

Detection Statistics for Cuvier’s beaked whales and Blainville’s beaked whales on the Marine Mammal Monitoring on Navy Ranges (M3R) System at the Atlantic Undersea Test and Evaluation Center (AUTEK)

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3 September 2023



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ADMINISTRATIVE INFORMATION

The research described in this technical memo was performed under funding from the Naval Sea Systems Command (NAVSEA) 09SE and the Living Marine Resources Program.

ACKNOWLEDGMENTS

This project was funded by NAVSEA 09SE and the Living Marine Resources Program. Data collection and collaborative tests at AUTECH by M3R were supported by NAVSEA 0-9SE (Ben Colbert, Rose Johnson, and Shelby Creager), the U.S. Chief of Naval Operations (CNO) N4i Living Marine Resources (LMR) program (Anu Kumar, Mandy Shoemaker), and the Office of Naval Research (ONR) (Michael Weise). M3R team members, Ronald P. Morrissey Code 7021, Susan M. Jarvis Code 7021, Nancy A. DiMarzio Code 709, Elena M. McCarthy Code 0CA3, and Jessica A. Shaffer Code 259 provided critical assistance with data collection. Additionally, AUTECH Range Control provided support, and Dave Moretti and Ashley Dilley formerly from NUWC Division Newport.

REPORT DOCUMENTATION PAGE

1. REPORT DATE 03092023		2. REPORT TYPE Technical Memorandum		3. DATES COVERED	
				START DATE 01-10-2022	END DATE 30-09-2023
4. TITLE AND SUBTITLE Detection Statistics for Cuvier's beaked whales and Blainville's beaked whales on the Marine Mammal Monitoring on Navy Ranges (M3R) system at the Atlantic Undersea Test and Evaluation Center (AUTEK)					
5a. CONTRACT NUMBER N/A		5b. GRANT NUMBER N/A		5c. PROGRAM ELEMENT NUMBER N/A	
5d. PROJECT NUMBER N/A		5e. TASK NUMBER N/A		5f. WORK UNIT NUMBER N/A	
6. AUTHOR Stephanie L. Watwood					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Undersea Warfare Center Division 1176 Howell Street Newport, RI 02841-1708				8. PERFORMING ORGANIZATION REPORT NUMBER TM 23-087	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Naval Sea Systems Command 1333 Isaac Hull Avenue, SE Washington Navy Yard, DC 20376			10. SPONSOR/MONITOR'S ACRONYM(S) NAVSEA		11. SPONSOR/MONITOR'S REPORT NUMBER(S) N/A
12. DISTRIBUTION/AVAILABILITY STATEMENT DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES N/A					
14. ABSTRACT Several species of beaked whales appear to be particularly sensitive to mid-frequency active sonar (MFAS); Cox, et al. 2006; D'Amico, et al., 2009)). The U.S. Navy maintains an instrumented training range, the Atlantic Undersea Test and Evaluation Center (AUTEK) on which exercises are regularly conducted with MFAS, and where species including Blainville's beaked whales (<i>Mesoplodon densirostris</i> , hereafter <i>Md</i>), Cuvier's beaked whales (<i>Ziphius cavirostris</i> , hereafter <i>Zc</i>), and Gervais' beaked whales (<i>Mesoplodon europeaus</i> , hereafter <i>Me</i>) are routinely acoustically detected and visually observed (Gillespie et al. 2009, Tyack et al. 2011, McCarthy et al. 2011). Beaked whales have been shown to respond to sonar in variety of ways, including cessation of foraging and avoidance of the area (REFS- are there references that need to be entered?). The Marine Mammal Monitoring on Navy Ranges (M3R) program has collected a long term data set of acoustic detection archives at AUTEK to provide further insight into the distribution, vocal activity and habitat use of beaked whales on the range. The aim of this project is to use this dataset to evaluate the long-term temporal and spatial distribution and habitat use of beaked whales at AUTEK. This technical memo describes the derivation of detection statistics for two species of beaked whales at AUTEK, <i>Zc</i> and <i>Md</i> . These results are important for long-term monitoring of population abundances on the range.					
15. SUBJECT TERMS Blainville's beaked whale, Cuvier's beaked whale, <i>Mesoplodon densirostris</i> , <i>Ziphius cavirostris</i> , Passive Acoustic Detection, Abundance, Density					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT		18. NUMBER OF PAGES
a. REPORT U	b. ABSTRACT U	c. THIS PAGE U	SAR		25
19a. NAME OF RESPONSIBLE PERSON Stephanie L. Watwood				19b. PHONE NUMBER (Include area code) 401-832-4929	

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LIST OF ABBREVIATIONS AND ACRONYMS

AG	Auto-grouper
AUTEC	Atlantic Undersea Test and Evaluation Center
BINFFT	Binary FFT map
CLASS	Algorithm Class
CLK	Click Samples
CNO	Chief of Naval Operations
CNT	Sample Count
CS-SVM	Class-Specific Support Vector Machine
CTP	Click-Train Processor
DET	Detector ID
DoD	Department of Defense
DT	Delta-T, Time Difference Successive Detections (sec)
FFT	Fast Fourier Transform
FM	Frequency Modulated
FN	False Negative
FP	False Positive
F _s	Sampling Frequency
FT	Fixed Threshold (volts)
FX	Quality Factor
GD	Generalized Dolphin
GVP	Group Vocal Period
H	Hydrophone
HYD	Hydrophone
ICI	Inter-Click Interval
ID	Identifier
LMR	Living Marine Resources
M3R	Marine Mammal Monitoring on Navy Ranges
Max	Maximum

LIST OF ABBREVIATIONS AND ACRONYMS (Cont'd)

