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U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
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1. INTRODUCTION

Southwest Fisheries Science Center (SWFSC) has been using combined visual and acoustic techniques to monitor marine mammal populations for the past eight years. Passive acoustic monitoring was added to visual surveys in an effort to improve the accuracy of cetacean population size estimates and increase the understanding of cetacean vocal behavior (Rankin et al. 2008a-b). Acoustic detection methods are beneficial because they are not limited by most weather conditions and are not restricted to daylight operations (Thomas et al., 1986). The addition of passive acoustic monitoring techniques to ship-based surveys can increase both the rate and distance of marine mammal detections (Clark and Fritrup, 1997; Gordon et al., 2000; Barlow and Taylor, 2005). Passive acoustic methods are now an integral part of SWFSC's marine mammal monitoring protocol.

There are two main components to passive acoustic monitoring: detection and classification. Detection refers to the ability to recognize marine mammal signals, whereas classification refers to species-specific acoustic identification of those signals. Marine mammal detection requires knowledge of marine mammal vocal behavior. Delphinid vocalizations are typically classified into three categories: whistles, echolocation clicks, and burst pulse signals. Whistles are continuous, narrow band, frequency-modulated signals. They can be pure tone or contain harmonics of the fundamental frequency. Whistles are believed to function as social signals (Janik and Slater 1998, Herzing 2000, Lammers et *al*. 2003) and range in duration from fractions of a second to several seconds. They typically range in fundamental frequency from 2 to 30 kHz, depending on the species (Lammers et al., 2003; Oswald et al., 2004). Echolocation clicks are impulsive, broadband signals that typically vary in peak frequency between 10 and over 100 kHz (Norris and Evans 1966; Au, 1980). These signals are used primarily for navigation and in object discrimination (Au, 1993). Burst pulse signals are composed of short-interval broadband click trains, resulting in a signal that may appear tonal due to the high repetition rate of the clicks (Watkins, 1967; Herzing, 2000). Burst pulse sounds may be used as social signals as well as for echolocation tasks (Dawson, 1991). These three categories of call types are not mutually exclusive, as transitions from increasing click rates to click bursts to purely tonal signals can occur during acoustic encounters (Murray et al., 1998).

Currently, SWFSC passive acoustic surveys of cetaceans require specially trained personnel to continually monitor the hydrophone array signals in real-time in order to detect cetacean vocalizations and plot bearings to the source. While effective, this method is time consuming and costly. Automated detection of cetacean vocalizations would be a valuable tool during marine mammal surveys, allowing for detection when experienced technicians are unavailable. This technique is advantageous not only because it significantly reduces human effort, but also because it removes sources of human error and bias in detection ability. Results from a recent SWFSC study, show that acoustic detection capability varies by group size, species, and acoustic behavior (Rankin et al., 2008b). These findings emphasize the need for comprehensive study of species-specific vocal behavior. Reliable automated detectors could provide valuable information about vocal behavior, species specific acoustic detectability, and vocalization rates for several cetacean species. This is an important step in the effort to utilize acoustic line-transect data to estimate population sizes for cetacean species.

The goal of this study was to evaluate the performance and utility of PAMGUARD 1.0 Core software for use in automated detection of marine mammal acoustic signals. Three different detector configurations of PAMGUARD are compared. These automated detection algorithms are evaluated by comparing them to the results of manual detections made by an experienced bio-acoustician (author TMY). Ultimately, it is our goal to integrate automated detection and localization methods into SWFSC's acoustic marine mammal monitoring protocol and this work is an important step in doing so.

2. BACKGROUND

Traditionally, acoustic surveys have been conducted using manual methods. This is time consuming and requires a highly trained technician. A number of automated detection and classification methods have been developed in the past several years. However, none of these methods have been incorporated into SWFSC's acoustic surveys.

The majority of automated detection methods have been used in post-processing to identify target species calls (primarily mysticete species), rather than in real-time to detect non-specific odontocete vocalizations. Automated detection methods are typically based on time series or spectrogram detection (Mellinger et al. 2008). Mellinger et al. (2008) provided a review of automated detection techniques, which included matched filters (Stafford, 1995), energy summation and statistical classification (Fristrup and Watkins, 1994; Oswald et al., 2004), spectrogram image-processing (Gillespie, 2004), template matching (Mellinger and Clark, 2000), band-limited amplitude in the time series (Gillespie and Chappell, 2002) or spectrogram (Mellinger et al., 2004), and wavelet-based decomposition (Lopatka et al., 2005).

In general, acoustic detection is dependent upon physical factors and species-specific behavioral factors (Mellinger et al. 2008). Physical factors refer to physical acoustical properties such as frequency range, source level, and directionality of vocalizations, whereas the behavioral factors refer to species and individual behavioral phenomenon that affect acoustical properties and signal detection ability. These may include the vocalization rate, type of signal used, group size, as well as depth and orientation of the animal while vocalizing.

When using automated techniques it is important to first consider the type of vocalizations that you wish to detect and the accuracy with which you wish to detect them (Mellinger et al., 2008). Species-specific, non-variable vocalizations are easiest to detect with the highest level of accuracy. However, SWFSC is most interested in generic detection of all cetacean species. In order to evaluate the automated detections using cue-counting statistical methods it will be important to choose a detection method in which the number of missed calls approximates the number of false detections, i.e. intermediate sensitivity (Mellinger et al., 2008).

3. METHODS

Recordings were made during a SWFSC dolphin survey conducted in the eastern tropical Pacific Ocean from 20 August to 28 November, 2007. A custom-built four-element hydrophone array (frequency response flat from 500 Hz to 48 kHz ±5 dB; sensitivity -155 dB re 1V/µPa) was towed at a depth of 4-6 m approximately 300 m behind the NOAA ship *McArthur II* while traveling at a survey speed of 10 kt during daylight hours and in sea states of Beaufort 6 or less. The four hydrophones were located at distances of 300, 304, 804 and 808 m behind the ship. Data were recorded in continuous five-minute-long WAV formatted files, in four channels, at a 96 kHz sample rate using Raven[1] software. The 48 kHz bandwidth imposed by this sampling rate limits our analyses to the lower range of frequencies in odontocete echolocation clicks but allows analysis of the full frequency range of odontocetes whistles.

One sample day (11 September, 2007) was chosen for the automated detection trials. The data from this day encompassed a 9.5 hour period between 09:28 and 18:58. For this sample day each channel was extracted and combined into 30-minute acoustic WAV files using custom software. This resulted in nineteen 30-minute acoustic files for each of the four channels. Hydrophone 4 was farthest from the ship and thus had the lowest levels of ship noise, so this channel was used for most of the analyses presented here. For comparison, in order to evaluate potential reception differences between different hydrophones, data from Channel 1 were included in some analyses. Analysis was conducted at two temporal resolutions, 30-min and 5-min. The 30-min resolution provided a broad perspective of the data, whereas the 5-min resolution allowed for detailed comparisons between detection trials. For example, the log values of minimum beam distance, where minimum beam distance was equal to the shortest distance from the observed group to the beam of the ship estimated from visual encounters that occurred within each 30-min sampling period, were plotted against the log click detection values, which equaled the number of click detections within each 30-min sampling period for each detection trial run on Channel 1 recordings. The 5-min resolution data were used to compare manual detections to the automated trials. Manual detection and automated trials were compared by overlaying detection plots of all trials (whistles, clicks, and total detections) and using regression plots.

For the purpose of this paper the term *Detection* will be used to describe individual marine mammal vocal events (e.g. a single click or whistle), whereas *Encounter* will be used to describe shipboard acoustic as well as visual marine mammal encounters with cetacean groups.

3.1 Real-Time Shipboard Acoustic and Visual Methods

During the shipboard survey an acoustic technician monitored signals from two array hydrophones using stereo headphones and real-time scrolling spectrographic display and processing software (ISHMAEL, Mellinger, 2001). Spectrograms were viewed at frequencies up to 24 kHz during real-time monitoring. Bearing angles to detected sound sources were then calculated using the phone-pair bearing estimation algorithm in ISHMAEL[1] (Mellinger, 2001). Localization of acoustic encounters is performed based on the convergence of consecutive bearing angles plotted using Whaltrak, a plotting program developed especially for this purpose (Rankin et al. 2008a). An acoustic 'encounter' occurred when more than five vocalizations were detected ("detections") within a five-minute period.

The visual survey methods followed standard SWFSC line-transect protocol for passing mode (Kinzey et al., 2000). A visual observation team consisting of three experienced observers rotated between two 'big-eye' 25x150 pedestal-mounted binoculars and a data-recording

[1] The use of brand names in this report does not indicate endorsement of these products by the U.S. Government.

position. Observation took place only during daylight hours in Beaufort sea states between 0 and 4 on the sample day. The survey was conducted entirely in passing mode, (i.e. the ship traveled along a pre-determined trackline and did not alter its course or speed during cetacean sightings). The visual observation team remained "on effort" during encounters and paused observations only briefly to record information on the sighting.

3.2 Manual Detections

Prior to the use of automated detectors, one author (TMY) reviewed each of the Channel 4 recordings by aurally monitoring the sounds while viewing a scrolling spectrographic display and counting each type of detection. Each file was filtered in Adobe Audition 1.5 using a high-pass Butterworth filter with a cut-off frequency of 3000 Hz in order to eliminate ship noise. For manual detection processing, a graphic equalizer was also used in order to amplify data in the 3-25 kHz range. Spectrograms (Hanning 1024 point FFT, 40 kHz bandwidth) were produced using *Spectra Plus* software. Acoustic detections were made using a combination of visual (scrolling spectrogram) and aural (stereo headphones) monitoring methods. Detections were categorized into four basic qualitative types; burst pulses, clicks, probable whistles, and whistles. The beginning time and frequency of each detected whistle was measured and recorded in a database along with a general description of the whistle type (e.g. upsweep, downsweep, stepped, etc.). For burst pulses, and clicks, the beginning time and estimated center frequency were measured and recorded.

Regression plots were created of manual detections (whistles, clicks, and total detections) and all PAMGUARD trial detections.

3.3 PAMGUARD Detection Methods

PAMGUARD (www.pamguard.org, Gillespie et al. 2008) is an initiative currently funded by the OGP E&P Sound and Marine Life project to provide standard software to address the needs of both developers and to users of Passive Acoustic Monitoring (PAM) systems. PAMGUARD is open source, platform independent and freely available. For the biologist and PAM operator, PAMGUARD provides a flexible and easy to use suite of detection, localization, data management and display modules which provide a standard interface across different platforms with the flexibility to allow multiple detectors to be added, removed and configured according to the species of interest and the hardware configuration on a particular project. For developers of PAM systems, an Application Programming Interface (API) has been developed which contains standard classes for the efficient handling of many types of data, interfaces to acquisition hardware and to databases, and provides a GUI framework for data display.

PAMGUARD 1.0 Core software was used for automated detection of dolphin whistles and clicks from the 09/11/2007 acoustic files. PAMGUARD features a dynamic multi-panel user interface. The PAMGUARD click and whistle detectors are closely based upon the IFAW RainbowClick (D. Gillespie and R. Leaper 1996) and Whistle programs (available from www.ifaw.org/sotw). While the RainbowClick software has been used on a number of surveys (e.g. Leaper, et al. 2000; Lewis et al. 2007), giving some indication of its performance and usefulness with sperm whales, we know of no published studies that have used the whistle detector.

For the purpose of this analysis only the 1024 FFT panel and the whistle and click detector modules were viewed. Whistle and click detector plug-ins were configured for three separate trials and automated detections for each 30-min file were recorded and exported directly into an Access database. Results were then exported to an Excel spreadsheet, where they could be further analyzed.

Preliminary results were reviewed in order to set the detection parameters. PAMGUARD provides only two possible detection categories, clicks and whistles. Burst pulses may be categorized as either type depending on the inter-click interval of the burst pulse (Figure 1a).

A 38 kHz echo-sounder was transmitting at two-second intervals during recordings. Preliminary results showed that PAMGUARD automatically classified these events and their associated echo return signals as whistles. These signals typically ranged between 37-40 kHz, and therefore to eliminate these detections from the results of our tests, the whistle detection parameters were set to detect whistles only in the bandwidth of 3 to 36 kHz. Another factor affecting the interpretation of trial data results was that frequency measurements were not recorded for click detections by PAMGUARD. Therefore, in order to graphically represent the trial results in a manner comparable to the manual results, random numbers between 25 and 35 kHz, corresponding to PAMGUARD's click trigger filter, were generated for each click detection.

PAMGUARD's click detector uses two filters: a pre-filter and a trigger filter. The trigger filter is used to optimize detection in the frequency band of interest. For a single narrow-band species, such as the harbor porpoise, the frequency band can be narrow, however for multiple species detection, the trigger filter band needs to be wider. If signals are detected in the output of the trigger filter, then the output of the pre-filter, which is generally only a low-pass filter intended to remove unwanted ship noise is turned into short sound clips which can be used in later analysis of source localization and species classification of clicks. In this study, PAMGUARD localization and species classification methods have not been tested. The trigger makes a continuous measure of background noise. When the signal reaches a threshold above the noise level a click clip is generated. This clip ends when the signal level drops below the threshold for a set number of samples.

PAMGUARD's whistle detector searches the spectrogram for 'ridges' of high intensity sounds using a three-step process. First, a background noise measurement is made for each spectrogram frequency and areas of the spectrogram exceeding the background noise level by a set threshold are selected. 'Peaks' are generated by searching for adjacent frequency bins above the threshold. Second, consecutive peaks are joined together if the defined conditions are met (e.g. frequency gradient, rate of change of frequency gradient and rate of change of amplitude between peaks in successive time partitions). This results in a time-frequency contour. If this contour exceeds a user-defined set minimum length it is considered to be a whistle . A whistle *event* occurs when the number of whistles exceeds some minimum value within a set time period (the lowest minimum value allowed is one-second), i.e. all whistle detections within a one-second period will be counted as a whistle event. It is important to note that single whistles are often counted as multiple whistles by the PAMGUARD whistle detector, especially when there are rapid amplitude changes or if there are frequency steps in the signal (Figures 1b-c).

Approximately fifty test trials of different parameters were run using two of the acoustic files as test cases, so that optimal click and whistle detection settings could be determined. Results from these test trials were used to determine the three best candidates for the final trial runs. The PAMGUARD whistle and click detectors for each of the three trials were configured using the settings specified in Tables 1. Settings for both the whistle and click detectors were made more conservative in Trial 2 in an effort to minimize false detection rates. For this trial, the minimum whistle length was changed from 5 to 6 bins and the click trigger threshold was changed from 15 to 18 dB (Table 1). For Trial 3 the whistle detection threshold was lowered from 6 to 5 dB in order to optimize the correct-detection to false-detection ratio (Table 1). Click detection frequencies were chosen to avoid false detections due to impulsive noise from the ship's echosounders (12 kHz and 38 kHz).

3.3.1 PAMGUARD Detection Sensitivity Analysis Methods

Sensitivity analysis was conducted on a subset of three hours of data from the sample day in an effort to evaluate the performance of the three PAMGUARD whistle detection trial configurations. Each file was processed through PAMGUARD Core 1.0 three times using each of the following configurations: T1 detector, T2 detector and T3 detector. One author (TMY) viewed each file from a spectrogram as it was processed and recorded the number of whistles correctly detected, the number of whistles missed, the number of false detections, the number of burst pulses counted as whistles, how many times each burst pulse was counted, the number of single whistles detected multiple times, and how many times each whistle was counted. The manual whistle count was used to calculate the percent of correct detections and missed detections for each of the three configurations. The total counts by PAMGUARD were used to calculate the percentage of false detections, burst pulses, and multiple single-whistle detections.

3.4 Beam Distance and Group Size

The log values of minimum beam distance estimated from visual encounters that occurred within each 30-min sampling period were plotted against the log click detection values for each detection trial run on Channel 1 recordings. This process was repeated for group size values estimated from visual encounters.

4. RESULTS

4.1 Real-time visual and Acoustic Encounters

A total of 29 unique groups of cetaceans were detected by the visual observation team during the 09/11/07 sample period (Table 2). Fourteen of the encounters were attributed to four different species, whereas the remaining encounters were attributed to unidentified groups (Table 2). Of the four identified species, 50% were *Stenella attenuata* (offshore morphotype), 29% were *Steno bredanensis*, 14% were *Stenella coeruleoalba*, and 7% were *Kogia sima*. Kogia sightings are not included in the comparisons for this study as they produce high frequency clicks (>100 kHz), which were outside of the range of our recording system. Sightings occurred during 79% of the 30-min acoustic sample periods (Table 3). Periods with *Stenella* (both species) present contained the most vocal activity. The sighting distance of cetacean groups from the beam of the ship ranged between 0.03 and 3.54 nm (mean 1.3 nm; sample size 49 groups) (Table 2).

During the sample day, a total of 25 unique ship-board acoustic encounters with groups of cetaceans were made, of which 80% were localized, and of these, 14 (56%) were matched to a visually detected group. The start time for each ship-board acoustic encounter was used to tally the encounters for each 30-min time period. Acoustic encounters were made during 79% of the 30-min sample periods (Table 4), whereas, individual detections occurred in 89% of sample periods. Whistles were detected in 89% of sample periods, burst pulses were detected in 63% of sample periods, and clicks were detected in 53% of sample periods. .

4.2 Manual Detections

Manual analysis of channel 4 of the 09/11/07 acoustic files resulted in a total of 26,748 detections: 86% (22,947) were clicks, 12% (3,343) were whistles, and 2% (458) were burst pulses (Table 5 and Figure 2). For the purpose of analysis the individual clicks within each detected click train seen in the figure were added to the total tally of clicks. An additional 185 detections were categorized as probable whistles but were not included in the analysis. Detections of burst pulses, clicks, and whistles were found in every 30-min acoustic file, with the exception of the 17:28 file, which contained no burst pulses. The highest number of whistles within any of the 30-min sample periods was 989 (30% of whistles) found during period 14:58. The highest number of burst pulses was 169 (37% of burst pulses) found during the 18:28 sample period and the highest number of clicks was 10,257 (45% of clicks) found during sample period 10:58. The lowest number of clicks (24) was found during the 17:28 sample period, while the fewest number of whistles (6) was found during period 16:58.

