network of flight-call monitoring stations, facilitating collection of larger training datasets and improved and increased comparative analysis of migration across a broader geographic context. What began as a project focused in the Northeastern US expanded to include numerous locations in the Central, Southwestern, and Northwestern US. As such, this type of project leads directly to the expansion of acoustic monitoring networks to the continental scale. Such a network could, in the future, produce real-time, species-specific data on migration patterns.

Additionally, this project has facilitated the ability to monitor difficult to survey species, such as Black Rail, Yuma Clapper Rail, and Whip-poor-will, with greater ease and objectivity, critically important aspects for advancing the abilities of acoustic monitoring. Numerous opportunities exist for DoD to collaborate with outside institutions and organizations and for DoD to reach many new demographics through outreach and education. As an example, we fostered new partnerships with a variety of contacts and organizations including: Mike Wilson and Fletcher Smith, William and Mary University (in-kind), responsible for deployment of ARUs to monitor Black Rails in the Chesapeake region (possibility of acquiring monetary contributions for additional data analysis of $3000 in the Fall 2007); Andy Paulios, Wisconsin Department of Natural Resources (in-kind), responsible for contacts and aid in deploying units in the central United States; Rich Fischer (ACoE) and Sidney A Gauthreaux (Clemson University), facilitated collection of acoustic data from Yuma SERDP project; Ian Agranat (Wildlife Acoustics), with whom we are investigating novel ARU design; and Mike Lanzone (Powdermill Avian Research Center), with whom we have been exploring software evaluation. We also collaborated with a critically important effort to advance classification of flight calls. A private donation to CLO supported Harold Figueroa and Kathryn Cortopassi for statistical modeling and developing software on a project on which Andrew Farnsworth explicitly collaborated and Legacy data were used. This type of collaboration required no expenditure of funds for Legacy on tasks not relevant to its mission, rather it applied data collected during our activities to a problem for which a solution will have direct Legacy benefits. In fact, the benefit to DoD in terms of increased automation and efficiency from such collaborations, this one in particular, will be huge. Additionally, we have presented data at several professional meetings in the United States and Europe, including the American Ornithologists' Union annual meeting, the Western Field Ornithologists meeting, a joint meeting of the Acoustical Society of America, the European Acoustical Society, and Euronoise at Acoustics08 in Paris, and numerous presentations to local bird clubs and university seminars including Georgia Southern University and Cornell University.



Acoustic Monitoring of Nocturnal Migration

31 sites in MD, VA, WV

- Public or TNC lands
- Most on ridge-tops, a few slope & valley sites
- Fall 2005 - 2007 (mid August-October), Spring 2006 - 2007 (April-May)

Sound files currently being processed!

In collaboration with Deanna Dawson (USGS) and Tim Jones (USFWS), we deployed mp3 style ARUs in the Appalachians between 2005-2007. The primary goal was to index abundance and species composition from flight calls. Ideally, we could identify birds flying within altitudinal zone that could be occupied by wind turbines in the future, or similarly we could identify targets passing over a DoD installation. In the future, this extensive and unique dataset will be an ideal source of information to model effects of geographic location, topography, weather, and time of night or season on migrant abundance.

Benefits to the Military Mission

DoD installations require accurate measurements of migratory landbird migration patterns and population sizes. For most installations neither an inventory of bird species nor year round inventories of all bird species that provides a continuous database on the distribution and abundance of birds at these sites exists. Our innovative monitoring network provides tools to monitor migratory activity by species, contribute towards more accurate population estimates for these species, and provide information for more accurate environmental risk assessments (MBTA and ESA) and Integrated Natural Resource Management Plans (INRMPs). This network documents migratory phenomena unobservable by other means and enables studies extending beyond the boundaries of DoD installations. We addressed three challenges confronting DoD - acquiring more detailed information to help reduce bird strike hazards, meeting environmental stewardship obligations while managing ongoing financial and operational costs, and engaging broader societal support and solutions for environmental problems.

Conclusions

We have shown that acoustic monitoring can provide invaluable and otherwise unavailable information on the presence and behavior of many species of birds, including many migratory species and target species of concern. We support and encourage applying the types of data we collected to developing protocols for future acoustic monitoring and to developing better protocols for more informed, traditional monitoring techniques. DoD installations can deploy ARUs to collect long term data on species composition, target species behavior, and temporal patterns of site usage, and they can now do so with increasing ease. The advances that we have made in sound analysis software for automating much of the processing of these data make it feasible for an expert to examine sound data from many locations simultaneously, thus expanding his abilities to do so while minimizing costs of extensive travel, multiple observers, and lengthy phases on analysis. We foresee the applications of this technology in many ways, all of which are directly applicable to the needs of local DoD installation missions. For example, using acoustic data to produce maps of bird migration with species-level detail; we can map the distribution of species in space and time, including information about stopover habitats and associated anthropogenic and meteorological factors, and then use these data to uncover migration strategies and to access risks to migrants posed by military or management activities. This has ramifications for target species of concern as well; for example, these methodologies allow a biologist to produce spatial and temporal distribution maps of species of interest and their calling behaviors, critical information to enhance the success of observers seeking to find and to study species on DoD lands.

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Special thanks to the DoD Legacy Resource Management Program for supporting three years of research (05-245, 06-245, 07-245). We thank, in particularly, Peter Boice for the sum of our support from Legacy projects (05-245, 06-245, and 07-245). This support was a primary source for funding for research on terrestrial acoustic monitoring of birds at Cornell Laboratory of Ornithology between 2005-2008. This funding was critical for advancing the automation of hardware and software for monitoring migratory birds. Additionally, this support facilitated the development of a data management tool for entering, archiving, and visualizing bird observations. This funding has been the only consistent source for supporting this research, and this support has produced some invaluable data, methods, and analyses. Without Legacy support, these advances would not have occurred.

We also thank, in particular, Pedro Morales and Jane Mallory for assisting us with our reporting and logistical questions, and for generally making administrative details easy to handle. Special thanks to all our contacts at DoD PiF and ACoE, particularly Chris Eberly, Rich Fischer, Joe Hautzenroder, and Dana Bradshaw, for helping us to develop our proposals and ideas and supporting our cause in all DoD meetings; additionally, thanks to Rich Fischer for allowing us to collaborate with him and his team on Yuma research with Dr Sid Gauthreaux.

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