<i>Md</i>	<i>Mesoplodon densirostris</i> (Blainville's beaked whale)
<i>Me</i>	<i>Mesoplodon europaeus</i> (Gervais' beaked whale)
MFAS	Mid-Frequency Active Sonar
Min	Minimum
MMAMMAL	Marine Mammal Monitoring and Localization Program
n	Number
NAVSEA	Naval Sea Systems Command
NDET	Number of Binary FFT Bins Set to 1
NPT	Newport
NUWC	Naval Undersea Warfare Center
NVT	Noise-Variable Threshold (dB)
ONR	Office of Naval Research
PD	Probability of Detection
PKBIN	FFT Bin Index of Peak Frequency
PKFRQ	Peak Frequency (Hz)
PKMAG	Magnitude of Peak Frequency (volts)
<i>Pm</i>	<i>Physeter macrocephalus</i> (sperm whale)
ps	Parameter Set
R	Report Number
RL	Receive Level
RMS	Root-Mean-Square
RQ	Requirement
S	Sensor
SVMJ	Name for the CS-SVM Report Type, Used In the Classifier Message Report
SYS	System
TDOA	Time Difference of Arrival
TH	Selected Threshold (Higher of NVT/FT)
TMO	Timeout
TOTO	Tongue of the Ocean
TRES	Time Resolution (sec)
TYP	Type (Algorithm:Class)
U.S.	United States
UTC	Coordinated Universal Time
<i>Zc</i>	<i>Ziphius cavirostris</i> (Cuvier's beaked whale)

1. INTRODUCTION

One aim of the Marine Mammal Monitoring on Navy Ranges (M3R) program is to use passive acoustics to characterize the long-term temporal and spatial distribution and habitat use of beaked whales on the Navy's instrumented ranges. This will enable a better understanding of beaked whale behavior and ecology and the associated impacts of man-made sounds.

Blainville's beaked whales (*Mesoplodon densirostris*, hereafter *Md*), Cuvier's beaked whales (*Ziphius cavirostris*, hereafter *Zc*), and Gervais' beaked whales (*Mesoplodon europeaus*, hereafter *Me*) are often acoustically detected and visually observed on the Atlantic Undersea Test and Evaluation Center (AUTEK). *Md* and *Zc* are the primary species involved in a number of mass stranding events linked to the use of mid-frequency active sonar (MFAS; Cox, et al. 2005; D'Amico, et al., 2009); however, they are regularly detected on the AUTEK range, where MFAS is routinely used during training exercises.

The M3R program has collected a multiyear passive acoustic dataset of *Md* and *Zc* vocalizations that can be used to carry out this study. M3R has also developed software tools to automatically generate *Md* and *Zc* animal groups (the auto-grouper program) based on detections of their vocalizations. The project seeks to develop detection statistics for the auto-grouper program to improve long-term abundance estimates of beaked whales at AUTEK.

2. METHODS

2.1 STUDY SPECIES

Zc are medium-sized oceanic whales that live in small mixed composition groups of about two-to-four animals (Falcone, et al., 2009; Baird, et al., 2006), and are usually found in deep offshore waters. They have the widest distribution of beaked whales, being found in all waters except high polar regions (Heyning, 1989; MacLeod, et al., 2005). Typical of beaked whales, *Zc* use echolocation to hunt for mesopelagic and bathypelagic squid and fish during breath-hold dives to over 1,000 m, for an average of nearly an hour (Santos, et al., 2007; Tyack, et al., 2006). *Md* in the Bahamas are found in small groups of 1–11 animals with a mean observed group size of 4.1 animals (Claridge 2006). They echolocate during deep foraging dives that can exceed 1,000 m in depth, may last for more than 60 min, and occur approximately every 2 h (Tyack et al. 2006, Baird et al. 2008). *Me* prefer deep tropical, subtropical, and warm temperature of the Atlantic Ocean. *Me* is the most common species of Mesoplodont to strand along the U.S. Atlantic Coast (Mead 1989).

During deep foraging-dives, beaked whales produce two distinct types of click vocalizations: loud, directional frequency-modulated (FM) echolocation foraging-clicks above 20 kHz with inter-click intervals of approximately 0.2–0.75 s (depending on the species) and rapid trains of lower source level “buzz” clicks just prior to attempted prey capture (Johnson, et al., 2004, 2006; Zimmer, et al., 2005). While a group of beaked whales is on a deep foraging dive, the individuals will vocalize for approximately 20–40 minutes (Tyack, et al., 2006). Due to their directed beam pattern (Shaffer et al. 2013) these clicks will be detected on a small number of neighboring hydrophones as the animals change direction and move their heads.

2.2 STUDY AREA

AUTEC is located south of the Northwest Providence Channel in a deep canyon known as the Tongue of the Ocean (TOTO) with water depths to 2,000 m. It is bounded on two sides by very shallow waters. The AUTEC range covers an area of approximately 1,500 km² that is instrumented with 82 bottom-mounted hydrophones that provide three-dimensional tracking of undersea vehicles. The hydrophones are optimally spaced for direct-path tracking of underwater targets and vehicles equipped with 35-kHz pingers. Because *Md* produce echolocation clicks with source levels similar to those of *Zc*, which are estimated at up to 214 dB, this layout assures their detection (Zimmer et al. 2005, Tyack et al. 2006).

2.3 PASSIVE ACOUSTIC MONITORING

The M3R system display allows for passive acoustic monitoring of activity on the range. The Marine Mammal Monitoring and Localization Program (MMAMMAL) display shows acoustic activity across the range, in real-time or via playback of detection archive files, by color coding the hydrophones (Figure 1). Windows of scrolling binary spectrograms can be launched by clicking on the hydrophones to visually verify the species or sound source present. Figure 1 shows the locations of two groups of *Md*, one group of *Zc*, and one group of sperm whales (*Physeter macrocephalus*).