4.3 PAMGUARD Detections

4.3.1 PAMGUARD Trial 1

Channel 1
The first PAMGUARD trial resulted in a total of 78,327 detections, of which 89% (69,948) were clicks and 11% (8,379) were whistles (Table 6a and Figure 3a). The highest number of whistle detections, 23% of all whistle detections (1,956) occurred during period 18:28. The lowest number of whistle detections, 1% of all whistles detected (94) occurred during sample period 15:28. The highest number of clicks was detected during period 10:58 (35%; 24,710); while only 1% (574) of clicks were detected during sample period 15:28. Because PAMGUARD does not discriminate burst pulse detections, they are not included as a category in any of the results

Channel 4
The first PAMGUARD trial resulted in a total of 77,220 detections of which 91% (70,419) were clicks and 9% (6,801) were whistles (Table 6b and Figure 3b). The highest number of whistle detections, 39% of all whistle detections (2,628) occurred during period 18:28. The lowest number of whistle detections, 0.4% of all whistles detected (26) occurred during sample period 09:28. The highest number of clicks was detected during period 10:58 (30%; 21,438), while only 0.4% (291) of clicks were detected during sample period 15:28 .

4.3.2 PAMGUARD Trial 2

Channel 1
The total number of whistle and click detections made in the second PAMGUARD trial was 47,168. Of these, 92% (43,551) were clicks and 8% (3,617) were whistles (Table 7a and Figure 4a). As was found in Trial 1, the highest number of whistle detections (34%; 1,220) occurred in file 18:28, however the lowest number (0.4%; 13) occurred in file 12:28. The highest number of click detections, (37%; 16,001) occurred during sample period 10:58 and the fewest detections (1%; 233) occurred during sample period 15:28, as in Trial 1.

Channel 4
The total number of whistle and click detections made in the second PAMGUARD trial for Channel 4 was 39,989. Of these, 91% (36,469) were clicks and 9% (3,520) were whistles (Table 7b and Figure 4b). As was found in Trial 1, the highest number of whistle detections (45%; 1,582) occurred in file 18:28 and the lowest number (0.1%; 2) occurred in file 09:28. The same was true of click detections, of which 37% (13,400) occurred during sample period 10:58 and the fewest detections (0.3%; 103) occurred during sample period 15:28.

4.3.4 PAMGUARD Trial 3
Channel 1
There were 50,297 detections in the third PAMGUARD trial for Channel 1. Of these, 87% (43,551) were click detections and the remaining 13% (6,746) were whistle detections (Table 8a and Figure 5a). Similarly to the other PAMGUARD trials the highest number of whistle detections (20%; 1,371) occurred in file 18:28 . The fewest whistle detections (1%; 98) occurred during sample period 12:28. Click detection settings were not changed during this trial, therefore the results are the same as in Trial 2.

Channel 4
There were 41,902 detections in the third PAMGUARD trial for Channel 4. Of these, 87% (36,469) were click detections and the remaining 13% (5,433) were whistle detections (Table 8b and Figure 5b). The highest number of whistle detections (33%; 1,798) occurred in file 18:28. The fewest whistle detections (1%; 39), occurred during sample period 09:28. Click detection settings were not changed during this trial, therefore the results are the same as in Trial 2.

4.4 *PAMGUARD* Trial comparison

For all three trials and both Channels 1 and 4, the highest number of click detections occurred during sample period 10:28 and the lowest during sample period 15:28. The highest number of whistle detections occurred during sample period 18:28 for both channels during all trials. The fewest whistle detections varied among trials and between channels. Trial 1 on Channel 1 resulted in the fewest detected whistles during sample period 15:28, whereas the subsequent trials resulted in the fewest detections during sample period 12:28. However, the fewest detected whistles occurred during sample period 9:28 for all three trials on Channel 4. For Channel 4, the ratios of click and whistle detections were the same for Trials 1 and 2, 91% and 9%, respectively. This ratio decreased by 4% for clicks in Trial 3 and increased by 4% for whistles.

4.5 Manual Detections VS. PAMGUARD Detections

Comparisons between manual detections and PAMGUARD trials for five-minute sampling periods are shown in Figures 6a-8b. These figures show that manual detection peaks correspond closely to automated detection trial peaks for both whistles and clicks. PAMGUARD trials were also plotted against manual detections (Figures 9-11). The R^2 value is highest overall for the Trial 3 detections, suggesting that this trial provided the closest match to manual detections. However, it is important to note that this does not necessarily reflect the accuracy of Trial 3 detections, as will be discussed in later sections. For PAMGUARD Trial 2 Channel 1 and Channel 4 detections were also compared to one another (Figure 12) . This figure shows that there were a greater number of detections on Channel 1 vs. Channel 4. Figures 9, 10 and 11 also show us that there is often a false detection rate from the click detector of a few hundred calls in each five minute period (1-2 clicks per second) from Trial 1, which decreased significantly when the threshold was raised from 15dB to 18dB in Trials 2 and 3.

4.6 PAMGUARD Sensitivity Analysis

Results from the PAMGUARD sensitivity analysis show that PAMGUARD Trial 2 was the most accurate of the three PAMGUARD whistle detectors (Figure 13). Trial 2 resulted in the most correct detections, fewest missed detections, and fewest false detections (Figure 14). Additionally, the majority of Trial 2 false detections (~60%) were attributed to burst pulse detections and multiple detections of single whistles (Figure 15). Trial 2 also resulted in the fewest multiple detections of single whistles (Figure 16).

4.7 Beam Distance and Group Size

Channel 1 detections are more useful for comparing beam distance and group size to detection numbers, given that these detections are closer to the beam of the ship, than the same detections from Channel 4, and therefore are least affected by transmission loss. Channel 1 detections show a negative, but non-significant relationship between minimum beam distance and number of detections, as would be expected (Figures 17a-c). This relationship is most pronounced for whistle detections. There appears to be a positive, but non-significant relationship between estimated group size and Channel 1 detections for whistles, clicks, and total detections (Figures 18a-c).

4.8 Manual Detections and real-time Shipboard Encounters

Periods with high levels of manual detections coincided closely with real-time shipboard acoustic encounters. However, there were three main periods during which manual post processing indicated cetacean presence when there were no real-time shipboard acoustic encounters (approximate mean times; 9:30, 15:30, and 17:45).

The five-minute sampling interval analysis resulted in recognition of detection peaks (high numbers of detected calls) which were temporally associated with visual encounters (Figures

19a-b). All significant detection peaks were associated with a ship-board visual or acoustic encounter.

5. DISCUSSION

This study provides the first detailed comparisons of PAMGUARD automated detection algorithms to manual detection methods. The results of these comparisons clearly illustrate the utility of automated detection methods for odontocete species.

5.1 Comparison of PAMGUARD Detection Trials

For the three separate PAMGUARD trials that were conducted in order to identify the best parameters for a general odontocete detector, the differences in settings between trials highlight the tradeoff between detecting faint calls and making erroneous detections. These tradeoffs will be necessary for different applications or goals. For example, counting numbers of calls, as needed for this study, requires use of an intermediate detection threshold where ideally the number of missed calls would be approximately equal to the number of false detections. Sensitivity analysis of the PAMGUARD trials indicated that Trial 2 was the best overall PAMGUARD detector of the three used.

Channel 1 and Channel 4 resulted in similar patterns of detection for all of the PAMGUARD trials, therefore only Channel 4, on which sensitivity analysis was conducted, will be discussed. Channel 4 detections decreased by 48% between PAMGUARD Trial 1 and Trial 2. This decrease was the result of setting changes in both the whistle and click detection modules that correspond to a decrease in the false detection rate and an increase in the overall accuracy of the detections. Whistle detection decreased by 38% most likely due to changes to the minimum length setting, which was increased from 5 to 6 bins for this trial, resulting in fewer false detections. Additionally, the smoothing constant (on) setting was increased from 8 to10 seconds, which also may have contributed to the decrease in erroneous whistle detection by eliminating some detections of impulsive noise. Sensitivity analysis showed that Trial 2 resulted in the highest number of correct whistle detections, the fewest false and missed detections and the fewest multiple whistle detections of single whistles (Figure 13). Click detection decreased by 48% (i.e. fewer false detections) as a result of increasing the detection threshold from 15 to 18 dB during Trial 2, thereby also increasing the accuracy of click detections for this trial.

In Trial 3 the only change made to the settings from Trial 2 was a decrease in the whistle detection threshold from 6 to 5 dB. Click detection settings were left unchanged in order to test the accuracy of click detection. Given this, there would be no expected change in click detection and none was seen. However, as expected, whistle detection increased by 54% from Trial 2, but decreased (20%) from Trial 1 The greater number of whistle detections were due to both a decrease in missed whistles and an increase in false detections. This resulted in a net decrease in the accuracy of these detections. While this trial resulted in the highest level of matches between PAMGUARD and Manual detections, sensitivity analysis showed that Trial 3 was the least accurate of the PAMGUARD detectors, resulting in the fewest correct whistle detections and the highest number of missed and false detections (Figure 13).

5.3 Channel 1 vs. Channel 4 Automated Detections

All trials resulted in an overall greater number of detections on Channel 1. Trial 1 had fewer click detections for Channel 1 than Channel 4, but more whistle detections. Trials 2 & 3 resulted in increases in both click and whistle detections for Channel 1. The peak number of clicks and whistles occurred during sample periods 10:58 and 18:28, respectively for both channels. However, while the lowest number of clicks was consistent during sample period 15:28 for both channels, the lowest number of whistles varied. For Channel 1 the fewest whistles occurred during sample period 15:28 in Trial 1 and sample period 12:28 in Trials 2 & 3. The fewest whistle detections for Channel 4 occurred during sample period 09:28 for all trials.

Although the automated detection results for Channel 1 and Channel 4 show similar peaks in detections, the differences are still appreciable. Hydrophones 1 and 4 were approximately 300 m and 808 m behind the ship, respectively. At a survey speed of approximately 18.5 km/hr, the 508 m distance between hydrophone locations would correspond to a transit time of ~100 seconds, which is less than the smallest time interval used in our analyses (5 min). Five-min samples should therefore be almost identical when comparing hydrophones 1 & 4. Ship noise was generally less on Hydrophone 4 because this hydrophone was farthest from the ship. However, a greater number of clicks and whistles were typically received on Channel 1 (Figure 14). This could be because the ship itself is stimulating the production of whistles and clicks, and some of these (especially clicks) do not propagate far enough to be received on Hydrophone 4. Another factor that may affect detection on these two channels is that Channel 1 may be able to pick up animals ahead of, or attracted to, the ship whereas Channel 4 cannot. Additionally, array depth may not be consistent between the two channels. The directionality of echolocation clicks and the orientation of the animal relative to the hydrophone would also be expected to correspond to detection differences between the two hydrophones. Additional studies are needed to help understand this effect and whether it is a general phenomenon.

5.4 Manual Detections VS. PAMGUARD Detections

Our goal was to use PAMGUARD as a general rather than species-specific detector, with which the majority of clicks and whistles from several cetacean species could be detected. It is important to note that if our goal had been more species-specific, a more finely tuned detector within PAMGUARD could have been configured. As stated above, PAMGUARD Trial 2 provided the closest match to manual detections (Figures 6a-8b and Figure 13). Although there were 52% more detections made by PAMGUARD Trial 2 than by manual detections, the majority of the inflated detections were attributed to clicks. Inflated click detection is likely due to missed manual detections, click detections associated with burst pulses, and some level of false detection of cavitation noise. There was only a 5% increase in the number of whistles detected overall in Trial 2, which would actually result in a near match to *manual* detections if half of the burst pulses from the manual detections were lumped into the whistle category. Burst pulse detections were responsible for nearly half of all false detection in channel two. These detections were almost always classified as both whistles and clicks (Figure 1). If we are able to correct the burst pulse detection problem, we believe that the overall accuracy of the whistle detector would increase dramatically, resulting in a near match between false detections and missed detections. Future studies will include quantifying the way in which burst pulses are classified. This will be an important step in addressing this issue.

There was a large discrepancy in click detections between the automated detector and the manual detections. Although 59% more clicks were detected overall by PAMGUARD Trial 2, there was not an overall trend of increased click detections within individual sample periods; in fact a decrease in click detection occurred during three of the sample periods. If an overall increase had occurred, the increased rate of detection could be attributed to erroneous detections and minimized by increasing the detection threshold, however detection threshold does not appear to be the only factor resulting in erroneous click detection. Manual click detections should be considered a low estimate as it was extremely difficult to count every click without additional post-processing to expand the time resolution of the spectrogram during click trains. The click detector also frequently triggers on the surface echoes of clicks, therefore counting each click twice. Additionally, clicks from burst pulse signals were counted during automated detections, but not during manual detections. Additionally some click detections were likely due to false detections of cavitation noise. The rate of false detection on cavitation noise is likely closely related to Beaufort sea state. As such, future studies should examine this relationship in more detail. No clear pattern was evident for clicks that were under-counted by PAMGUARD and this also requires further investigation.

Overall, PAMGUARD appears to be effective as an automated detection method for most odontocete species. However, all of the PAMGUARD trials resulted in an inflated number of detections when compared to manual detections. This is likely due to three main sources of error in the detection process. First, PAMGUARD may be able to detect a greater number of clicks than manual methods, given the difficulty associated with reliably measuring clicks manually during rapid click trains. Second, PAMGUARD sometimes counts a single whistle more than once, especially if there is a great deal of amplitude variation within the signal (Figure 1b) or if the whistle contains steps (Figure 1c). And finally, burst pulses present a unique problem for PAMGUARD as these signals are often counted as both multiple clicks and multiple whistles (Figure 1a). While it was important to count all detections for this study, in reality it is most important to detect the presence of cetacean groups. PAMGUARD did not appear to miss any group detections, although in some cases detections were lower than expected and did not result in significant detection peaks (Figures 18 a-b).

In this study, we have compared the results of a 100% manual analysis of acoustic data with the results of 100% automatic analysis. In reality, the best results can be achieved through a combination of manual and automatic methods. The automatic detectors can be used in the field or to analyze continuous recordings, thereby greatly reducing the work load on operators in the field. The output of the automatic detectors can then be relatively quickly reviewed during post processing to eliminate false detections and to group individual *detections* into acoustic *encounters* (as defined in section 3). Indeed, this is exactly how the studies reported in Leaper et al. 2000 and Lewis et al. 2007 were conducted using the software predecessor of the PAMGUARD click detector.

5.1 Manual Detections and real-time Shipboard Encounters

Vocalizations were detected during post-processing that were not detected in real time. This is likely due to two factors. First, the real-time scrolling spectrogram was only viewed at frequencies up to 24 kHz aboard the ship, whereas the spectrogram was viewed at frequencies up to 48 kHz during post processing. This likely resulted in some level of missed echolocation click detection during real-time surveys. Second, a great deal of ship noise was filtered out during post-processing. This would have increased the likelihood of detecting faint whistles during post-processing analysis.

The five-min sampling interval analysis resulted in recognition of detection peaks (high numbers of detected calls) which were temporally associated with visual encounters (Figures 18a-b). It is important to note that while detection peaks were a valuable means of comparing detection methods, they may not provide an accurate means of comparison to visual sightings. For example, a greater number of vocalizations does not necessarily represent a greater number of animals. There are numerous factors that can play an important role in acoustic detection of cetacean groups, including differences in the vocal behavior of individuals, groups and species, beam patterns of clicks and whistles, signal to noise ratios, propagation effects, system noise, vessel noise, and depth of the array.

Although there were no significant acoustic detection peaks without a visual or real-time acoustic association, there were visual sightings with no significant acoustic detection peaks associated for either clicks and whistles. There were four unique encounters with no discernible click detection peaks associated with them (parenthesis refers to estimated group size: (1) *Stenella attenuata* (50), (2) an unidentified small delphinid (3), (3) *Steno bredanensis* (6)and (4) unidentified small delphinid (80). There were three unique encounters with no associated whistle peaks: (1) *Stenella attenuata* (50), (2) unidentified medium delphinid (35) and (3) unidentified small delphinid (80) (Table 2 and Figures 17a-b).

Other important differences between visual and acoustic methods include temporal and spatial variations. Visual methods only detect groups when they are at the surface, whereas acoustic methods can detect groups both when they are at the surface and when they are below the surface. Additionally, the search areas are different between the two methods. Visual methods essentially look ahead of the ship whereas acoustic methods search to the sides of the ship and the hydrophones are centered behind the ship.

6. CONCLUSIONS

A standard protocol for combined visual and acoustic shipboard line-transect cetacean surveys has been used by SWFSC for the past eight years. This protocol involves real-time monitoring by experienced bio-acousticians and has been highly successful in detecting and localizing odontocete groups. These methods have also provided valuable insight into the vocal repertoire and vocal behavior of many cetacean species. However, these methods are labor intensive and require highly trained personnel. If effective, the incorporation of automated detection methods into the SWFSC protocol would reduce both manpower requirements and associated costs. Incorporation of automated detection into survey protocols is the first step in a long process of automation that may eventually replace the need for highly skilled shipboard bio-acousticians to monitor data in real-time. Ultimately, automation will require that we are able to not only detect marine mammals, but also localize these detections, separate localized detections into distinct groups and match these groups to concurrent visual encounters, and identify groups to species when visual information is not present. The results of this study indicate that it will be worth the additional effort to further explore and integrate automated methods into our acoustic survey protocols.

It is evident that the majority of whistles and click events can be detected using PAMGUARD software. All of the PAMGUARD trials were capable of detecting whistles and clicks of cetacean species. It is important to note that the detection threshold could be adjusted for both the PAMGUARD detectors in an effort to increase or decrease detection capability, as needed. In practice, different automated detection methods are needed for different levels of specificity. The method employed will vary based upon the intentions of the study. For example, if the primary objective is detecting cetaceans within a short range, a more conservative PAMGUARD detector than those tested here should be configured. However, if the primary objective is counting total numbers of calls or detecting every dolphin group over a large area, the PAMGUARD Trial 2 configuration would be the best choice. Regardless of the detector employed, automated detection has the potential to be a valuable tool during acoustic surveys and for studies of the vocal behavior of cetaceans. Other factors affecting the future of automated detection will be the detectability of small groups missed by visual observers and the effect of ship and equipment related noise on the performance of the automated system.