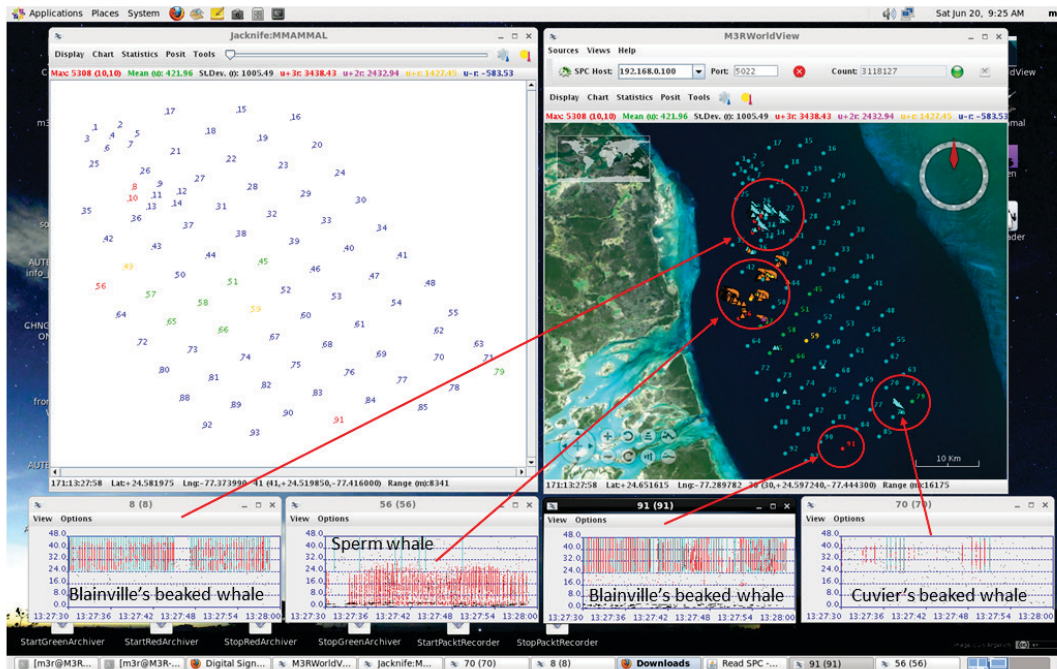


Figure 1. MMAMMAL Display on the left, Worldwind on the right, and Binary Spectrograms along the bottom showing two groups of *Md*, one *Zc* group, and one group of sperm whales.

2.4 DATASETS

The M3R system uses the bottom-mounted hydrophones on the Navy test and training ranges to automatically detect, classify, and localize marine mammal vocalizations in real time (Jarvis, et al., 2014). M3R collects continuous, year-round archives of acoustic detections, time differences of arrival (TDOAs), and localizations from all range hydrophones, and periodically gathers raw acoustic recordings from all hydrophones on the range. These archive files include both marine mammal vocalizations and sonar, and can be replayed for later analysis (McCarthy, et al, 2011; Shaffer, et al., 2013). The acoustic detection archives are the primary source of data for this project.

The two types of detection archives of interest are those from the Class-Specific Support Vector Machine (CS-SVM) classifier (Jarvis, 2012), and the fast Fourier transform (FFT)-based spectral domain energy detector referred to as “Whdetect” (Jarvis, et al; 2014; Morrissey, et al., 2006). The CS-SVM detector provides robust real-time, automated detection and classification of six different categories of call types within four classes: *Md* (Blainville’s beaked whale, *Mesoplodon densirostris*, foraging and buzz clicks), *Zc* (Cuvier’s beaked whale foraging and buzz clicks), sperm whale clicks, and delphinid clicks (Jarvis, 2012; METEOR, 2014). Whdetect is the original detector used within the M3R system. The output of this detector is used to generate the binary spectrograms in the MMAMMAL display program (Figure 1) that are used to manually review the data.

2.5 BEAKED WHALE GROUP DETECTIONS

The first step in the data preparation for calculating beaked whale abundance is to extract the beaked whale groups present on the AUTEK range, and to reliably characterize the group detection process. As the process of manually identifying groups for the multi-year dataset is too cumbersome to be practical, an auto-grouper (AG) program is run on the data to extract *Zc* and *Md* groups. Detection statistics must be obtained for the AG program. These detection statistics are then used to derive false-positive and false-negative correction factors that are applied to the AG output to find the actual number of *Md* and *Zc* groups on the range.

Several steps are involved in automatically detecting *Md* and *Zc* groups. Clicks are first detected using a detection algorithm such as the CS-SVM classifier; clicks from a given detector and class are then formed into click-trains on a per-hydrophone basis using the click-train processor (CTP) program; and finally, the click-trains are automatically formed into groups with the AG program. For this analysis, two detectors are used: the CS-SVM classifier and the FFT-based Whdetect detector.

2.5.1 Click Detection

2.5.1.1 CS-SVM

The CS-SVM algorithm detects and classifies signals into a number of classes, based in part on the particular Navy range and implementation. When the classifier was initially installed at AUTEK, it had six classes:

1. *Md* *Mesoplodon densirostris*
2. *Zc* *Ziphius cavirostris*
3. *Gm* *Globicephala macrorhynchus*
4. *Gg* *Grampus griseus*
5. *Pm* *Physeter macrocephalus*
6. *Sa* *Stenella attenuata*

As of May 2014 the dolphin classes 3, 4, and 6 were combined into a “generalized dolphin” (GD) class (8) and the *Md* buzz (51) and *Zc* buzz (52) classes were added (METEOR, 2014). Therefore, CS-SVM at AUTECH currently has the following six classes:

1. *Md* *Mesoplodon densirostris*
2. *Zc* *Ziphius cavirostris* foraging-click
5. *Pm* *Physeter macrocephalus*
8. GD generalized dolphin
51. *Md* *Mesoplodon densirostris* buzz click
52. *Zc* *Ziphius cavirostris* buzz-click.