Future directions for this work include; (1) field testing automated detection methods (including investigating the detectability of cetacean groups missed by visual observers and the effects of ship noise and equipment related noise on the performance of the automated system) (2) further refinement of automated detection algorithms, (3) resolution of burst pulse detection issues, (4) investigation of the relationship between whistle type, species, and detection capability, (5) development and testing of automated estimation of bearing angles and localizations, (6) differentiation of 'independent' groups from each other--- or, lumping detections into appropriate groups, and (7) examination of the effects of the survey vessel on the acoustic behavior of individuals and groups (e.g. are different species more or less vocal when they encounter a survey ship?).

The PAMGUARD software continues to develop. Work is currently underway at SMRU to develop new species classifiers for both the whistle and click detectors and an entirely new method of whistle contour extraction. These developments will be implemented in a future release of PAMGUARD. Apart from the obvious advantages of being able to identify detected vocalization to species, vocalizations may also be discarded as noise if they either fail all classification tests or are positively identified as noise. These updates are due to be implemented in 2009.

PAMGUARD also contains a number of localization and mapping functions, some of which are built into the click and whistle detectors. The output of these localization methods has not been compared with either visual or acoustic localizations from the field.

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8. REFERENCES

Au. W.W. L. 1993. *The Sonar of Dolphins.* Springer-Verlag, New York.

Au. W.W. L. 1980. Echolocation signals of the Atlantic bottlenose dolphin (*Tursiops truncatus*) in open waters, " in *Animal Sonar Systems*, edited by R.G. Busnel and J.F. Fish. Plenum, New York. Pp. 251-282.

Barlow, J. and Taylor, B.I. 2005. Estimates of sperm whale abundance in the northeastern temperate4 Pacific from a combined acoustic and visual survey. Marine Mammal Science 21:429-445.

Clark, C.W. and Fristrup, K.M. 1997. Whales '95: A combined visual and acoustic survey of blue and fin whales off Southern California. Report of the International Whaling Commission 47: 583-600

Dawson, S. M. 1991. Clicks and Communication: The behavioral and social contexts of Hector's dolphin vocalizations. Ethology, 88: 265-276.

Fristrup, K.M., and Clark, C.W. 1997. Combining visual and acoustic survey data to enhance density estimation. Scientific Report, International Whaling Commission. 47:933-936.

Gillespie, D., and R. Leaper. 1996. Detection of sperm whale (Physeter macrocephalus) clicks and discrimination of individual vocalisations. *Eur. Res. Cetaceans*: 87-91

Gillespie, D. 2004. Detection and classification of right whale calls using an edge detector operating on a smoothed spectrogram. Canadian Acoustics. 32:39-47.

Gillespie, D., and Chappell, O. 2002. An automatic system for detecting and classifying the vocalizations of harbour porpoises. Bioacoustics. 13:37-61.

Gillespie, Douglas, Jonathan Gordon, Ron Mchugh, et al. 2008. PAMGUARD: Semi-automated, open source software for real-time acoustic detection and localization of cetaceans . *Proceedings of the Institute of Acoustics* 30, no. 5

Gordon, J.C.D, Matthews, J.N., Panigada, S., Gannier, A., Borsani, J.F., and Notarbartolo di Sciara, G. 2000. Distribution and relative abundance of striped dolphins in the Ligurian

Sea Cetacean Sanctuary: Results from an acoustic collaboration. Journal of Cetacean Research Management. 2:27-36.

Herzing, D.L. 2000. Acoustics and social behavior of wild dolphins: implications for a sound society in *Hearing by Whales and Dolphins*. Edited by W.W. L. Au., A.N. Popper, and R.R. Fay. Springer-Verlag, New York. Pp. 225-272.

Janik, V. M., and P. J. B. Slater. 1998. Context-specific use suggests that bottlenose dolphin signature whistles are cohesion calls. Animal Behavior 56:829-838.

Kinzey, D., Olson P., and Gerrodette T. 2000. Marine mammal data collection procedures on research ship line-transect surveys by the Southwest Fisheries Science Center. NOAA Administrative Report LJ-00-07C, available from SWFSC, 8604 La Jolla Shores Dr, La Jolla, CA 92037.

Leaper, Russell, Douglas Gillespie, and Vassili Papastavrou. 2000. Results of passive acoustic surveys for odontocetes in the Southern Ocean. *JOURNAL OF CETACEAN RESEARCH AND MANAGEMENT* 2, no. 3: 187-196.

Lewis, T., D. Gillespie, C. Lacey, et al. 2007. Sperm whale abundance estimates from acoustic surveys of the Ionian Sea and Straits of Sicily in 2003. *Journal of the Marine Biological Association of the UK* 87, no. 01: 353-357.

Lopatka, M., Adam, O.,, Laplanche, C., Zarzycki, J., and Motsch, J.-F. 2005. An attractive alternative for specm whale click detection using the wavelet transform in comparison the Forier spectrogram. Aquatic Mammals. 31:463-467.

Lammers, M.O., Aus, W.W.L. and Herzing, D.L. 2003. The broadband social acoustic signaling behavior of spinner and spotted dolphins. Journal of Acoustical Society of America. 114:1629-1639.

Mellinger, D.K, Stafford, K.M., Moore, S.E., Dziak, R.P., and Matsumoto, H. 2008. An overview of fixed passive acoustic observation methods for cetaceans. Oceanography. 20:4; 36-45.

Mellinger, D.K., and Clark, C.W. 2000. Recognizing transient low-frequency whale sounds by spectrogram correlation. Journal of the Acoustical Society of America. 107:3,518- 3,529.

Mellinger, D.K. 2001. ISMAEL 1.0 User's Guide. NOAA Technical Memorandum OAR PMEL-120. Available from NOAA/PMEL, 2600 Sand Point Way. NE, Seattle, WA 98115-6349.

Murray, S.O, Mercado, E.O, and Roitblat, H.L. 1998. Characterizing the graded structure of false killer whale (*Pseudorca crassidens*) vocalizations. Journal of Acoustical Society of America. 104:1679-1688.

Norris, K.S., and Evans, W.E. 1966. Directionality of echolocation clicks in the rough-toothed porpoise, *Steno bredanensis* (Lesson), in *Marine Bio-acoustics*, edited by W.N. Tavolga. Pergamon, New York. Pp. 305-324.

Oswald, J.N., Rankin, S., and Barlow, J. 2004. The effect of recording and analysis bandwidth on acoustic identification of delphinid species. Journal of Acoustical Society of America. 116: 3178-3185.

Rankin, S., Barlow, J., and Oswald, J.N. 2008a. An assessment of the accuracy and precision of a stationary sound source using a two-element towed hydrophone array. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-416. Available from SWFSC, 8604 La Jolla Shores Dr, La Jolla, CA 92037.

Rankin, S., Oswald, J.N., and Barlow, J. 2008b. Acoustic behavior of dolphins in the Pacific ocean: implications for using passive acoustic methods for population studies. Canadian Acoustics. 36:88-92.

Stafford, K.M. 1995. Characterization of blue whale calls from the northeast Pacific and development of a matched filter to locate blue whales on U.S. Navy SOSUS(Sound Surveillance System) arrays. Master's Thesis, Oregon State University, Corvallis, OR.

Thomas, J.A., F.A. Awbrey, and S.R. Fisher. 1986. Use of acoustic techniques in studying whale behaviors. In: Behavior of Whales in Relation to Management, G.P. Donovan, ed. Report of the International Whaling Commission, Special Issue 8 (pp.121-138)

Watkins, W.A. 1967. Harmonic interval: fact or artifact in spectral analysis of pulse trains. Pp. 15-42 in *Marine Bio-Acoustics, 2* (W.N. Tavolga, ed.), Pergamon Press, Oxford.

TABLES

Table 1. PAMGUARD Trial Settings

Whistles	**Trial 1**	**Trial 2**	**Trial 3**
Smoothing Constant (off)	1.0 s	1.0 s	1.0 s
Smoothing Constant (on)	*8.0 s*	10 s	10 s
Detection Threshold	6.0 dB	6.0 dB	*5.0 dB*
Minimum Bins Over Threshold	40%	40%	40%
Minimum Width	1	1	1
Maximum Width	5	5	5
Max Sweep	75 kHz/s	75 kHz/s	75 kHz/s
Max Sweep Differential	900 kHz/s	900 kHz/s	900 kHz/s
Max Amplitude Change	800 dB/s	800 dB/s	800 dB/s
Max Gap	0 time partitions	0 time partitions	0 time partitions
Minimum Length	*5 bins*	6 bins	6 bins
Minimum Occupancy	80%	80%	80%
Integration Time	60 s	60 s	60 s
Minimum Whistle Count	1	1	1
Max Gap	1 s	1 s	1 s
Clicks	**Trial 1**	**Trial 2**	**Trial 3**
Pre-Filter	High Pass: 20KHz	High Pass: 20KHz	High Pass: 20KHz
Trigger Filter	Band Pass: 20-35kHz	Band Pass: 20-35kHz	Band Pass: 20-35kHz
Threshold	*15 dB*	18 dB	18 dB
Long Filter	0.00001	0.00001	0.00001
Long Filter 2	0.000001	0.000001	0.000001
Short Filter	0.1	0.1	0.1
Min Click Separation	100 samples	100 samples	100 samples
Max Click Length	1024 samples	1024 samples	1024 samples
Pre Sample	40 samples	40 samples	40 samples
Post Sample	0 samples	0 samples	0 samples

Table 2. STARLITE 09-11: Visual and Acoustic Encounters.
Visual encounters were recorded by shipboard visual observers and classified as a unique sighting (with a sighting ID number) event or a re-sight event. Beam distance (nm) and group size were estimated. Acoustic encounters were recorded by shipboard acoustic technicians and classified with an acoustic ID number. Time at the beam and beam distance (nm) were recorded based on visual estimation. When an acoustic encounter matched a visual encounter a species id was provided. The Peak ID column shows the recognized detection peaks for clicks and whistles detected on Channels 1 and 4 that were temporally associated with the corresponding visual encounter (Figures 18a-b).

Sighting ID	Acoustic ID	Event	Time	Beam Distance (nm)	Species	Group Size	Acoustic Peak ID (Figures 18a-b)
-	68	Acoustic Only	10:06:49	***4.50***	Unknown	Unknown	-
173	70	Sighting	10:11:35	0.21	*Stenella coeruleoalba*	49	A
174	-	Sighting	10:21:05	3.76	Unidentified small delphinid	29	-
173	70	Resight	10:22:27	0.03	*Stenella coeruleoalba*	49	A
-	69	Acoustic Only	10:23:00	1.20	Unknown	Unknown	-
176	-	Sighting	10:24:17	0.64	*Steno bredanensis*	2	A
177	-	Sighting	10:41:32	2.08	*Stenella attenuata (offshore)*	50	-
178	-	Sighting	10:42:02	2.35	*Stenella attenuata (offshore)*	31	-
179	71	Sighting	10:46:22	3.54	*Unidentified small delphinid*	3	-
180	72	Sighting	10:50:26	1.38	*Stenella attenuata (offshore)*	45	B
180	72	Resight	10:59:09	0.97	*Stenella attenuata (offshore)*	45	B
180	72	Resight	11:03:41	0.76	*Stenella attenuata (offshore)*	45	B
178	-	Resight	11:06:25	2.00	*Stenella attenuata (offshore)*	31	B
-	73	Acoustic Only	11:30:00	1.10	Unknown	Unknown	-
-	74	Acoustic Only	11:33:00	1.60	Unknown	Unknown	-
181	77	Sighting	11:38:30	0.13	Mixed group	85	C1
181	77	Resight	11:44:12	0.27	Mixed group	85	C1
182	-	Sighting	11:48:38	0.69	Unidentified small whale	1	-
183	75	Sighting	11:55:14	1.56	*Steno bredanensis*	6	-
181	77	Resight	11:56:20	0.61	Mixed group	85	C4
184	76	Sighting	12:03:37	1.23	Unidentified small delphinid	2	C4
185	-	Sighting	12:08:41	2.07	Unidentified small delphinid	5	C4
186	-	Sighting	12:32:58	0.74	Unidentified small whale	2	-
187	-	Sighting	12:36:30	0.85	*Stenella attenuata (offshore)*	50	D
188	-	Sighting	12:37:46	0.63	Unidentified medium delphinid	35	-
177	-	Resight	12:41:10	0.45	*Stenella attenuata (offshore)*	50	D
189	78	Sighting	12:42:22	1.60	*Stenella attenuata (offshore)*	40	D
177	-	Resight	12:48:50	0.20	*Stenella attenuata (offshore)*	50	D
190	-	Sighting	13:05:55	2.01	*Kogia sima*	1	-
191	-	Sighting	13:17:05	0.65	*Steno bredanensis*	7	E
192	79	Sighting	13:21:38	0.97	Unidentified small delphinid	4	E
192	79	Resight	13:33:35	1.19	Unidentified small delphinid	4	F1
193	80	Sighting	13:55:55	2.16	Unidentified dolphin or porpoise	5	F1
185	-	Resight	14:07:41	1.88	Unidentified dolphin or porpoise	5	F1
-	81	Acoustic Only	14:13:53	*4.50*	Unknown	Unknown	-
194	-	Sighting	14:17:43	0.68	Unidentified dolphin or porpoise	1	F4, G
195	-	Sighting	14:29:56	3.42	Unidentified small delphinid	80	-

Sighting ID	Acoustic ID	Event	Time	Beam Distance (nm)	Species	Group Size	Acoustic Peak ID (Figures 18a-b)
196	83	Sighting	14:31:58	1.47	Unidentified dolphin or porpoise	6	G
-	82	Acoustic Only	14:35:00	1.20	Unknown	Unknown	-
197	84	Sighting	15:11:39	3.72	Unidentified small delphinid	30	H
-	86	Acoustic Only	16:22:15	3.20	Unknown	Unknown	-
199	-	Sighting	16:24:08	0.62	Unidentified dolphin or porpoise	16	I
198	87	Resight	16:30:58	0.30	*Stenella coeruleoalba*	75	I
200	-	Sighting	16:30:58	1.55	*Mesoplodon sp.*	2	-
-	88	Acoustic Only	16:52:00	0.30	Unknown	Unknown	-
-	89	Acoustic Only	17:03:52	*4.50*	Unknown	Unknown	-
201	92	Sighting	18:27:27	0.18	*Stenella attenuata (offshore)*	65	J, K1, K4
-	90	Acoustic Only	18:33:00	0.20	Unknown	Unknown	-
202	91	Sighting	18:48:05	0.57	*Steno bredanensis*	8	K4
201	92	Resight	18:51:11	0.46	*Stenella attenuata (offshore)*	65	K4

Table 3. STARTLITE 09-11: Visual Encounters. Number of cetacean sightings by visual observers. Tallied by 30-min period starting at 09:28 and classified as unique sightings or tallied with re-sights. Group size estimates were also tallied for each period.

Sample Period	0928	0958	1028	1058	1128	1158	1228	1258	1328	1358	1428	1458	1528	1558	1628	1658	1728	1758	1828	Total
Original Sightings	0	3	4	0	3	2	4	3	1	1	2	1	*0	2	1	0	0	1	1	29
Total Sigtings[1]	0	5	4	3	6	2	6	3	2	2	2	1	*0	2	2	0	0	1	2	43
Group Size	0	80	129	76	92	9	127	12	9	6	86	30	*0	93	82	0	0	65	73	969

[1] Total Sightings include re-sightings; *Observers were off effort due to weather.

Table 4. STARTLITE 09-11: Shipboard Acoustic Detections. Number of cetacean calls detected by the shipboard acoustic technician (SR) by visual inspection of a scrolling spectrographic display and aided by aural monitoring. Encounters (groups) and localizations (individual detections) were tallied by 30-min time periods starting at 09:28 and the presence of whistles, burst pulses and clicks were noted for each time period.

Sample Period	0928	0958	1028	1058	1128	1158	1228	1258	1328	1358	1428	1458	1528	1558	1628	1658	1728	1758	1828	Total
Encounters	0	3	2	1	3	1	1	1	0	3	1	1	0	2	2	1	0	1	2	25
Localizations	0	23	11	35	24	29	5	3	12	10	31	28	4	9	21	4	1	4	39	293
Whistles	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	-
Burst Pulse	N	Y	Y	Y	Y	N	N	N	Y	Y	Y	Y	N	Y	Y	N	N	Y	Y	-
Clicks	N	Y	Y	Y	Y	Y	N	Y	N	N	Y	N	N	N	Y	N	N	Y	Y	-

Table 5. STARLITE 09-11: Ch. 4 Manual Acoustic Detections. Number of cetacean calls detected by the author (TMY) by visual inspection of a scrolling spectrographic display and aided by aural monitoring. Detections were classified as burst pulses, clicks and whistles and were tallied by 30-min time periods starting at 09:28

Sample Period	0928	0958	1028	1058	1128	1158	1228	1258	1328	1358	1428	1458	1528	1558	1628	1658	1728	1758	1828	Total
Burst Pulse	2	127	1	9	9	3	5	2	2	20	40	23	4	9	13	1	0	19	169	458
Clicks	374	1263	193	10257	1907	2354	361	125	91	192	1264	1159	177	369	132	30	24	26	2649	22947
Whistles	47	38	84	325	126	156	57	18	39	41	85	989	32	81	269	6	23	8	919	3343
Total Detections	423	1428	278	10591	2042	2513	423	145	132	253	1389	2171	213	459	414	37	47	53	3737	26748

Table 6a. STARLITE 09-11: Channel 1 PAMGUARD Trial 1 Acoustic Detections. Number of cetacean calls detected on Channel 1 recordings using PAMGUARD Core 1.0 software with Trial 1 detection parameters. Detections were classified as whistles, whistle events and clicks and were tallied by 30-min time periods starting at 09:28.