For each classifier detection, a CS-SVM message report is generated. Figure 2 shows an example of two detection report messages, one for a *Zc* foraging-click and one for a GD-click. The highlighted fields show the sensor, classifier report type (CS-SVM, referred to here as SVMJ), and the class. Other fields include the report number, the detection timestamp, the sample count, and the 44 boxcar samples. FX is a quality factor (FX): the magnitude of the output of the detector, which indicates the strength of the class. Following the click samples (CLK) are the CLK values, normalized so that the peak magnitude is the absolute value of 30,000. Prior to May 2014 Delta-T, (the time difference between successive detections (sec) (DT)) indicated the time since the last detection; after it showed the inter-click interval (ICI) used by the classifier.

```
R:4502023 DDS:09 DET:09509 S:509 H:509 TM:266:16:31:46.444136 CNT:00000604:2595336496640
SYS:CLASS TP:SVMJ(1) CLASS:Zc(2) FX:0.6516369 BXLEN:44 DT:0.45 CLK:185,89,90,-152,-216,
48,120,131,160,-85,-49,-249,34,342,-1172,1419,2997,-8429,7482,-6159,6935,7617,-30000,21698,6909,-
14482,12054,-10065,-5983,5776,19549,-22121,7219,-3666,-410,739,4312,2830,-7371,1395,-2392,6129,-
4523,2273,
R:4898217 DDS:09 DET:09101 S:101 H:101 TM:266:16:31:46.473988 CNT:00000604:2595467845120
SYS:CLASS TP:SVMJ(1) CLASS:GD(8) FX:0.453025 BXLEN:44 DT:0.11 CLK:-699,-981,-
1041,1604,155,267,1465,-1026,-810,-100,-2032,-974,4239,3269,-3092,-1935,-1339,443,-2047,13620,-13331,-
10952,30000,-10520,-10814,-792,3839,4786,2369,-2527,-2737,-1417,211,1067,743,856,556,-455,-1089,-581,-
1186,1180,1601,140,
```

Figure 2. CS-SVM Detection reports for *Zc* and GD.

2.5.1.2 Whdetect

The Whdetect algorithm generates detection reports that include a hard-limited, or binary FFT. Figure 3 shows an example of the detection report. The highlighted fields show the sensor, report type (Whdetect or WH), various FFT parameters, and the binary FFT (or BINFFT) that is

HYD	TYP	TH	RQ	TMO	CNT	START		STOP		DT	ICI
703	12:05	-1	5	180	5	2015	014:00:09:37.870694	2015	014:00:10:15.534693	37.664	0.221333
703	12:00	-1	5	180	22	2015	014:00:07:26.521360	2015	014:00:10:15.534693	169.013	0.3885919
303	12:01	-1	5	180	2990	2015	013:23:40:21.539912	2015	014:00:10:25.582577	1804.04	0.4414427
608	17:02	-1	5	180	36	2015	013:23:52:51.196103	2015	014:00:10:25.466624	1054.27	0.4927931
607	17:05	-1	5	180	11	2015	014:00:09:22.218992	2015	014:00:10:26.683200	64.4642	0.409333
607	17:02	-1	5	180	15	2015	014:00:08:55.681054	2015	014:00:10:28.291565	92.6105	0.3744269
107	17:03	-1	5	180	7	2015	014:00:08:16.457119	2015	014:00:10:29.422839	132.966	0.0829738
64	12:03	-1	5	180	5	2015	014:00:10:27.315275	2015	014:00:10:29.437965	2.12269	0.2613388
508	12:03	-1	5	180	266	2015	013:23:59:22.179362	2015	014:00:10:42.392695	680.213	0.1620577
305	17:04	-1	5	180	12474	2015	013:22:54:00.621685	2015	014:00:10:46.412663	4605.79	0.1560063
309	17:05	-1	5	180	22	2015	013:23:55:27.804045	2015	014:00:10:48.507930	920.704	0.2703853

2.5.3 Autogrouper

The Autogrouper is a Matlab program that associates beaked whale click-trains that are close in time and space to form beaked whale group vocal periods (GVPs) that are used to represent the time that a group of beaked whales is vocalizing during a deep foraging dive. The GVPs are automatically generated through several software processing steps. Cuvier's or Blainville's beaked whale foraging clicks detected with the CS-SVM classifier are each first combined into click-trains on a per-hydrophone basis, then click-trains are used to form groups, and the resulting group data are filtered and post-processed in the report number (R).

The Autogrouper program uses a set of rules based on time and location of the click-trains to associate the CTP click-trains into GVPs. For Cuvier's beaked whales only click-trains with an ICI greater than or equal to 0.35 sec and an ICI less than or equal to 0.75 sec, and with duration greater than 1 min and less than 60 min, are used in the grouping process. Blainville's beaked whale click-trains with an ICI between 0.23 and 0.4 sec are used. Locations are based on the hydrophone locations, with the beaked whale group center being the hydrophone with the highest click density (number of clicks per min). To form a GVP, the click-trains must be within 9.75 km of the group center.

2.6 DETECTION STATISTICS

Md and *Zc* groups generated by the AG program were compared to a manual review of samples of the archive data using MMAMMAL. The *Md* and *Zc* groups determined by manual review were considered "truth," and the probability of detection (PD), percent of false-negatives (FNs), and percent of false-positives (FPs), and FN and FP correction factors were calculated for the AG program.

2.6.1 Manual Review

Detection statistics were generated for the AG program by comparing the *Md* and *Zc* groups produced by the AG with *Md*, *Zc*, and *Me* groups found during the same time periods by manual analysis, using MMAMMAL. In generating the detection statistics, the groups found manually were considered the truth. Correction factors, derived from the detection statistics, were applied to the AG group dive start results to find the true number of group dive starts present.

Fifty random one-hour samples were identified between 2010 and 2018 and manually reviewed for the presence of *Md*, *Zc*, and *Me* (Table 2). Group vocal periods (i.e., group dives) that began within the one-hour sample period, were used for the analysis. Samples hours were distributed across hours of the day, days of the year, and years (Figure 4).

Table 2. Archives manually reviewed.

Sample	Date	Julian Day	Archive File Name	Archives	UTC Hour start	UTC Hour stop
1	12/5/2018	339	spc-20181201-220051.arch.gz	102-103	10:00	11:00
2	12/3/2018	337	spc-20181201-220051.arch.gz	32-33	8:00	9:00
3	7/10/2016	192	spc-20160709-063335.arch.gz	37-38	17:00	18:00
4	7/16/2016	198	spc-20160716-084435.arch.gz	11-12	22:00	23:00
5	6/30/2016	182	spc-20160630-110645.arch.gz	1-2	15:00	16:00
6	7/11/2014	192	spc-20140710-174556.arch.gz	7-8	3:00	4:00
7	7/11/2014	192	spc-20140710-174556.arch.gz	15-16	10:00	11:00
8	8/5/2013	217	spc-20130805-053534.arch.gz	10-12	15:00	16:00
9	8/5/2013	217	spc-20130805-053534.arch.gz	3-5	12:00	13:00
10	3/14/2013	73	spc-20121212-111402.arch.gz	2328-2329	6:00	7:00
11	1/22/2013	22	spc-20121212-111402.arch.gz	1012-1013	5:00	6:00
12	9/5/2012	249	spc_20120710_port5022.arch.gz	709	7:00	8:00
13	12/23/2012	358	spc-20121212-111402.arch.gz	290	16:00	17:00
14	8/12/2012	225	spc_20120710_port5022.arch.gz	399	21:00	22:00
15	5/5/2012	126	spc_20120504_port5022.arch.gz	21-23	1:00	2:00
16	5/11/2011	131	spc_04272011_port5022.arch.gz	683-685	0:00	1:00
17	4/18/2011	108	spc_02112011_port5022.arch.gz	3263-3265	3:00	4:00
18	2/22/2011	53	spc_02112011_port5022.arch.gz	541-543	20:00	21:00
19	7/9/2014	190	spc-20140708-164537.arch.gz	15-17	9:00	10:00
20	5/3/2015	123	spc-20150502-092742.arch.gz	16-17	4:00	5:00
21	5/10/2015	130	spc-20150507-064446.arch.gz	111-112	11:00	12:00
22	6/20/2015	171	spc-20150619-161304.arch.gz	8-9	2:00	3:00
23	10/24/2015	297	spc-20151023-081230.arch.gz	32-33	13:00	14:00
24	11/2/2015	306	spc-20151029-165954.arch.gz	123-124	23:00	0:00
25	7/4/2016	186	spc-20160703-140157.arch.gz	19-20	14:00	15:00
26	7/23/2016	204	spc-20160722-083822.arch.gz	14-15	0:00	1:00

Sample	Date	Julian Day	Archive File Name	Archives	UTC Hour start	UTC Hour stop
27	6/9/2017	160	spc-20170609-141926.arch.gz	1-3	19:00	20:00
28	12/2/2018	336	spc-20181201-220051.arch.gz	11-12	13:00	14:00
29	4/29/2010	119	spc0427100929L_port5020.arch.gz	101-102	12:00	13:00
30	5/19/2010	139	spc0509101936L_port5022.arch.gz	472-474	2:00	3:00
31	6/9/2010	160	spc0509101936L_port5022.arch.gz	1581-1583	11:00	12:00
32	12/21/2011	355	spc_20111201_port5022.arch.gz	1000-1003	22:00	23:00
33	10/25/2011	298	spc_20111025_port5022.arch.gz	2-4	19:00	20:00
34	11/6/2011	310	spc_20111025_port5022.arch.gz	559-662	5:00	6:00
35	11/6/2011	310	spc_20111025_port5022.arch.gz	559-662	6:00	7:00
36	5/4/2012	125	spc_20111201_port5022.arch.gz	7786-7789	12:00	13:00
37	6/11/2010	162	spc-20100611-101842.arch.gz	3-6	16:00	17:00
38	7/10/2014	191	spc-20140708-164537.arch.gz	38-49	7:00	8:00
39	7/10/2014	191	spc-20140708-164537.arch.gz	38-49	8:00	9:00
40	7/10/2014	191	spc-20140710-105850.arch.gz	2-5	16:00	17:00
41	7/10/2014	191	spc-20140710-105850.arch.gz	2-5	17:00	18:00
42	7/10/2014	191	spc-20140710-105850.arch.gz	2-5	18:00	19:00
43	7/10/2014	191	spc-20140710-105850.arch.gz	1-2	15:00	16:00
44	7/20/2016	202	spc-20160716-084435.arch.gz	100-103	2:00	3:00
45	7/20/2016	202	spc-20160716-084435.arch.gz	100-103	3:00	4:00
46	7/25/2016	207	spc-20160724-153541.arch.gz	10-13	3:00	4:00
47	7/25/2016	207	spc-20160724-153541.arch.gz	10-13	4:00	5:00
48	7/25/2016	207	spc-20160724-153541.arch.gz	10-13	5:00	6:00
49	7/25/2016	207	spc-20160724-153541.arch.gz	19-22	12:00	13:00
50	7/25/2016	207	spc-20160724-153541.arch.gz	19-22	13:00	14:00

Coordinated Universal Time (UTC)