Sample Period	0928	0958	1028	1058	1128	1158	1228	1258	1328	1358	1428	1458	1528	1558	1628	1658	1728	1758	1828	Total
*Whistles	139	1291	194	294	500	287	108	295	564	313	336	762	94	239	371	121	170	345	1956	8379
Whistle Events	67	137	94	115	141	119	76	129	174	120	127	238	69	140	134	77	100	97	148	2302
Clicks	863	6709	2167	24710	2566	3210	1176	925	1526	1479	3791	2044	574	1190	1418	1430	1060	1805	11304	69948
Total (Clicks + Whistles)	1002	8000	2361	25005	3066	3497	1284	1220	2090	1792	4127	2806	668	1429	1789	1551	1230	2150	13260	78327

* Whistles include Raw PAMGUARD whistle detections between 3000 and 36000 Hz

Table 6b. STARLITE 09-11: Channel 4 PAMGUARD Trial 1 Acoustic Detections. Number of cetacean calls detected on Channel 4 recordings using PAMGUARD Core 1.0 software with Trial 1 detection parameters. Detections were classified as whistles, whistle events and clicks and were tallied by 30-min time periods starting at 09:28.

Sample Period	**0928**	**0958**	**1028**	**1058**	**1128**	**1158**	**1228**	**1258**	**1328**	**1358**	**1428**	**1458**	**1528**	**1558**	**1628**	**1658**	**1728**	**1758**	**1828**	**Total**
Whistles	26	137	52	273	265	317	143	149	125	198	290	1119	55	184	361	145	106	228	2628	6801
Whistle Events	26	64	38	93	96	141	72	85	79	92	124	243	47	101	122	55	76	101	215	1870
Clicks	630	861	446	21438	2500	3984	916	380	1670	972	3524	1699	291	1581	3145	4097	2353	3861	16071	70419
Total (Clicks + Whistles)	656	998	498	21711	2765	4301	1059	529	1795	1170	3814	2818	346	1765	3506	4242	2459	4089	18699	77220

* Whistles include Raw PAMGUARD whistle detections between 3000 and 36000 Hz

Table 7a. STARLITE 09-11: Channel 1 PAMGUARD Trial 2 Acoustic Detections. Number of cetacean calls detected on Channel 1 recordings using PAMGUARD Core 1.0 software with Trial 2 detection parameters. Detections were classified as whistles, whistle events and clicks and were tallied by 30-min time periods starting at 09:28.

Sample Period	**0928**	**0958**	**1028**	**1058**	**1128**	**1158**	**1228**	**1258**	**1328**	**1358**	**1428**	**1458**	**1528**	**1558**	**1628**	**1658**	**1728**	**1758**	**1828**	**Total**
Whistles	22	717	53	106	149	118	13	61	184	80	108	365	17	58	166	20	32	128	1220	3617
Whistle Events	19	76	30	40	52	48	11	32	81	32	54	141	13	40	67	17	26	28	106	913
Clicks	325	5357	862	16001	1686	2166	671	547	702	790	2477	915	233	424	532	427	394	976	8066	43551
Total (Clicks + Whistles)	347	6002	915	16107	1835	2284	684	608	886	870	2585	1280	250	482	698	447	426	1104	9286	47168

* Whistles include Raw PAMGUARD whistle detections between 3000 and 36000 Hz

Table7b. STARLITE 09-11: Ch4 PAMGUARD Trial 2 Acoustic Detections. Number of cetacean calls detected on Channel 4 recordings using PAMGUARD Core 1.0 software with Trial 2 detection parameters. Detections were classified as whistles, whistle events and clicks and were tallied by 30-min time periods starting at 09:28.

Sample Period	**0928**	**0958**	**1028**	**1058**	**1128**	**1158**	**1228**	**1258**	**1328**	**1358**	**1428**	**1458**	**1528**	**1558**	**1628**	**1658**	**1728**	**1758**	**1828**	**Total**
Whistles	2	23	14	139	96	321	57	50	26	74	115	670	6	53	178	27	21	66	1582	3520
Whistle Events	2	19	11	45	40	78	22	25	22	32	43	186	6	33	62	15	20	28	157	846
Clicks	383	324	151	13400	1491	2605	572	197	339	288	2345	434	103	443	812	851	616	909	10206	36469
Total (Clicks + Whistles)	385	347	165	13539	1587	2926	629	247	365	362	2460	1104	109	496	990	878	637	975	11788	39989

* Whistles include Raw PAMGUARD whistle detections between 3000 and 36000 Hz

Table 8a. STARTLITE 09-11: Channel 1 PAMGUARD Trial 3 Acoustic Detections. Number of cetacean calls detected on Channel 1 recordings using PAMGUARD Core 1.0 software with Trial 3 detection parameters. Detections were classified as whistles, whistle events and clicks and were tallied by 30-min time periods starting at 09:28.

Sample Period	**0928**	**0958**	**1028**	**1058**	**1128**	**1158**	**1228**	**1258**	**1328**	**1358**	**1428**	**1458**	**1528**	**1558**	**1628**	**1658**	**1728**	**1758**	**1828**	**Total**
Whistles	164	754	205	262	412	275	98	305	460	264	294	656	121	214	324	125	185	257	1371	6746
Whistle Events	87	123	102	111	150	114	68	131	173	121	125	215	77	129	124	86	107	103	140	2286
Clicks	325	5357	862	16001	1686	2166	671	547	702	790	2477	915	233	424	532	427	394	976	8066	43551
Total (Clicks + Whistles)	489	6111	1067	16263	2098	2441	769	852	1162	1054	2771	1571	354	638	856	552	579	1233	9437	50297

* Whistles include Raw PAMGUARD whistle detections between 3000 and 36000 Hz

Table 8b. STARTLITE 09-11: Channel4 PAMGUARD Trial 3 Acoustic Detections. Number of cetacean calls detected on Channel 4 recordings using PAMGUARD Core 1.0 software with Trial 3 detection parameters. Detections were classified as whistles, whistle events and clicks and were tallied by 30-min time periods starting at 09:28.

Sample Period	**0928**	**0958**	**1028**	**1058**	**1128**	**1158**	**1228**	**1258**	**1328**	**1358**	**1428**	**1458**	**1528**	**1558**	**1628**	**1658**	**1728**	**1758**	**1828**	**Total**
Whistles	39	162	64	181	217	457	91	136	102	146	230	962	40	151	294	120	85	158	1798	5433
Whistle Events	32	85	45	69	111	135	49	80	70	85	112	236	34	93	113	67	67	78	197	1758
Clicks	383	324	151	13400	1491	2605	572	197	339	288	2345	434	103	443	812	851	616	909	10206	36469
Total (Clicks + Whistles)	422	486	215	13581	1708	3062	663	333	441	434	2575	1396	143	594	1106	971	701	1067	12004	41902

FIGURES

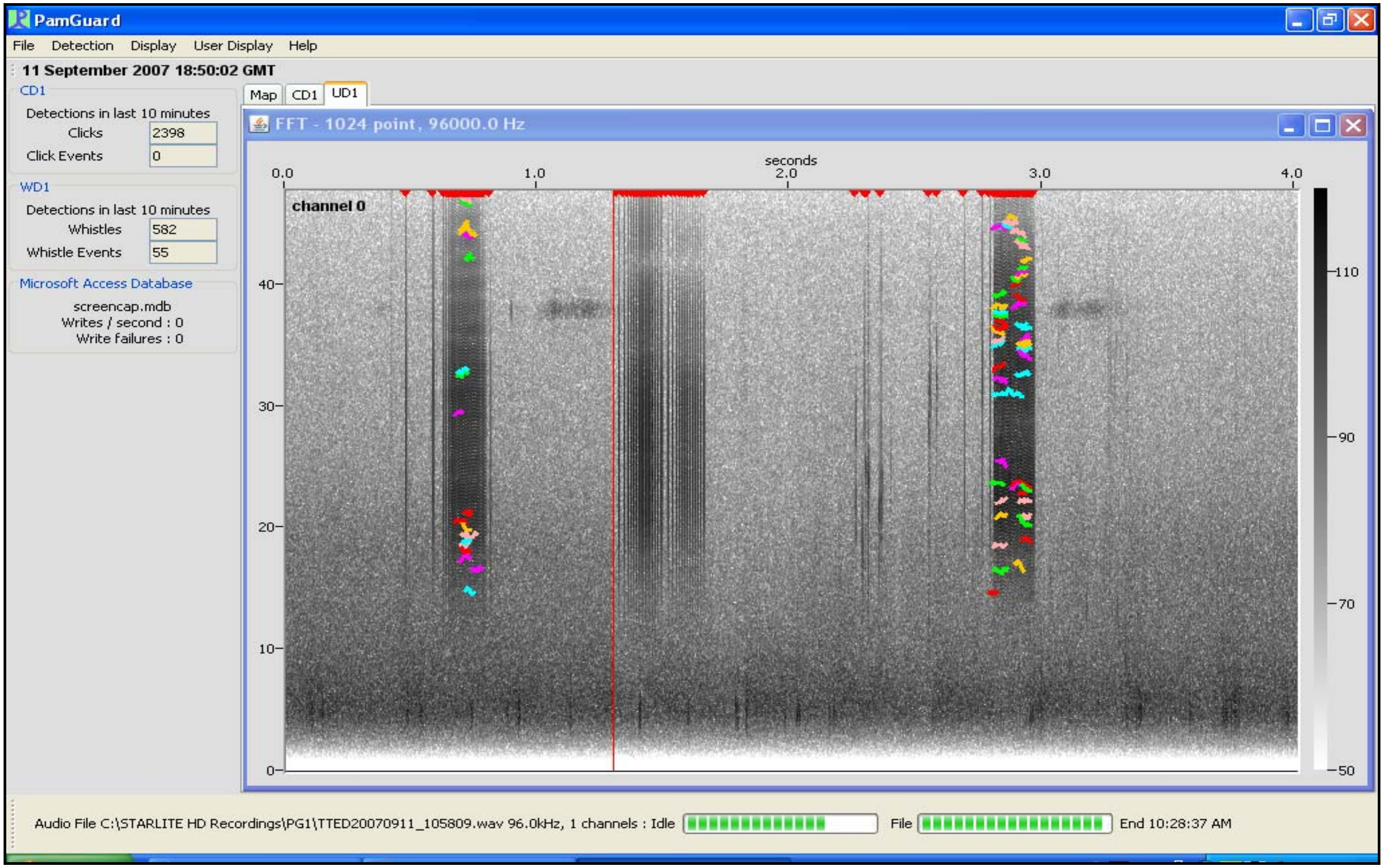

Figure 1a. Burst Pulse Detection Example.
Spectrogram (1024 FFT; 4 sec window; Hann) showing two burst pulses detected in PAMGUARD Trial 2. This figure illustrates that burst pulses are counted as both clicks (red pointers at top of screen) and several whistles. Thereby resulting in inflated numbers of click and whistle detections.

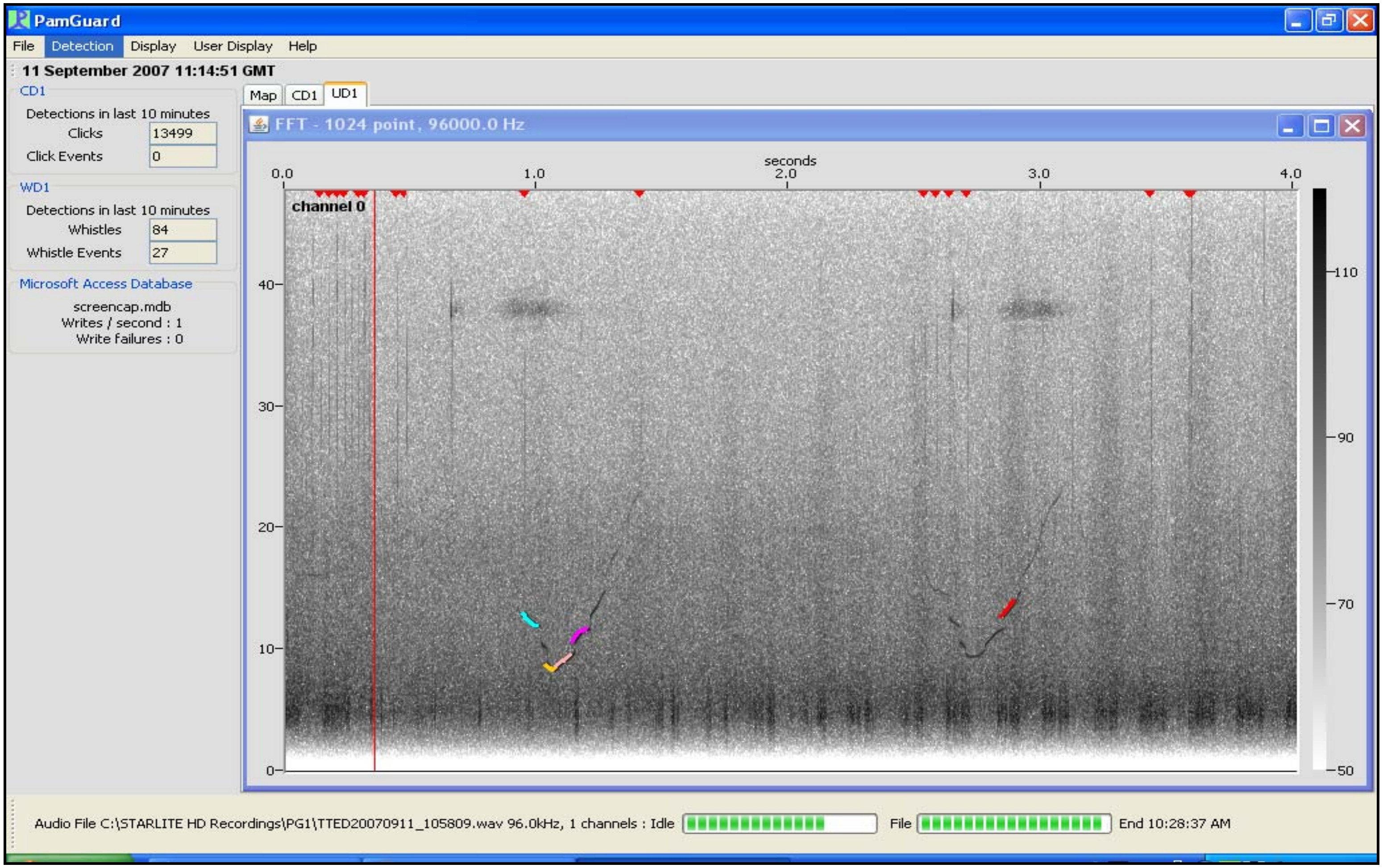

Figure 1b. Whistle Detection Example.

Spectrogram (1024 FFT; 4 sec window; Hann) showing two whistles detected in PAMGUARD Trial 2. The first whistle has been counted as four (blue, yellow, salmon, and pink) separate whistles whereas the second whistle was only counted once (red).

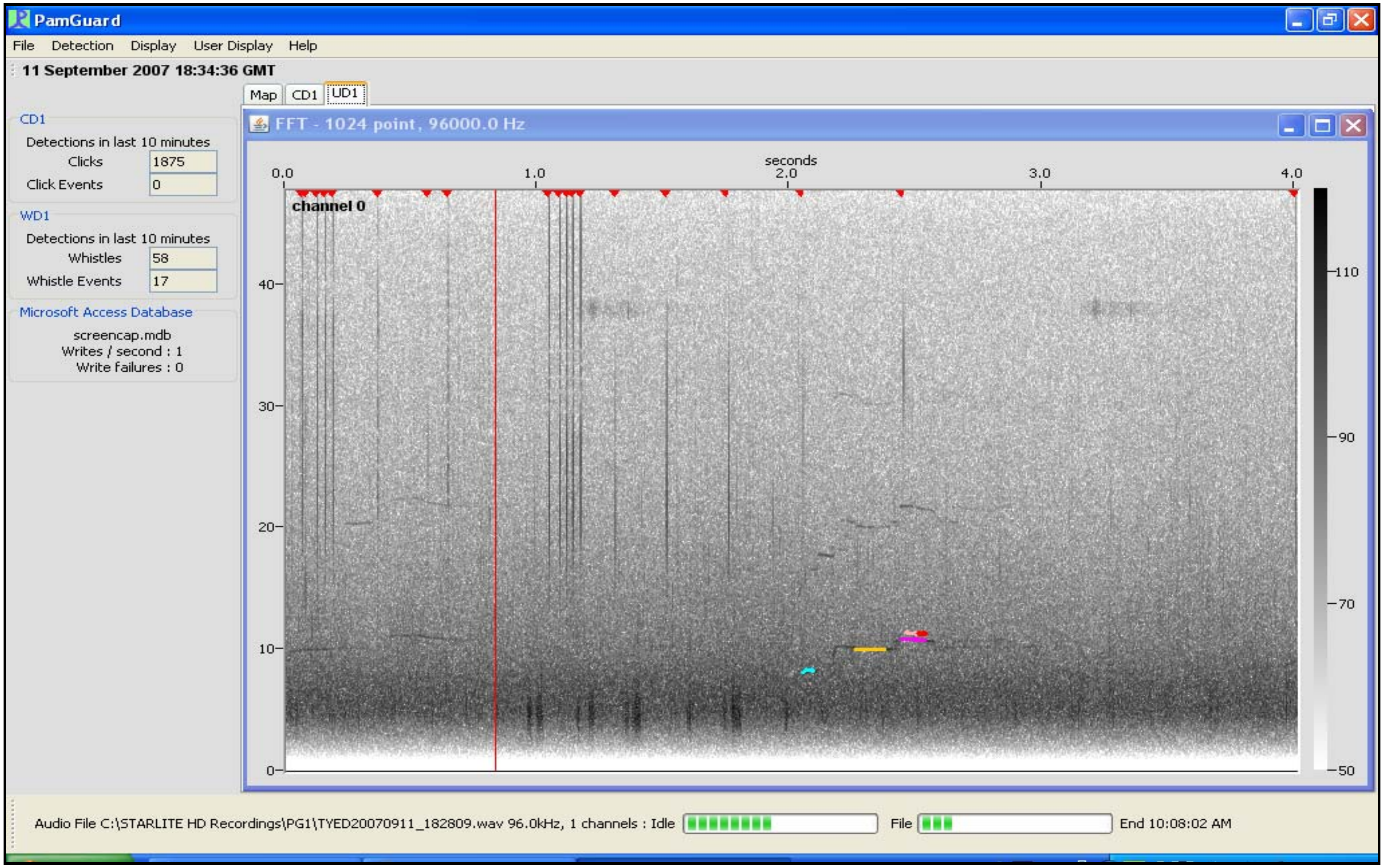

Figure 1c. Step Whistle Detection Example.
Spectrogram (1024 FFT; 4 sec window; Hann) showing a stepped whistle detected in PAMGUARD Trial 2. This whistle has been counted as five separate whistles (blue, yellow, salmon, pink, and red).