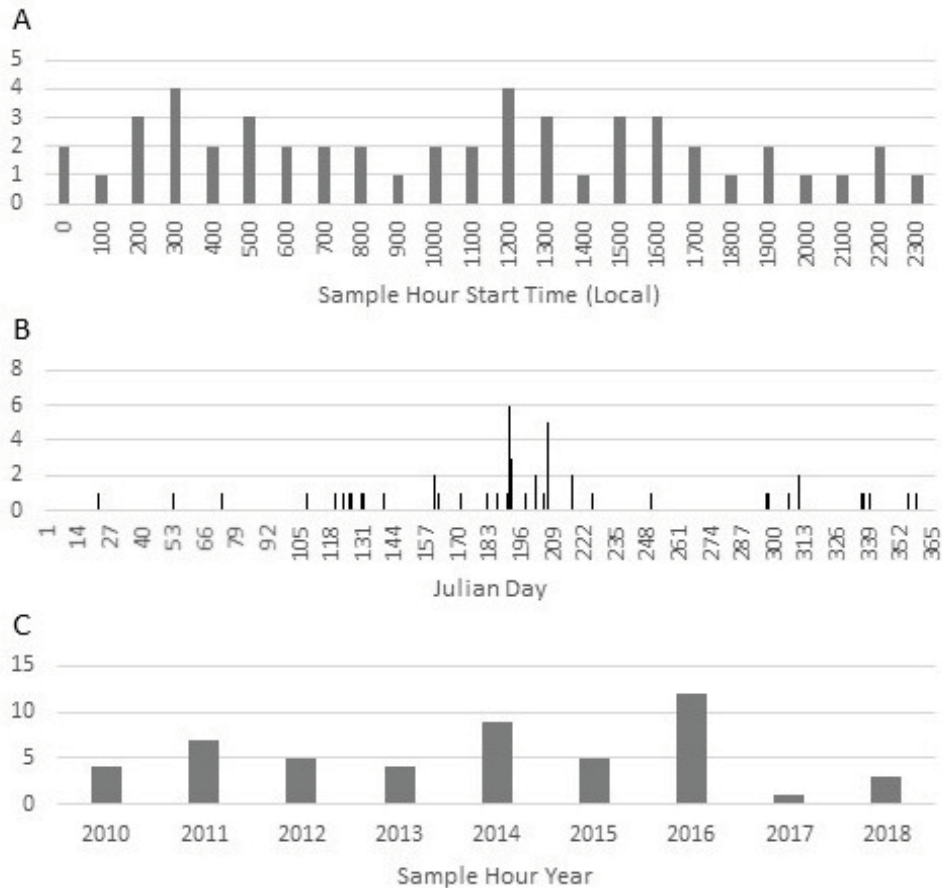


Figure 4. Histograms of sample hours. A: hours of the day (local time), B: Julian day, C: sample year.

Md, *Zc*, and *Me* can be identified in MMAMMAL by species-specific patterns of echolocation clicks. *Zc* clicks have an ICI of about 0.5 seconds (range 0.35–0.75 s), a bandwidth extending to 48 kHz, and vary between about 12 and 24 kHz on the lower end of the band. *Md* clicks have an ICI of about 0.3 seconds (range 0.23–0.4 s) and a bandwidth primarily of 24–48 kHz. *Me* clicks have energy primarily in the 30–50 kHz band with a faster ICI than the other two species, averaging 0.26 s. As the animals scan their heads, neighboring hydrophones are ensonified with most of the clicks on one or two center hydrophones. For all three species, the group vocal period lasts for roughly 20-to-40 minutes.

All hydrophones on the range were reviewed for each sample hour. Hydrophones with identified beaked whale clicks were recorded, along with start and stop times for click-trains. Click-trains that overlapped spatially and temporally were considered part of the same group vocal period. A group typically could include hydrophones within a baseline of the hydrophone with the highest click density, and with a group vocal period of less than one hour. At times, neighboring groups ensonify some common hydrophones. The manual review groups were then compared to the automated results produced by the AG program. Table 3 shows a subset of groups detected manually and a comparison to groups formed from the results of the SVMJ detectors and the AG program.

Table 3. Sample of groups detected manually and by the SVMJ detectors and Autogrouper algorithm. Individual click-trains are listed for each hydrophone.

Sample	Manually Reviewed Groups					Autogrouper Groups					
	Manual GroupID	HYD	start time UTC	stop time UTC	Species	AG GroupID	HYD	Clicks	start time UTC	stop time UTC	Species
25	94	1	14:38:44	14:56:32	Md	128	1	928	14:39:14	14:57:2	Md
25						128	2	200	14:45:42	14:57:38	Md
25	94	3	14:38:44	15:12:12	Md	128	3	2134	14:39:14	14:57:25	Md
25	94	4	14:41:39	14:56:20	Md	128	4	374	14:42:9	14:56:50	Md
25	94	5	14:44:43	14:57:08	Md	128	5	86	14:45:3	14:57:38	Md
25	94	6	14:41:41	15:12:06	Md	128	6	1113	14:42:11	15:15:12	Md
25	94	7	14:43:40	15:12:03	Md	128	7	263	14:44:10	15:12:33	Md
25	94	25	14:46:30	15:11:59	Md	128	25	1589	14:47:0	15:12:29	Md
25	94	26	14:49:03	15:12:23	Md	128	26	56	14:48:22	15:12:53	Md
25	96	14	14:48:14	14:57:16	Md	130	14	164	14:48:44	14:57:46	Md
25						130	11	31	14:49:21	14:51:31	Md
25	96	13	14:48:39	15:18:44	Md	130	13	1049	14:49:9	15:19:14	Md
25	96	12	14:49:15	15:11:35	Md	130	12	31	14:49:49	14:51:27	Md
25						130	12	12	14:55:35	14:57:44	Md
25	96	31	14:49:15	15:11:29	Md	130	31	27	14:49:47	14:50:48	Md
25						130	31	15	14:55:33	15:0:55	Md
25						130	31	33	15:4:31	15:11:59	Md
25						130	31	161	15:15:53	15:33:23	Md
25	96	10	14:52:50	15:18:47	Md	130	10	63	14:56:3	15:5:18	Md
25						130	10	29	15:14:56	15:19:17	Md
25	96	35	14:51:57	15:19:19	Md	130	35	10	15:18:28	15:19:49	Md
25	97	50	14:57:18	15:23:48	Md	131	50	610	14:57:51	15:17:17	Md
25	97	49	14:57:34	15:22:21	Md	131	49	493	14:58:4	15:18:59	Md
25	97	57	14:59:52	15:02:28	Md	131	57	11	15:0:22	15:2:58	Md
25	98	93	14:50:15	15:21:49	Md	No matching AG group					
25	98	92	15:02:30	15:19:35	Md						

2.6.2 AG Algorithm

The AG algorithm was run on AUTECH archives and beaked whale groups that occurred within the sample hour were compared to corresponding *Md* and *Zc* groups identified manually. The AG algorithms often generated short sequences of clicks, and at times long series of delphinid clicks that were misidentified as beaked whale groups. Thus the AG output was filtered before comparison to the manual groups. Additionally, the AG was run with species-specific ICI filters. The filtering parameters are in Table 4.