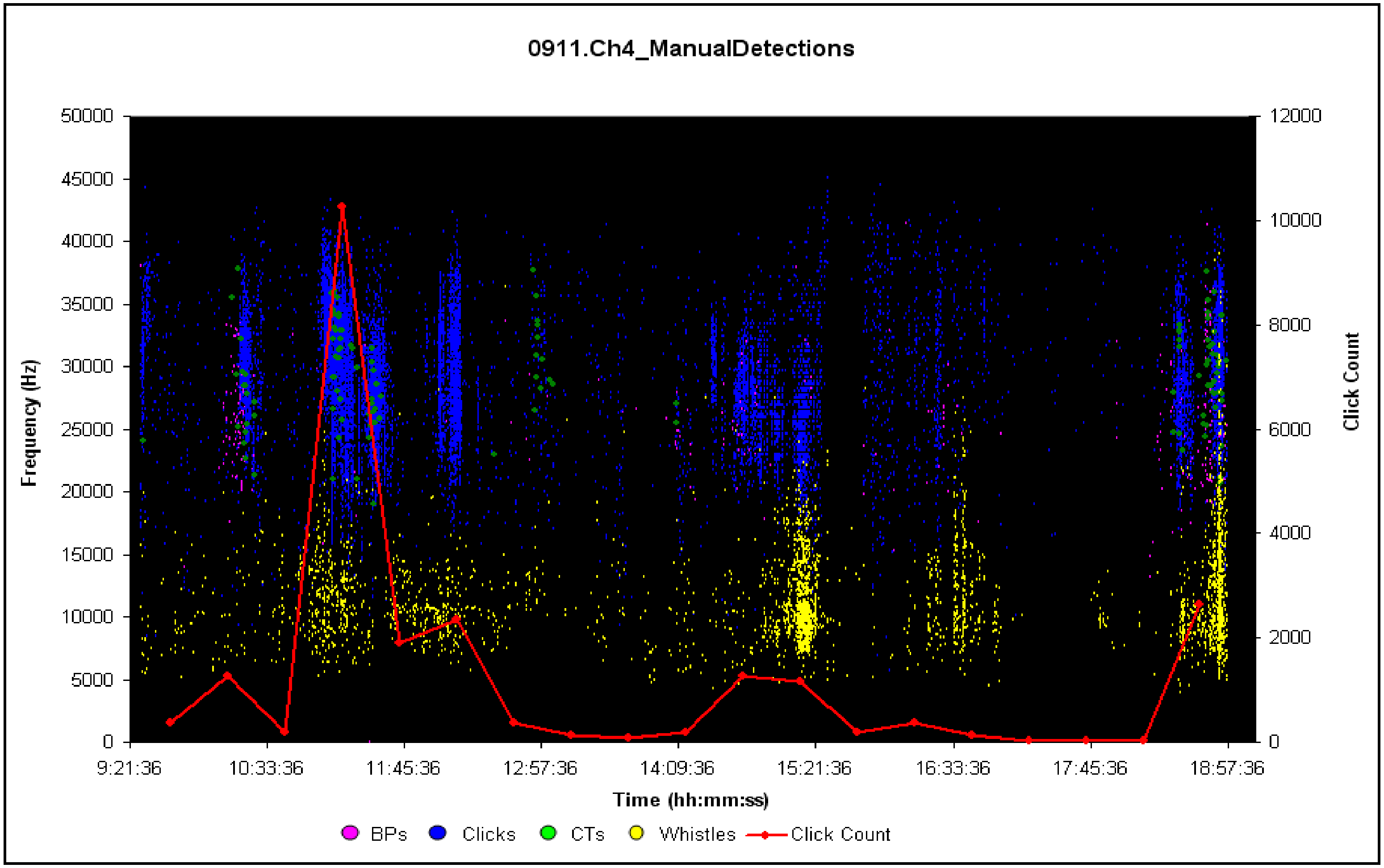

Figure 2. STARLITE 0911: Manual Detections.
Number of cetacean calls detected by the author (TMY) using visual inspection of a scrolling spectrographic display and aided by simultaneous aural monitoring. Detections were classified as burst pulses (pink), clicks (blue), click trains (CT) (green) and whistles (yellow). Whistles were plotted using detection time and start frequency, while burst pulses, clicks and click trains were plotted using detection time and center frequency. The 30-min click count is shown in red.

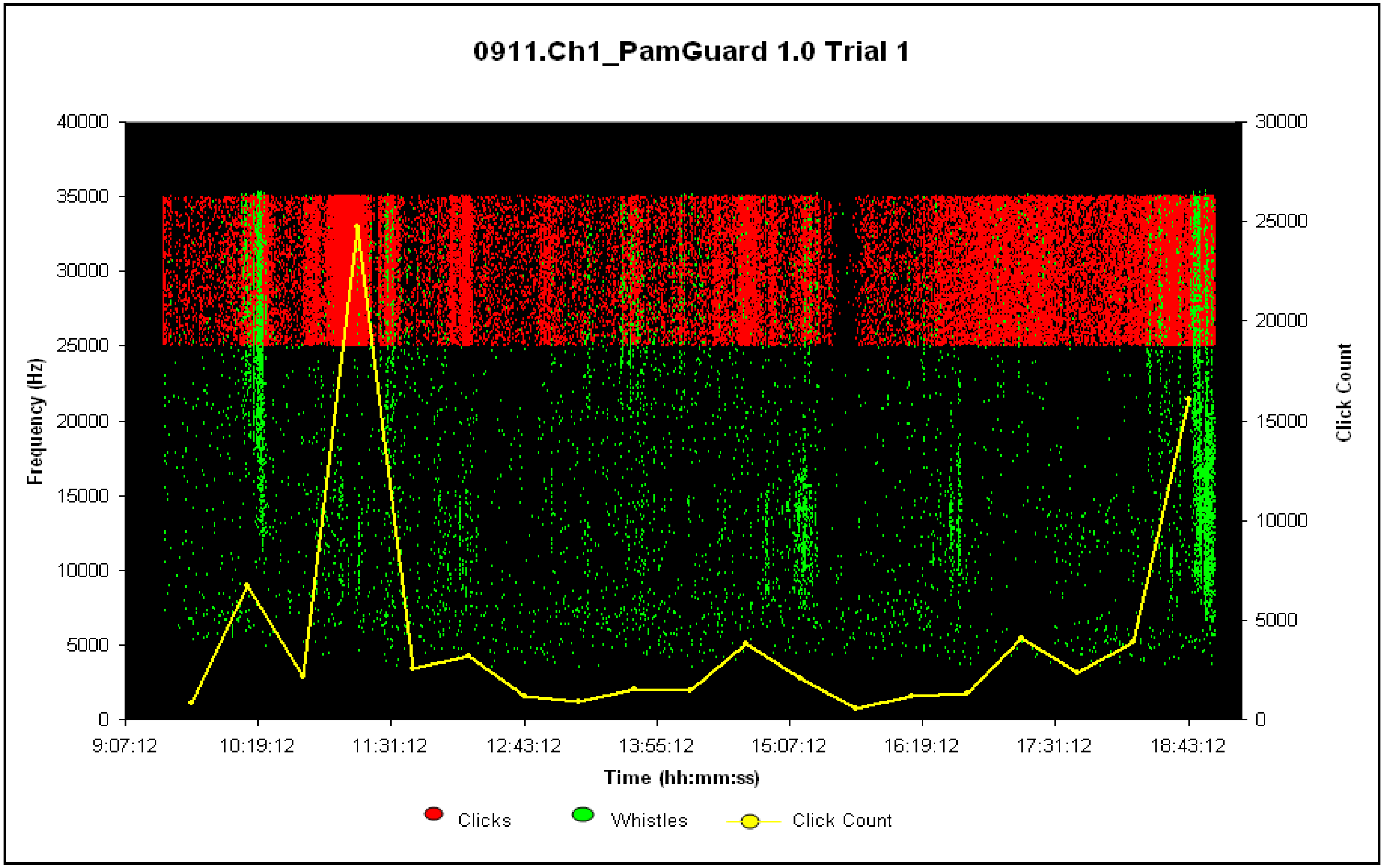

Figure 3a. STARLITE 0911: Channel 1 PAMGUARD Trial 1 Acoustic Detections.
Number of cetacean calls detected on Channel 1 recordings using PAMGUARD Core 1.0 software with Trial 1 detection parameters. Detections were classified as either whistles (green) or clicks (red). Each whistle detection was plotted using detection time and minimum frequency, whereas click detections were plotted using detection time and randomly generated frequencies between 25 and 35 kHz, corresponding to the click trigger filter. The 30-min click count is shown in yellow.

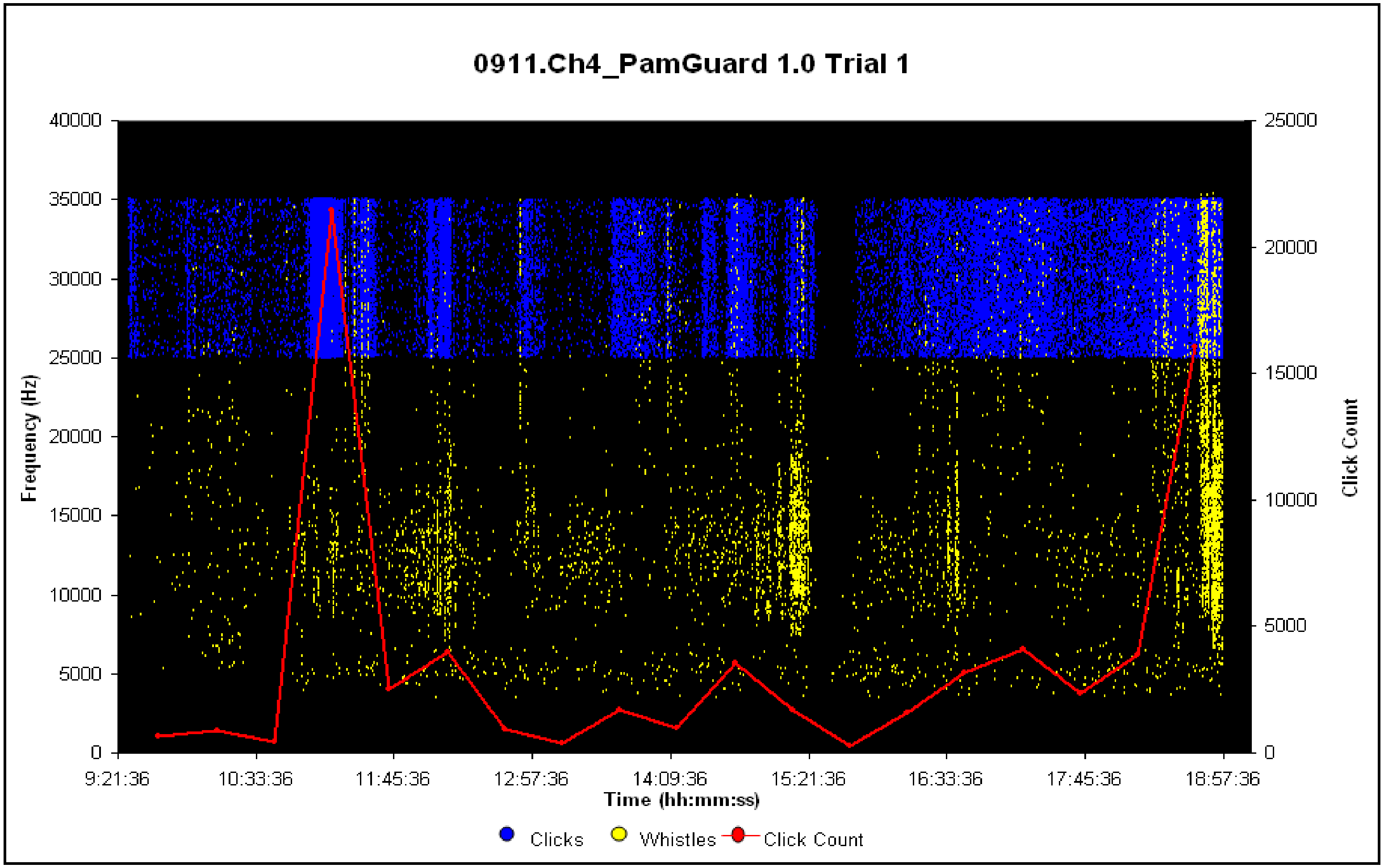

Figure 3b. STARLITE 0911: Channel 4 PAMGUARD Trial 1 Acoustic Detections.
Number of cetacean calls detected on Channel 4 recordings using PAMGUARD Core 1.0 software with Trial 1 detection parameters. Detections were classified as either whistles (yellow) or clicks (blue). Each whistle detection was plotted using detection time and minimum frequency, whereas click detections were plotted using detection time and randomly generated frequencies between 25 and 35 kHz, corresponding to the click trigger filter. The 30-min click count is shown in red.

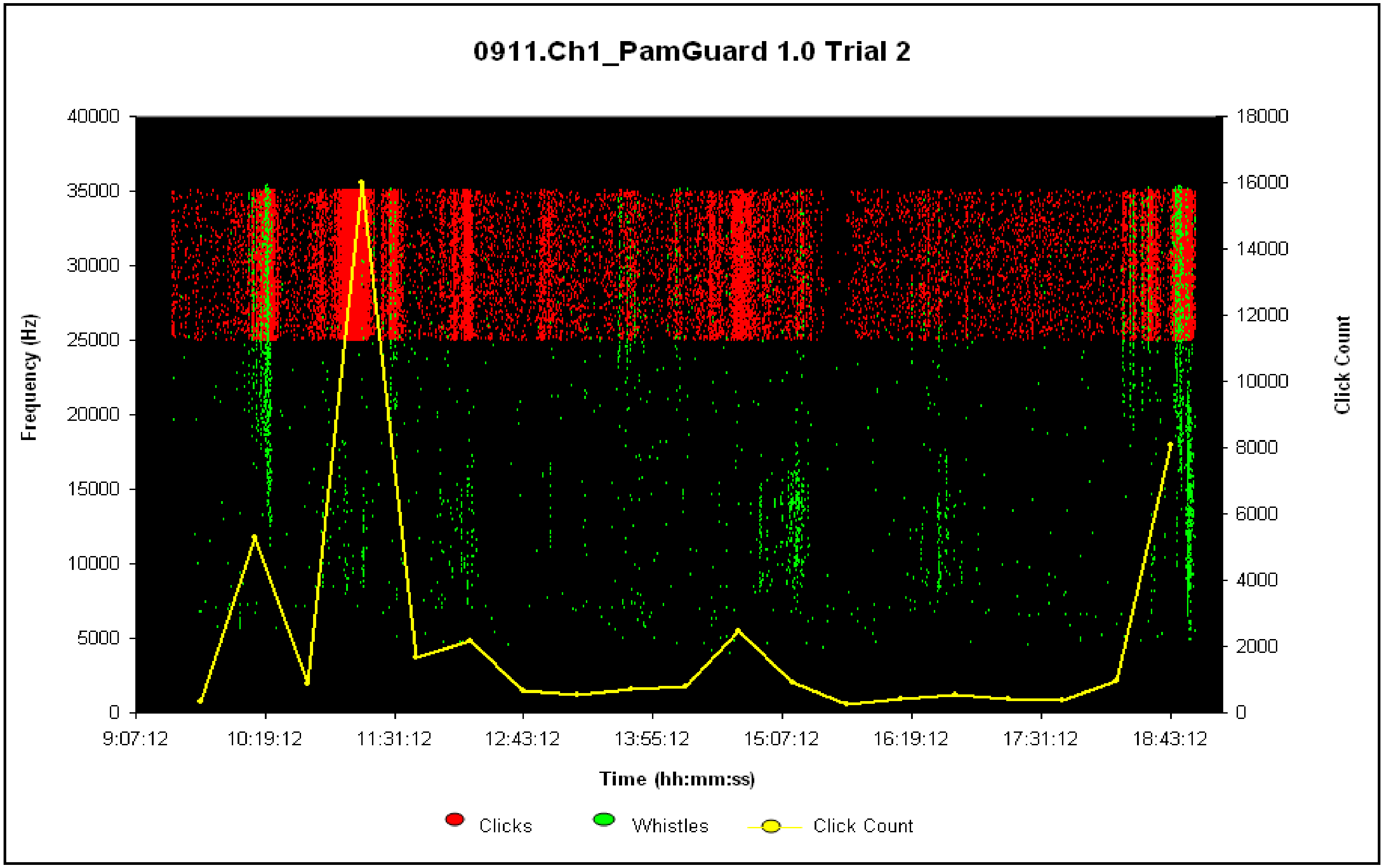

Figure 4a. STARLITE 0911: Channel 1 PAMGUARD Trial 2 Acoustic Detections.
Number of cetacean calls detected on Channel 4 recordings using PAMGUARD Core 1.0 software with Trial 2 detection parameters. Detections were classified as either whistles (green) or clicks (red). Each whistle detection was plotted using detection time and minimum frequency, whereas click detections were plotted using detection time and randomly generated frequencies between 25 and 35 kHz, corresponding to the click trigger filter. The 30-min click count is shown in yellow.

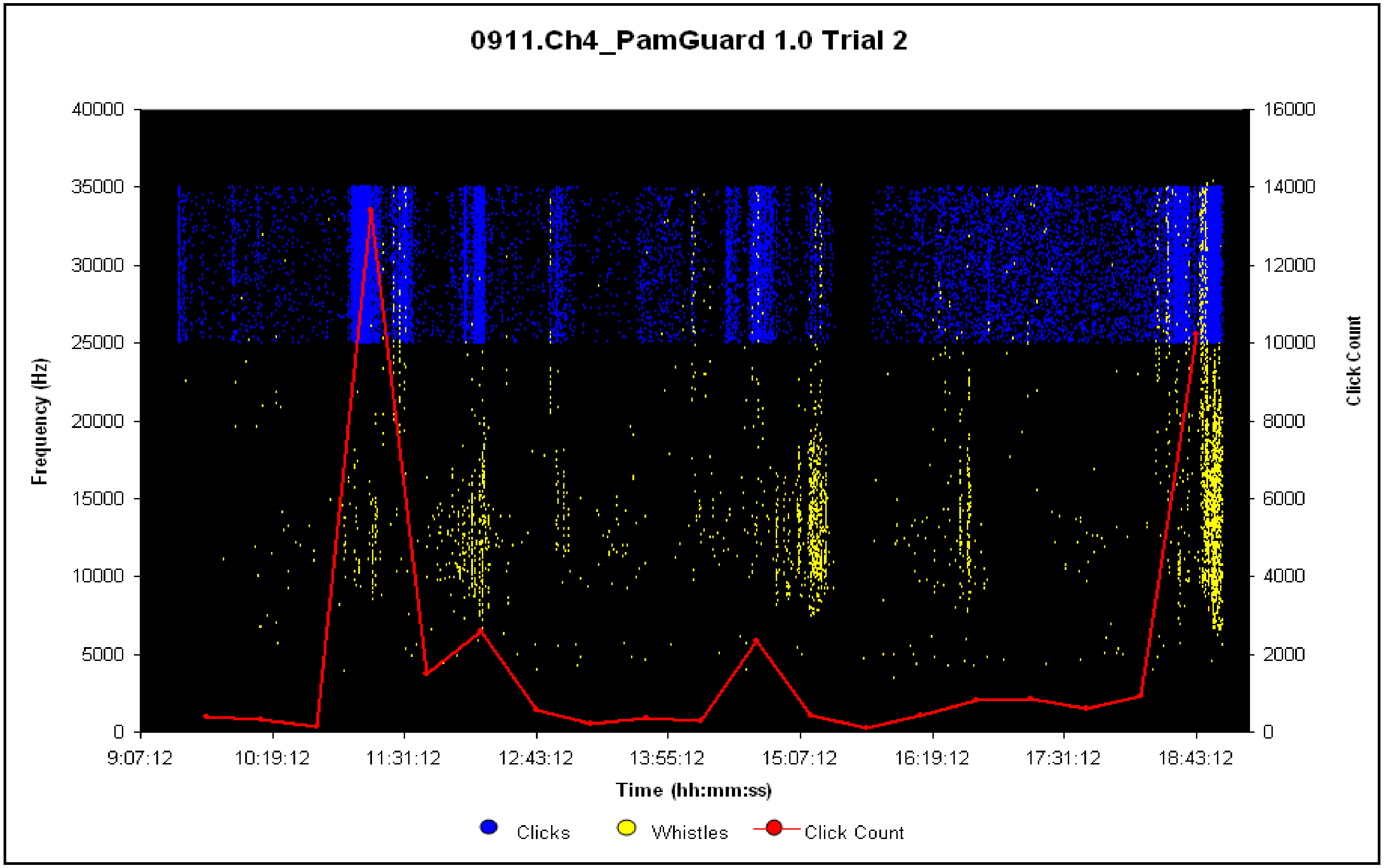

Figure 4b. STARLITE 0911: Channel 4 PAMGUARD Trial 2 Acoustic Detections.
Number of cetacean calls detected on Channel 4 recordings using PAMGUARD Core 1.0 software with Trial 2 detection parameters. Detections were classified as either whistles (yellow) or clicks (blue). Each whistle detection was plotted using detection time and minimum frequency, whereas click detections were plotted using detection time and randomly generated frequencies between 25 and 35 kHz, corresponding to the click trigger filter. The 30-min click count is shown in red.

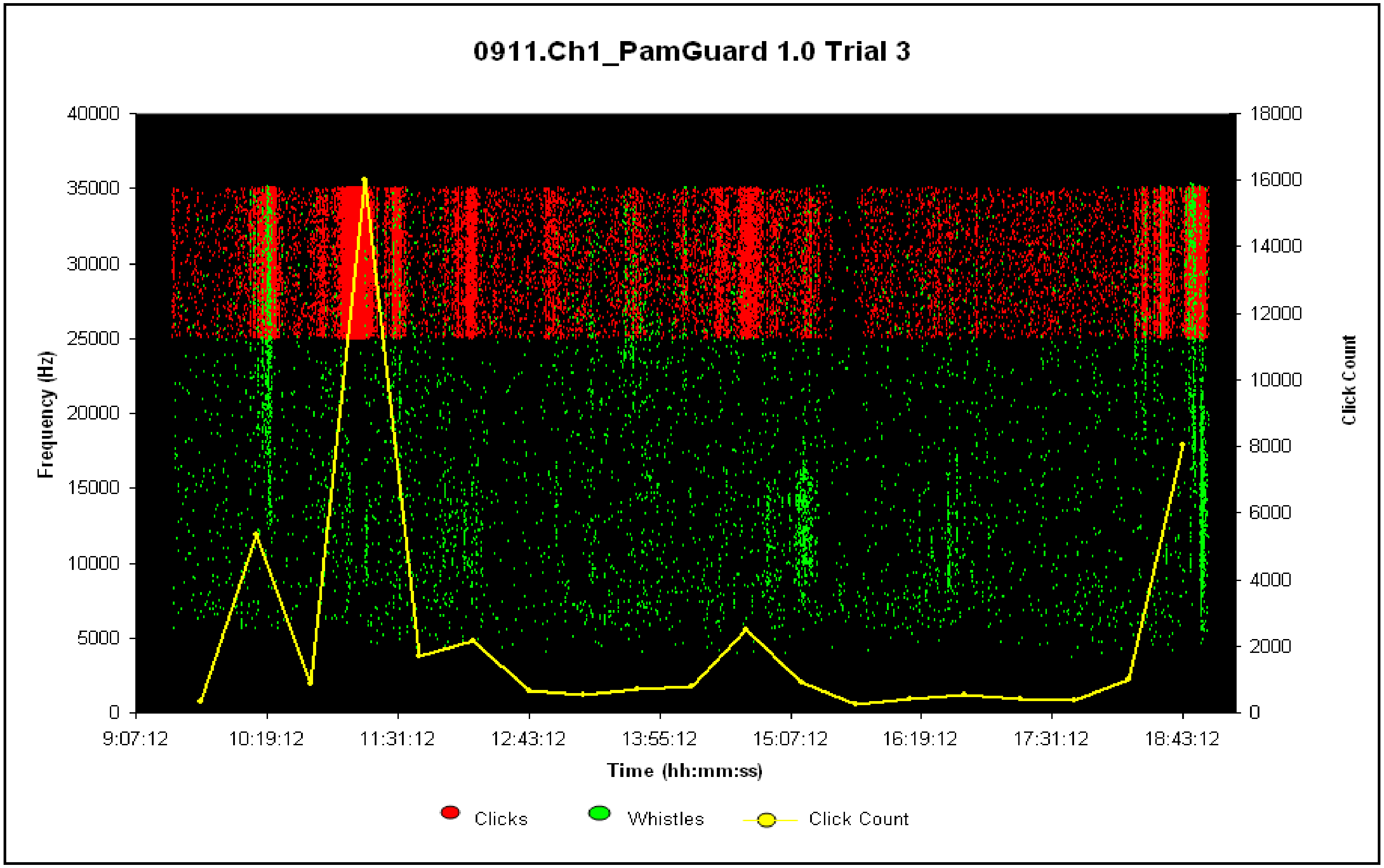

Figure 5a. STARLITE 0911: Channel 1 PAMGUARD Trial 3 Acoustic Detections.
Number of cetacean calls detected on Channel 1 recordings using PAMGUARD Core 1.0 software with Trial 3 detection parameters. Detections were classified as either whistles (green) or clicks (red). Each whistle detection was plotted using detection time and minimum frequency, whereas click detections were plotted using detection time and randomly generated frequencies between 25 and 35 kHz, corresponding to the click trigger filter. The 30-min click count is shown in yellow.

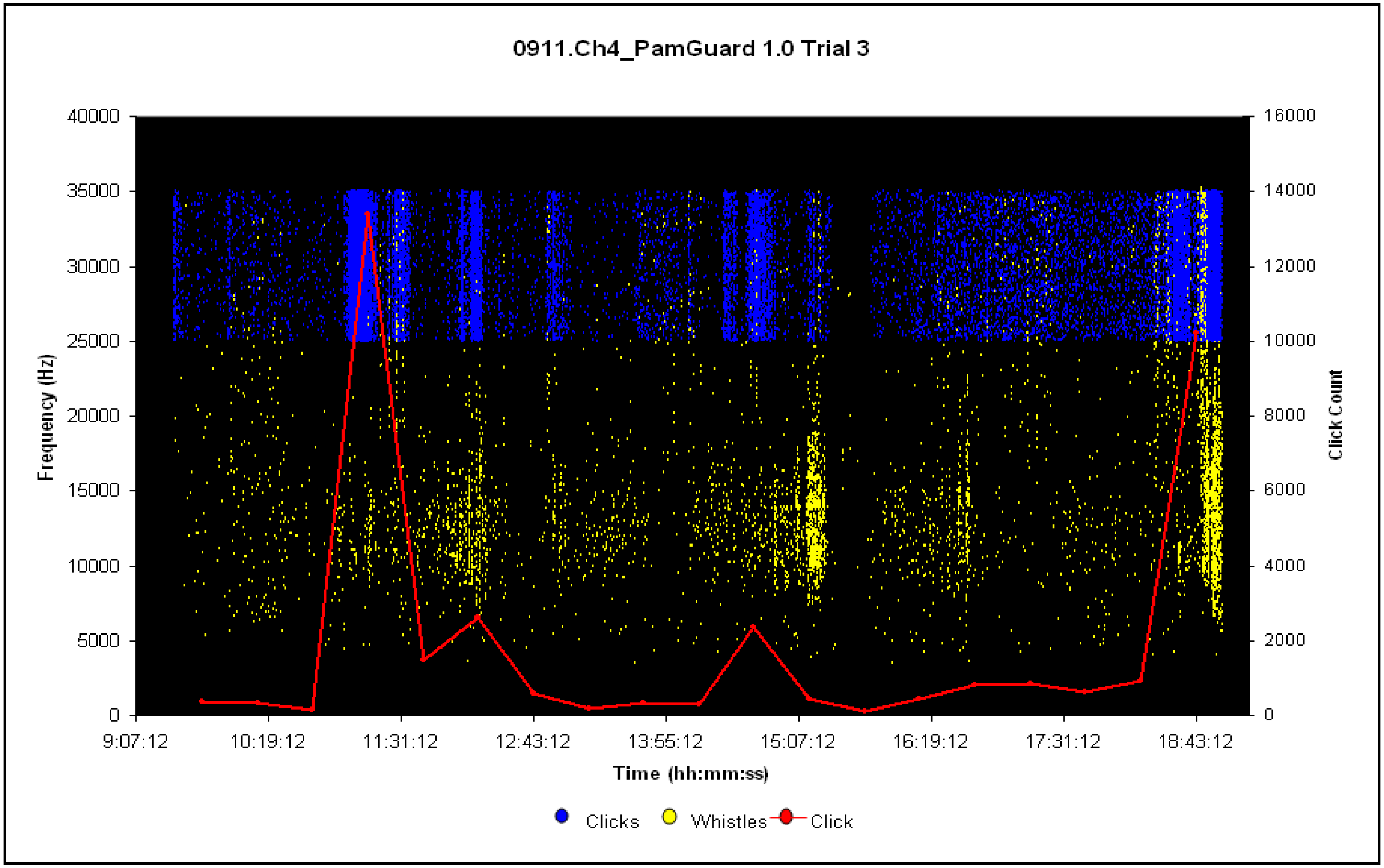

Figure 5b. STARLITE 0911: Channel 4 PAMGUARD Trial 3 Acoustic Detections.
Number of cetacean calls detected on Channel 4 recordings using PAMGUARD Core 1.0 software with Trial 3 detection parameters. Detections were classified as either whistles (yellow) or clicks (blue). Each whistle detection was plotted using detection time and minimum frequency, whereas click detections were plotted using detection time and randomly generated frequencies between 25 and 35 kHz, corresponding to the click trigger filter. The 30-min click count is shown in red.

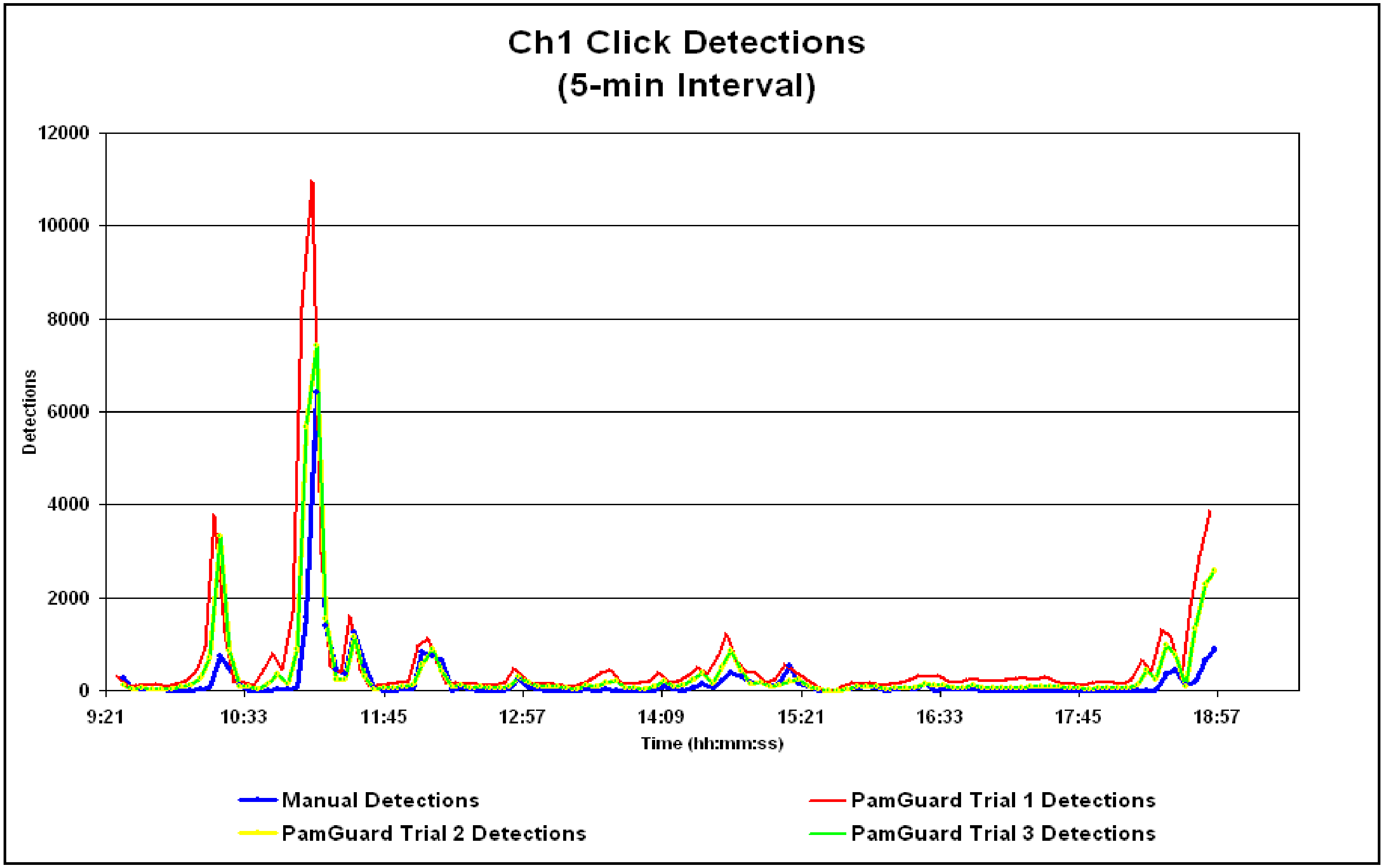

Figure 6a. Channel 1 Click Detections (5-min Intervals).
Detection results for each cetacean click detection found on the Channel 1 recordings [Manual (blue), PAMGUARD Trial 1 (red), PAMGUARD Trial 2 (yellow), and PAMGUARD Trial 3 (green)] were tallied into 5-min bins. **Manual detections are from the Channel 4 analysis.