Table 4. Filtering parameters for Autogrouper groups.

Filtering parameter	Md	Zc
Minimum group clicks	360 (3 clicks/s*60 s/min*2 min*1 animal)	300 (2 clicks/s*60 s/min*2.5 min*1 animal)
Maximum group clicks	64800 (3 clicks/s*60 s/min*60 min*6 animals)	43200 (2 clicks/s*60 s/min*60 min*6 animals)
Minimum group duration	5 min	5 min
Maximum group duration	90 min	90 min
Minimum ICI	0.23 s	0.35 s
Maximum ICI	0.40 s	0.75 s

Detection statistics were evaluated after removing groups that occurred solely on edge hydrophones. If an edge-only group was found either manually or with the AG, it was removed from both.

The total number of manual group and total number of AG groups were first annotated for each sample. Then, for each sample, the groups were placed into one of four categories: (1) exact matches, (2) ‘confused’ matches, (3) manual only (FN), or (4) AG only (FP). A group was considered an exact match if: (1) the groups had at least one hydrophone in common, (2) the hydrophones were not part of another group, and (3) the time periods overlapped. The confused matches occurred when all or some of the same hydrophones were identified by both the manual process and the AG program, and the time periods overlapped, but the number of groups and/or the hydrophone combinations forming the groups were not the same. For the confused matches, both the total number of manual groups and the total number of AG groups were noted. The manual-only cases consisted of groups only identified manually (FN), and the AG only were those identified solely by the AG (FP).

Prior to calculating the detection statistics from these data, the groups under the confused matches category were reassigned to either the exact matches, FN, or FP category with the following procedure:

1. The minimum of the manual and AG groups for the confused matches was calculated and added to the exact matches for each sample. This sum was listed under the heading (Correctly Detected).
2. Under the confused matches category, if there were more manual groups than AG groups, then the difference was added to the FNs; otherwise the difference was added to the FPs. This was equivalent to calculating the new FN as the total number of manual groups minus the number correctly detected, and the new FP as the total number of AG groups minus the number correctly detected.

Comparisons between the manual review and AG output for *Md* and *Zc* for the SVMJ and Whdetect detectors are in Table 5 through Table 8.

Table 5. Comparison of filtered AG output and manual group detection using the SVMJ detector for Md.

Sample	Total No. Manual Groups	Total No. AG Groups	No. Exact Matches	No. Confused Matches		Min of Confused	Correctly Detected	No. Manual Only Groups (FN)	No. AG Only Groups (FP)
				No. Manual Groups	No. AG Groups				
1	0	2	0	0	0	0	0	0	2
3	4	5	4	0	0	0	4	0	1
4	4	3	3	0	0	0	3	1	0
5	4	4	2	1	2	1	3	1	1
6	2	2	2	0	0	0	2	0	0
7	5	5	3	2	2	2	5	0	0
8	4	4	2	2	2	2	4	0	0
9	2	1	1	0	0	0	1	1	0
19	1	1	1	0	0	0	1	0	0
20	5	3	3	0	0	0	3	2	0
21	6	3	3	0	0	0	3	3	0
22	7	7	2	5	5	5	7	0	0
23	3	2	2	0	0	0	2	1	0
25	5	3	3	0	0	0	3	2	0
26	1	0	0	0	0	0	0	1	0
27	1	1	1	0	0	0	1	0	0
28	4	4	4	0	0	0	4	0	0
38	2	1	1	0	0	0	1	1	0
39	5	4	4	0	0	0	4	1	0
40	3	3	3	0	0	0	3	0	0
41	4	2	2	0	0	0	2	2	0
42	2	1	1	0	0	0	1	1	0
43	3	3	3	0	0	0	3	0	0
44	2	2	2	0	0	0	2	0	0
45	1	1	1	0	0	0	1	0	0
46	2	2	1	1	1	1	2	0	0
47	2	2	1	1	1	1	2	0	0
48	1	1	1	0	0	0	1	0	0
49	4	3	3	0	0	0	3	1	0
50	2	2	2	0	0	0	2	0	0
30	91	77	61	12	13	12	73	18	4

Table 6. Comparison of filtered AG output and manual group detection, using the SVMJ detector for Z_c .

Sample	Total No. Manual Groups	Total No. AG Groups	No. Exact Matches	No. Confused Matches		Min of Confused	Correctly Detected	No. Manual Only Groups (FN)	No. AG Only Groups (FP)
				No. Manual Groups	No. AG Groups				
1	0	1	0	0	0	0	0	0	1
4	0	1	0	0	0	0	0	0	1
7	1	2	1	0	0	0	1	0	1
8	0	1	0	0	0	0	0	0	1
9	0	1	0	0	0	0	0	0	1
19	1	1	1	0	0	0	1	0	0
21	0	1	0	0	0	0	0	0	1
22	0	1	0	0	0	0	0	0	1
24	0	1	0	0	0	0	0	0	1
27	0	1	0	0	0	0	0	0	1
38	5	5	3	2	2	2	5	0	0
39	2	2	2	0	0	0	2	0	0
40	1	3	0	1	2	1	1	0	2
41	0	2	0	0	0	0	0	0	2
14	10	23	7	3	4	3	10	0	13

Table 7. Comparison of filtered AG output and manual group detection, using the Whdetect detector for M_d .