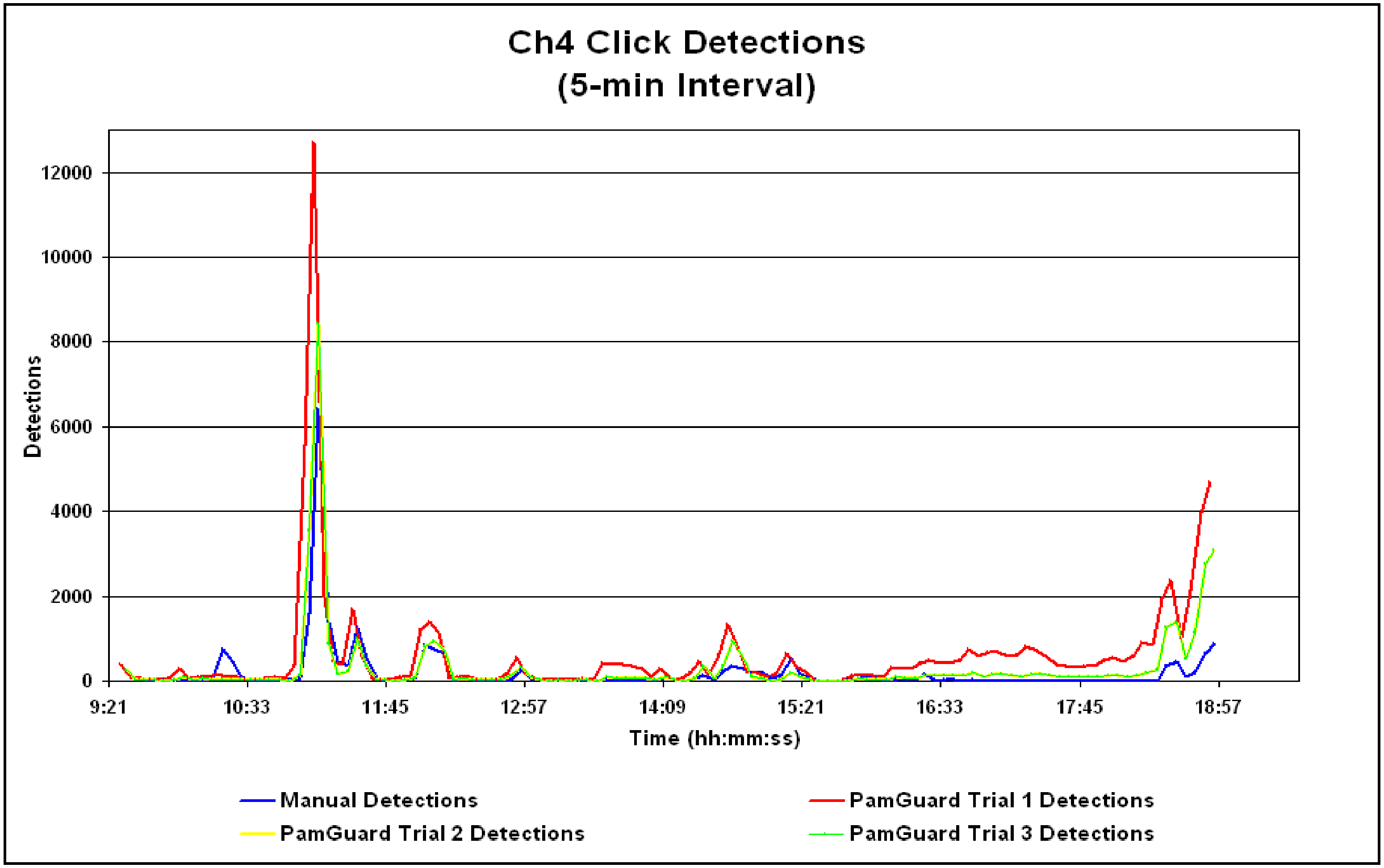

Figure 6b. Channel 4 Click Detections (5-min Intervals).
Detection results for each cetacean click detection found on the Channel 4 recordings [Manual (blue), PAMGUARD Trial 1 (red), PAMGUARD Trial 2 (yellow), and PAMGUARD Trial 3 (green)] were tallied into 5-min bins.

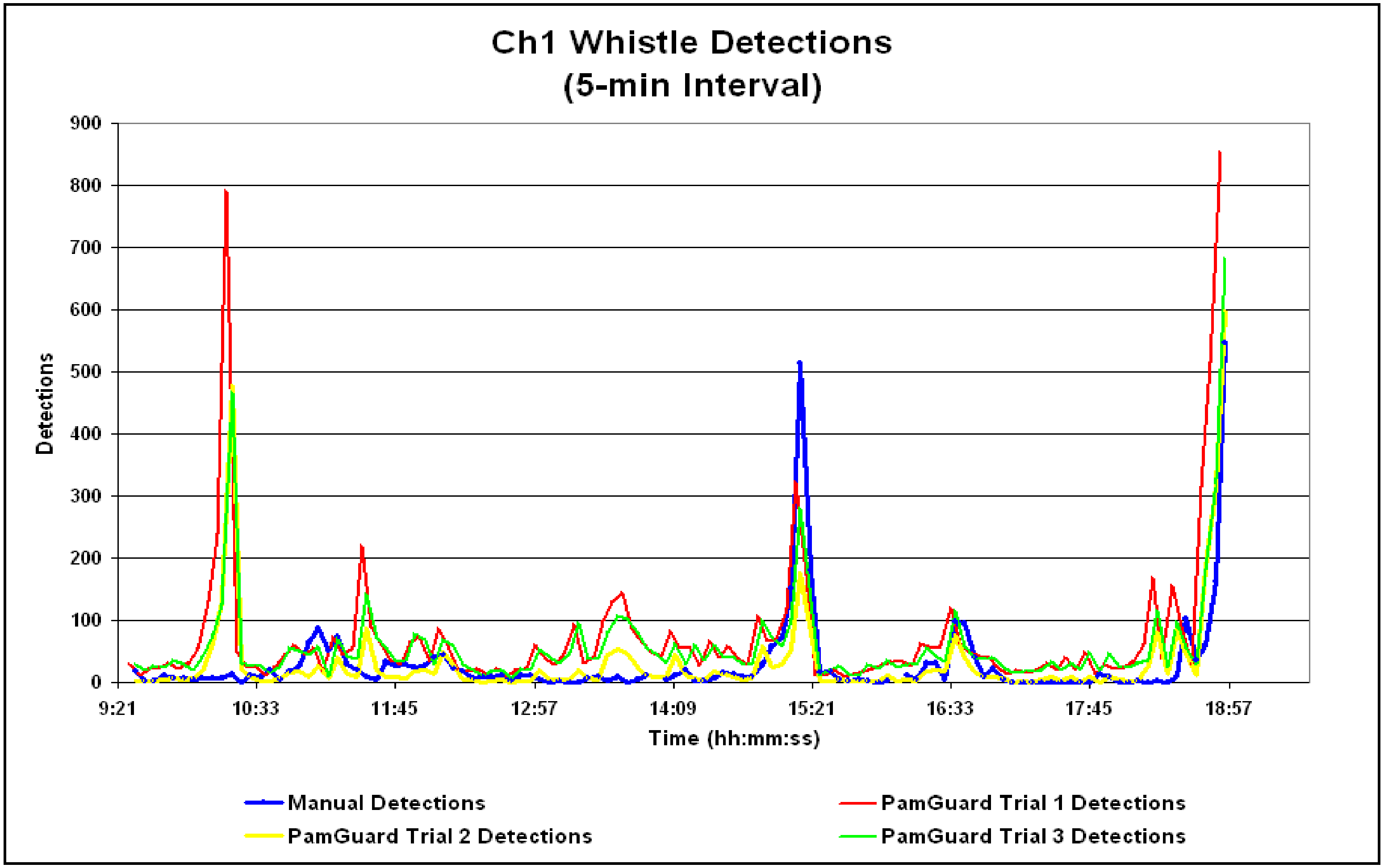

Figure 7a. Channel 1 Whistle Detections (5-min Intervals).
Detection results for each cetacean whistle detection found on the Channel 1 recordings [Manual (blue), PAMGUARD Trial 1 (red), PAMGUARD Trial 2 (yellow), and PAMGUARD Trial 3 (green)] were tallied into 5-min bins. **Manual detections are from Channel 4.

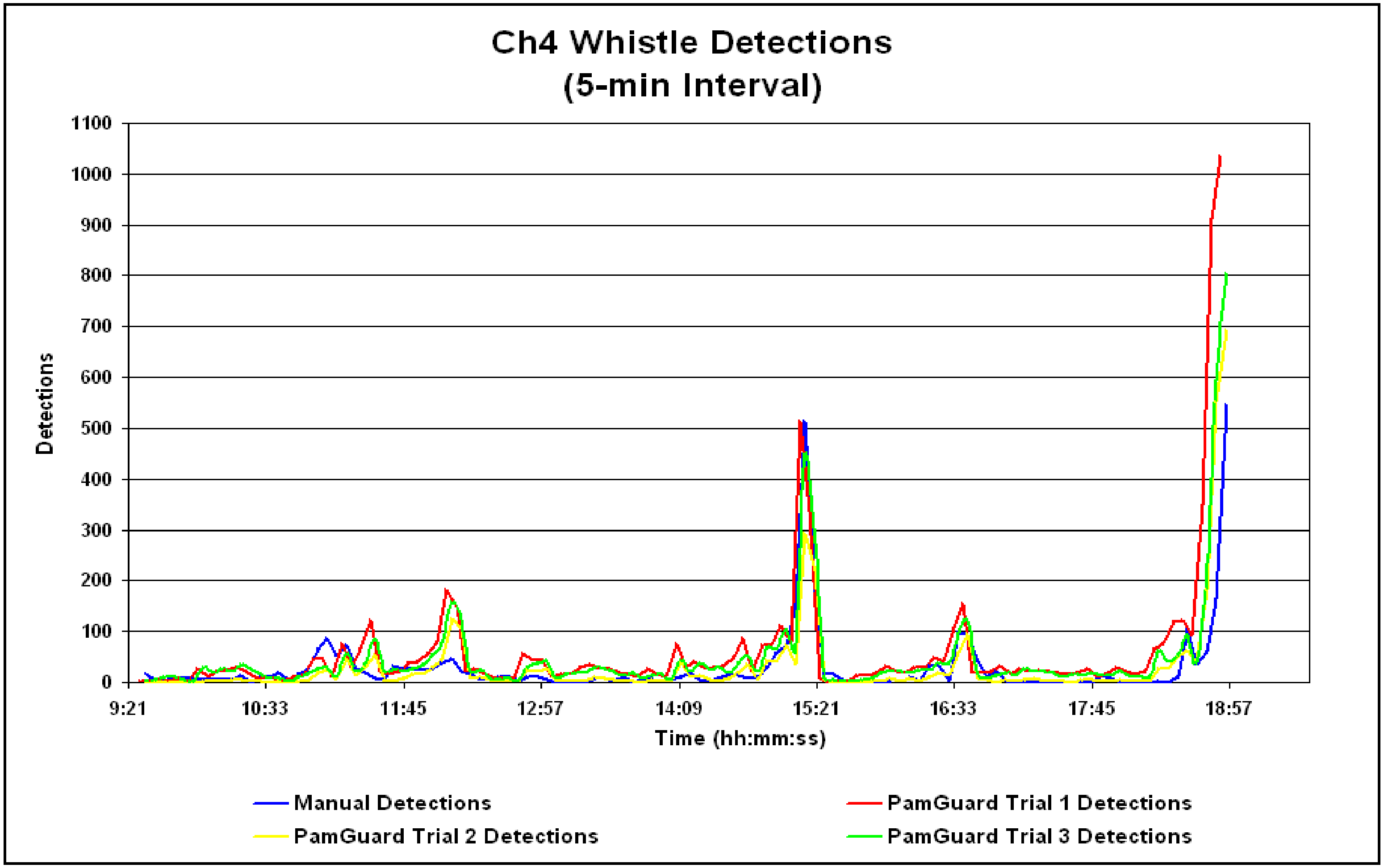

Figure 7b. Channel 4 Whistle Detections (5-min Intervals).
Detection results for each cetacean whistle detection found on the Channel 4 recordings [Manual (blue), PAMGUARD Trial 1 (red), PAMGUARD Trial 2 (yellow), and PAMGUARD Trial 3 (green)] were tallied into 5-min bins.

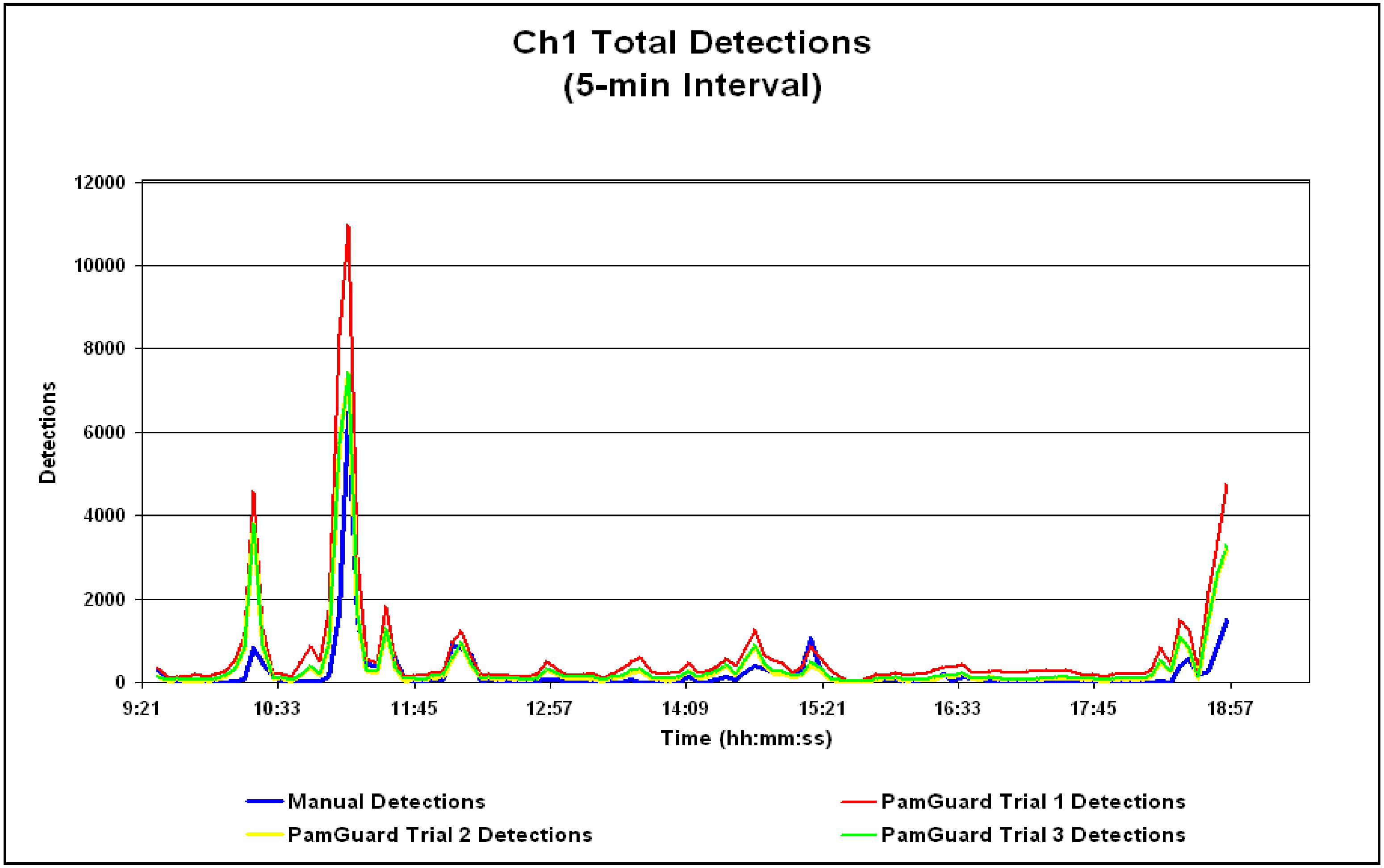

Figure 8a. Channel 1 Total Detections (5-min Intervals).
Detection results for each cetacean click and whistle detection found on the Channel 1 recordings [Manual (blue), PAMGUARD Trial 1 (red), PAMGUARD Trial 2 (yellow), and PAMGUARD Trial 3 (green)] were tallied into 5-min bins. **Manual detections are from Channel 4 and include burst pulse detections.

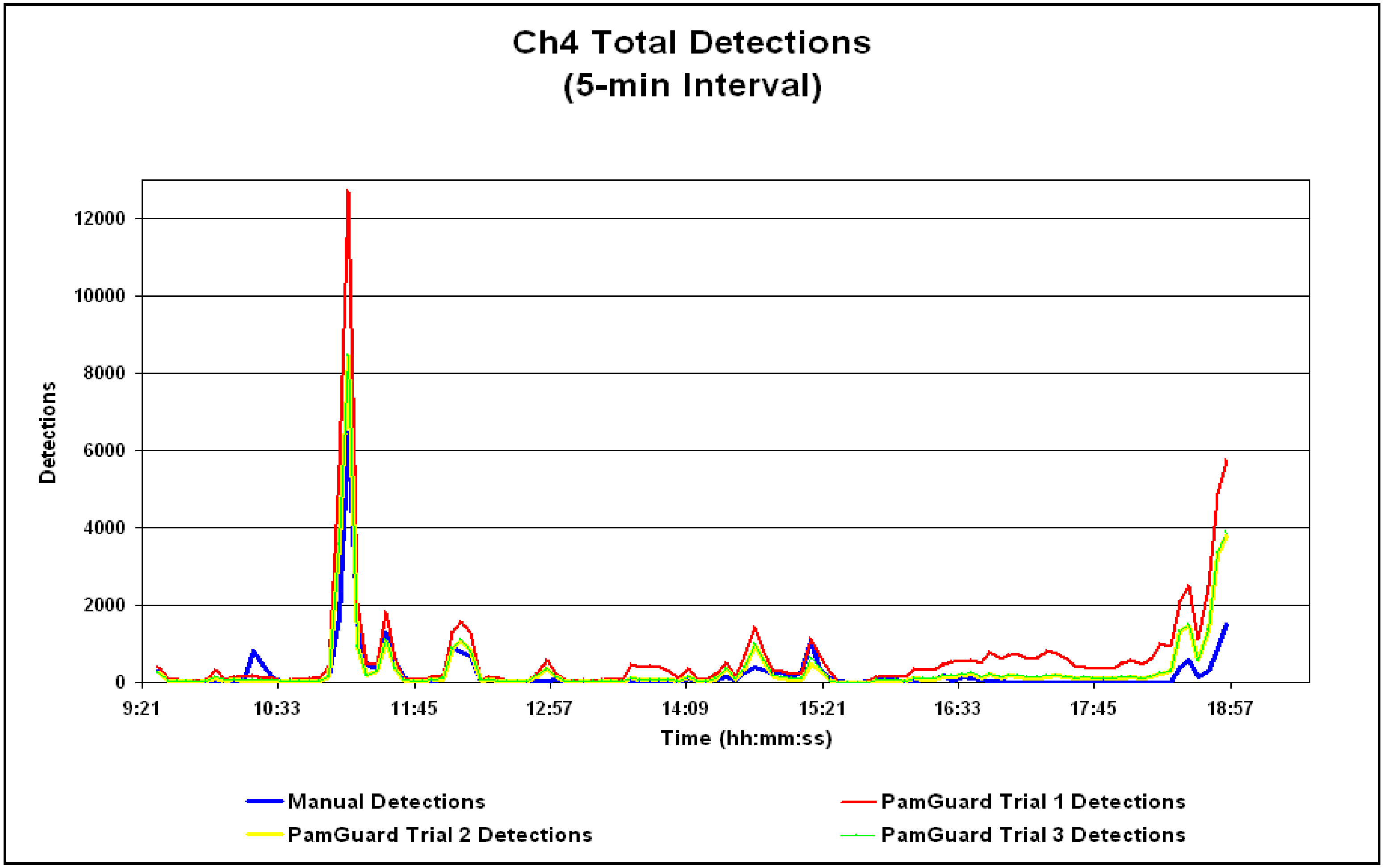

Figure 8b. Channel 4 Total Detections (5-min Intervals).
Detection results for each cetacean click and whistle detection found on the Channel 1 recordings [Manual (blue), PAMGUARD Trial 1 (red), PAMGUARD Trial 2 (yellow), and PAMGUARD Trial 3 (green)] were tallied into 5-min bins. **Manual detections include burst pulse detections.