Sample	Total No. Manual Groups	Total No. AG Groups	No. Exact Matches	No. Confused Matches		Min of Confused	Correctly Detected	No. Manual Only Groups (FN)	No. AG Only Groups (FP)
				No. Manual Groups	No. AG Groups				
8	5	5	3	2	2	2	5	0	0
9	2	2	2	0	0	0	2	0	0
10	3	0	0	0	0	0	0	3	0
11	1	1	1	0	0	0	1	0	0
12	3	3	1	2	1	1	2	1	1
13	5	4	3	0	0	0	3	2	1
14	6	7	3	2	3	2	5	1	2
15	6	6	0	4	5	4	4	2	2
17	2	3	1	1	2	1	2	0	1
18	2	2	2	0	0	0	2	0	0
19	2	1	1	0	0	0	1	1	0
20	4	4	4	0	0	0	4	0	0
21	6	5	3	2	2	2	5	1	0

Sample	Total No. Manual Groups	Total No. AG Groups	No. Exact Matches	No. Confused Matches		Min of Confused	Correctly Detected	No. Manual Only Groups (FN)	No. AG Only Groups (FP)
				No. Manual Groups	No. AG Groups				
22	6	7	4	2	2	2	6	0	1
23	3	3	2	0	0	0	2	1	1
25	5	3	3	0	0	0	3	2	0
26	1	1	1	0	0	0	1	0	0
27	1	1	1	0	0	0	1	0	0
29	3	2	2	0	0	0	2	1	0
30	2	2	2	0	0	0	2	0	0
31	3	3	3	0	0	0	3	0	0
32	1	1	1	0	0	0	1	0	0
33	3	3	3	0	0	0	3	0	0
34	5	6	0	5	6	5	5	0	1
35	2	1	1	0	0	0	1	1	0
36	2	3	0	1	2	1	1	1	2
37	4	6	3	0	0	0	3	1	3
38	1	1	1	0	0	0	1	0	0
39	6	9	3	3	4	3	6	0	3
40	3	3	3	0	0	0	3	0	0
41	3	2	2	0	0	0	2	1	0
42	2	2	2	0	0	0	2	0	0
32	103	102	61	24	29	23	84	19	18

Table 8. Comparison of filtered AG output and manual group detection, using the Whdetect detector for Zc.

Sample	Total No. Manual Groups	Total No. AG Groups	No. Exact Matches	No. Confused Matches		Min of Confused	Correctly Detected	No. Manual Only Groups (FN)	No. AG Only Groups (FP)
				No. Manual Groups	No. AG Groups				
8	0	4	0	0	0	0	0	0	4
11	0	1	0	0	0	0	0	0	1
12	0	2	0	0	0	0	0	0	2
13	0	1	0	0	0	0	0	0	1
14	0	4	0	0	0	0	0	0	4
15	1	3	1	0	0	0	1	0	2
18	0	1	0	0	0	0	0	0	1
19	1	1	1	0	0	0	1	0	0
20	0	2	1	0	0	0	1	0	1
21	0	6	0	0	0	0	0	0	6

Sample	Total No. Manual Groups	Total No. AG Groups	No. Exact Matches	No. Confused Matches		Min of Confused	Correctly Detected	No. Manual Only Groups (FN)	No. AG Only Groups (FP)
				No. Manual Groups	No. AG Groups				
22	0	5	0	0	0	0	0	0	5
25	0	4	0	0	0	0	0	0	4
27	0	1	0	0	0	0	0	0	1
29	0	1	0	0	0	0	0	0	1
30	0	2	0	0	0	0	0	0	2
31	1	4	1	0	0	0	1	0	3
32	0	1	0	0	0	0	0	0	1
33	0	2	0	0	0	0	0	0	2
34	0	1	0	0	0	0	0	0	1
36	1	0	0	0	0	0	0	1	0
37	0	6	0	0	0	0	0	0	6
38	5	6	2	3	2	2	4	1	2
39	2	6	2	0	0	0	2	0	4
40	1	2	1	0	0	0	1	0	1
41	0	1	0	0	0	0	0	0	1
42	0	3	0	0	0	0	0	0	3
26	12	70	9	3	2	2	11	2	59

The mean number of *Md* and *Zc* groups detected per sample hour for the samples evaluated for the SVMJ detector was 3.03 *Md*/hr and 0.33 *Zc*/hr. For the samples evaluated for the Whdetect detector, the means were 3.22 *Md*/hr and 0.38 *Zc*/hr.

2.6.3 Derivation of Detection Statistics and Correction Factors

The detection statistics were then calculated along with correction factors to apply to the number of AG groups detected in order to derive the true number of *Md* and *Zc* groups present. The PD was calculated as the sum over all samples of the groups correctly detected divided by the sum over all samples of the number of manual groups. The percentage of FNs (groups missed by the AG) was the sum over all samples of the FN divided by the sum over all samples of the number of manual groups; and the percentage of FPs (groups misidentified by the AG) was the sum over all samples of the FP divided by the sum over all samples of the number of AG groups. Detection statistics are in Table 9.

Table 9. Detection statistics for *Md* and *Zc* using the SVMJ and Whdetect detectors.

Detector class	SVMJ		Whdetect	
	<i>Md</i>	<i>Zc</i>	<i>Md</i>	<i>Zc</i>
PD	0.80	1.00	0.82	0.92
FN	0.20	0.00	0.18	0.17
FP	0.05	0.57	0.18	0.84

FP and FN correction factors for the AG group results were then derived as follows and shown in Table 10:

1. The FP correction factor = $1 - (\text{sum over all samples of FP} / \text{sum over all samples of the AG groups})$.
2. The FN correction factor = $1 + (\text{sum over all samples of FN} / \text{sum over all samples of the AG groups} * \text{FP correction factor})$.

Table 10. Correction Factors for AG output.

Detector Class	SVMJ		Whdetect	
Species	<i>Md</i>	<i>Zc</i>	<i>Md</i>	<i>Zc</i>
FP Correction Factor	0.95	0.43	0.82	0.16
FN Correction Factor	1.25	1.00	1.23	1.18

These steps essentially start with the number of AG groups, subtract the number of FP and add the number of FN to recover the number of manual groups that are considered the true number of beaked whale groups. Note that one can recover the true number of manual groups by first applying the FP correction factor and then the FN correction factor to the number of AG groups (Table 10).

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