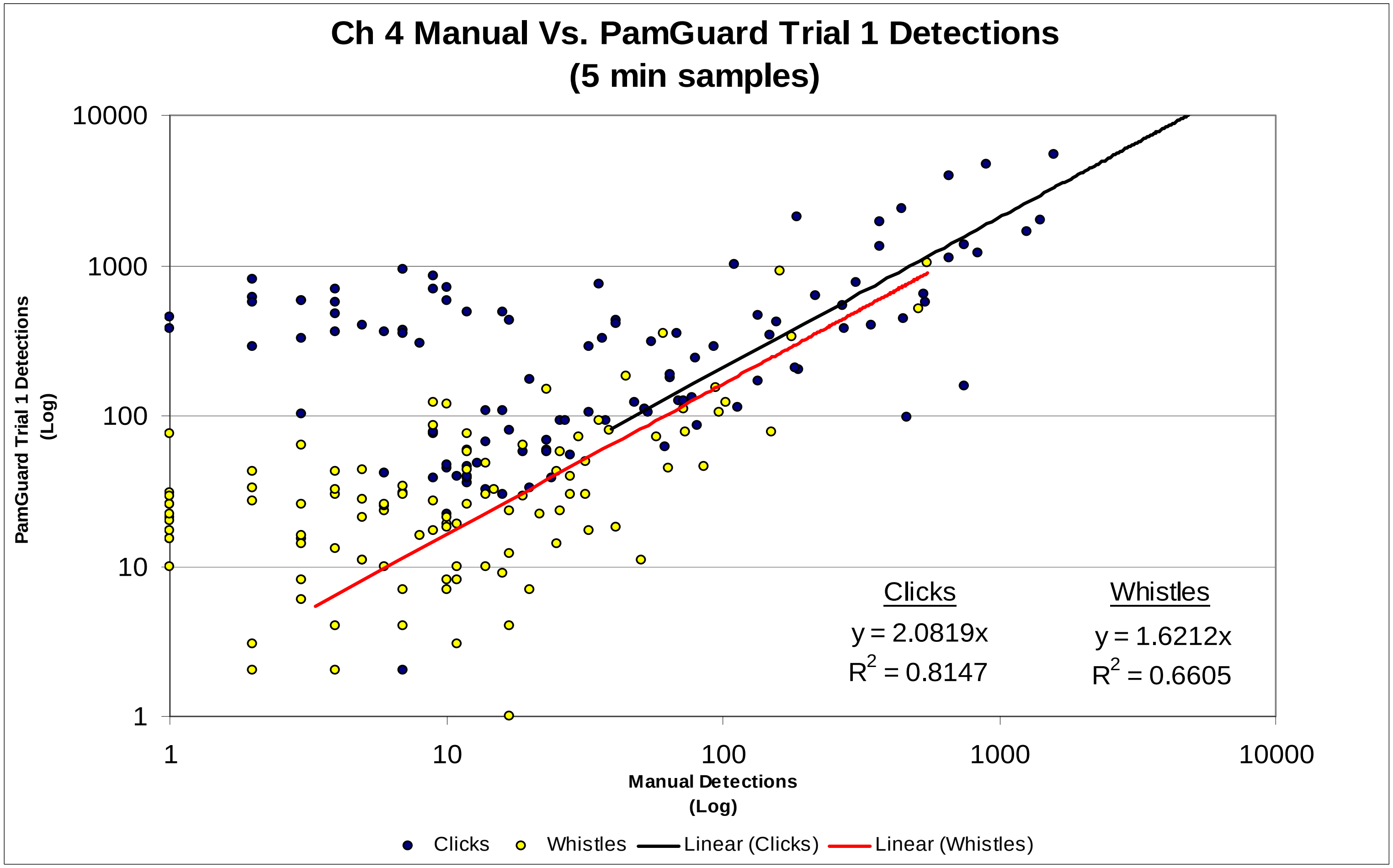

Figure 9. Channel 4 (5-min interval) Manual Detections Vs. PAMGUARD Trial 1 Detections.
The log values of the cetacean click (blue) and whistle (yellow) detection values obtained from manual processing were tallied for each 5-min period of data. These values were then plotted against the log detection values tallied for each 5-min period obtained from PAMGUARD Trial 1. The linear trendlines for whistles (red) and clicks (black) are plotted.

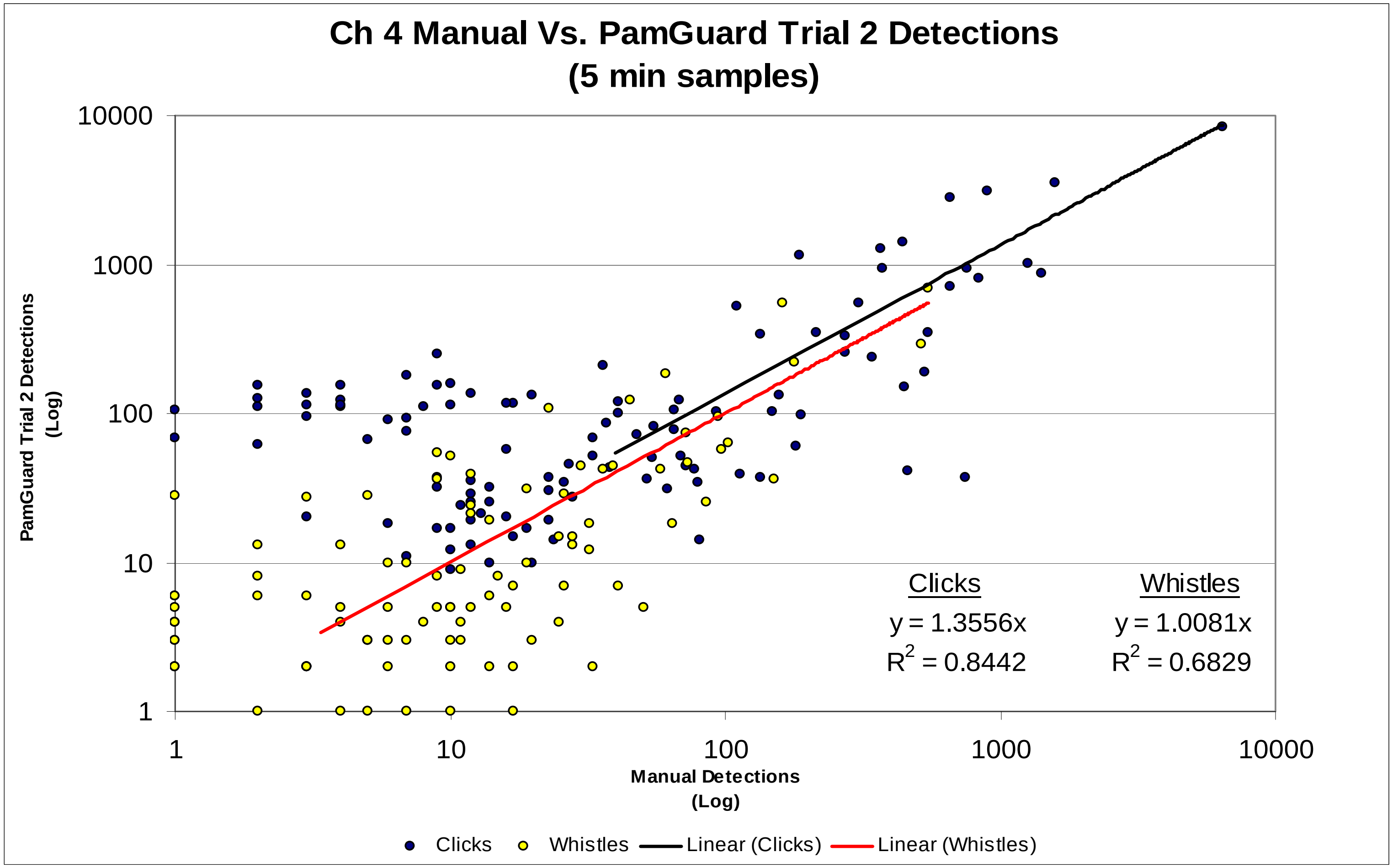

Figure 10. Channel 4 (5-min interval) Manual Detections Vs. PAMGUARD Trial 2 Detections.
The log values of the cetacean click (blue) and whistle (yellow) detection values obtained from manual processing were tallied for each 5-min period of data. These values were then plotted against the log detection values tallied for each 5-min period obtained from PAMGUARD Trial 2. The linear trendlines for whistles (red) and clicks (black) are plotted.

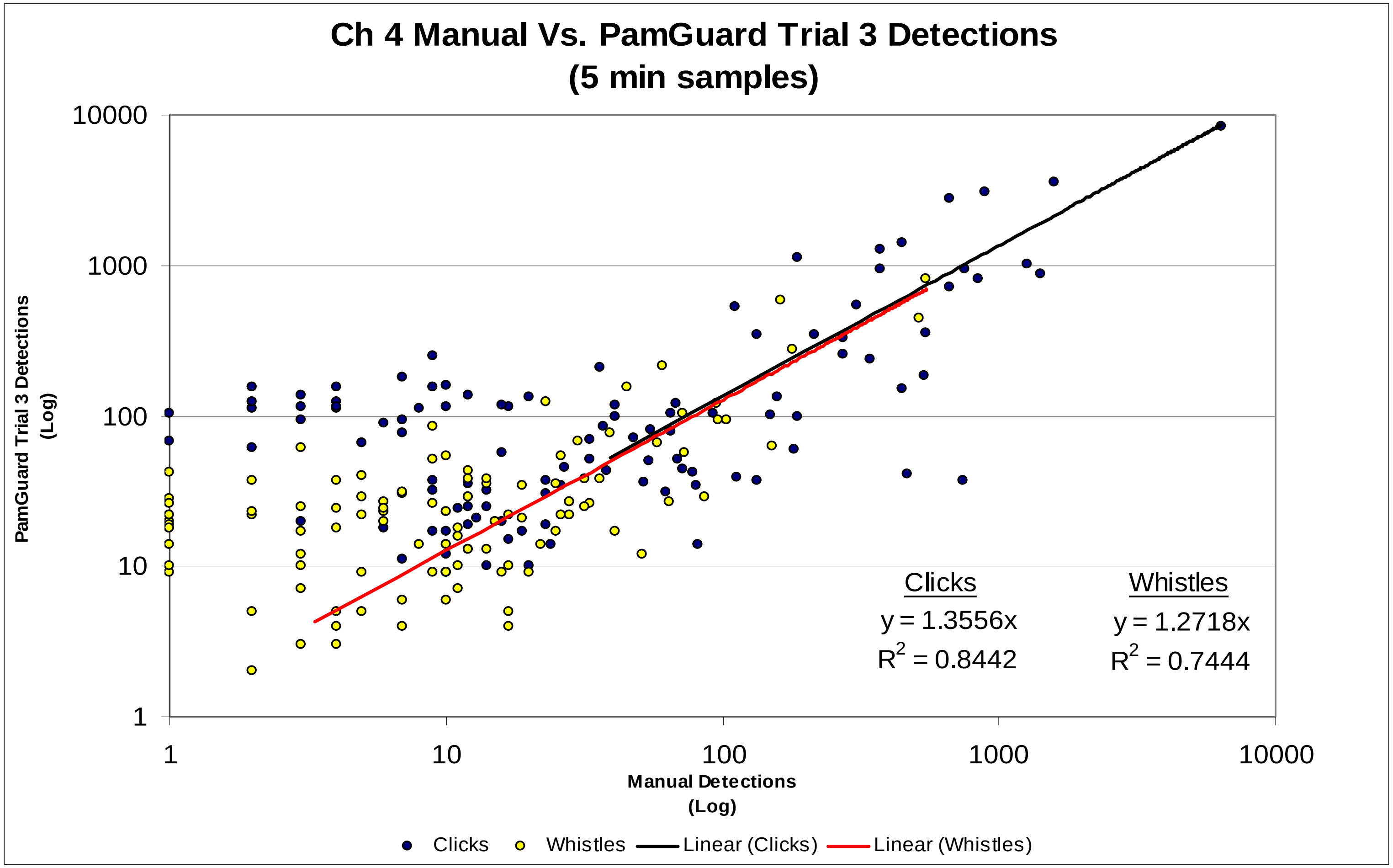

Figure 11. Channel 4 (5-min interval) Manual Detections Vs. PAMGUARD Trial 3 Detections. The log values of the cetacean click (blue) and whistle (yellow) detection values obtained from manual processing were tallied for each 5-min period of data. These values were then plotted against the log detection values tallied for each 5-min period obtained from PAMGUARD Trial 3. The linear trendlines for whistles (red) and clicks (black) are plotted.

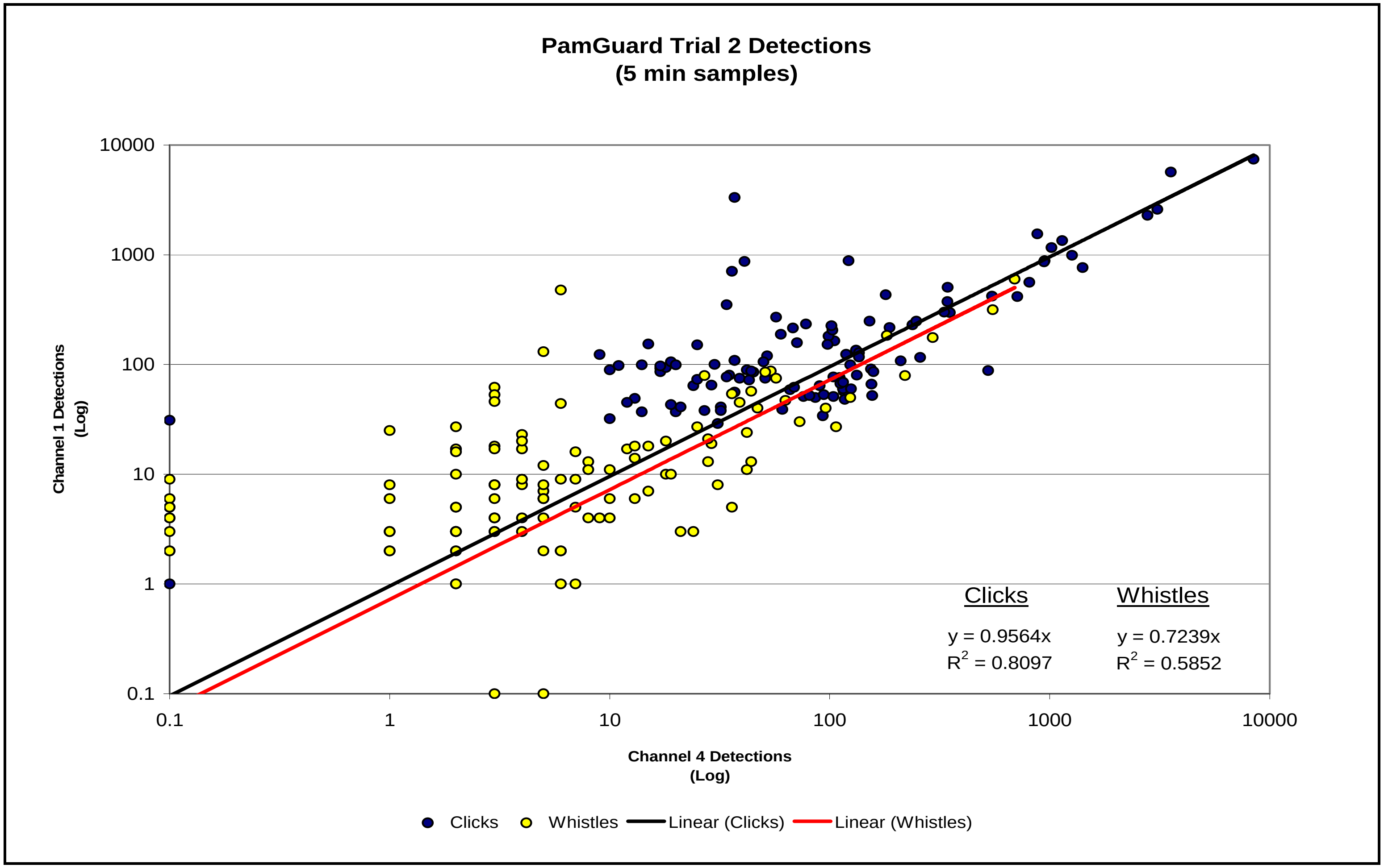

Figure 12. PAMGUARD Trial 2 Detections (5-min interval): Channel 1 Vs. Channel 4.
The log values of the cetacean click (blue) and whistle (yellow) detection values obtained from PAMGUARD Trial 2 were tallied for each 5-min period of data for Channel 1 and Channel 4 recordings. The log values of these totals were then plotted against one another. The linear trendlines for whistles (red) and clicks (black) are plotted.

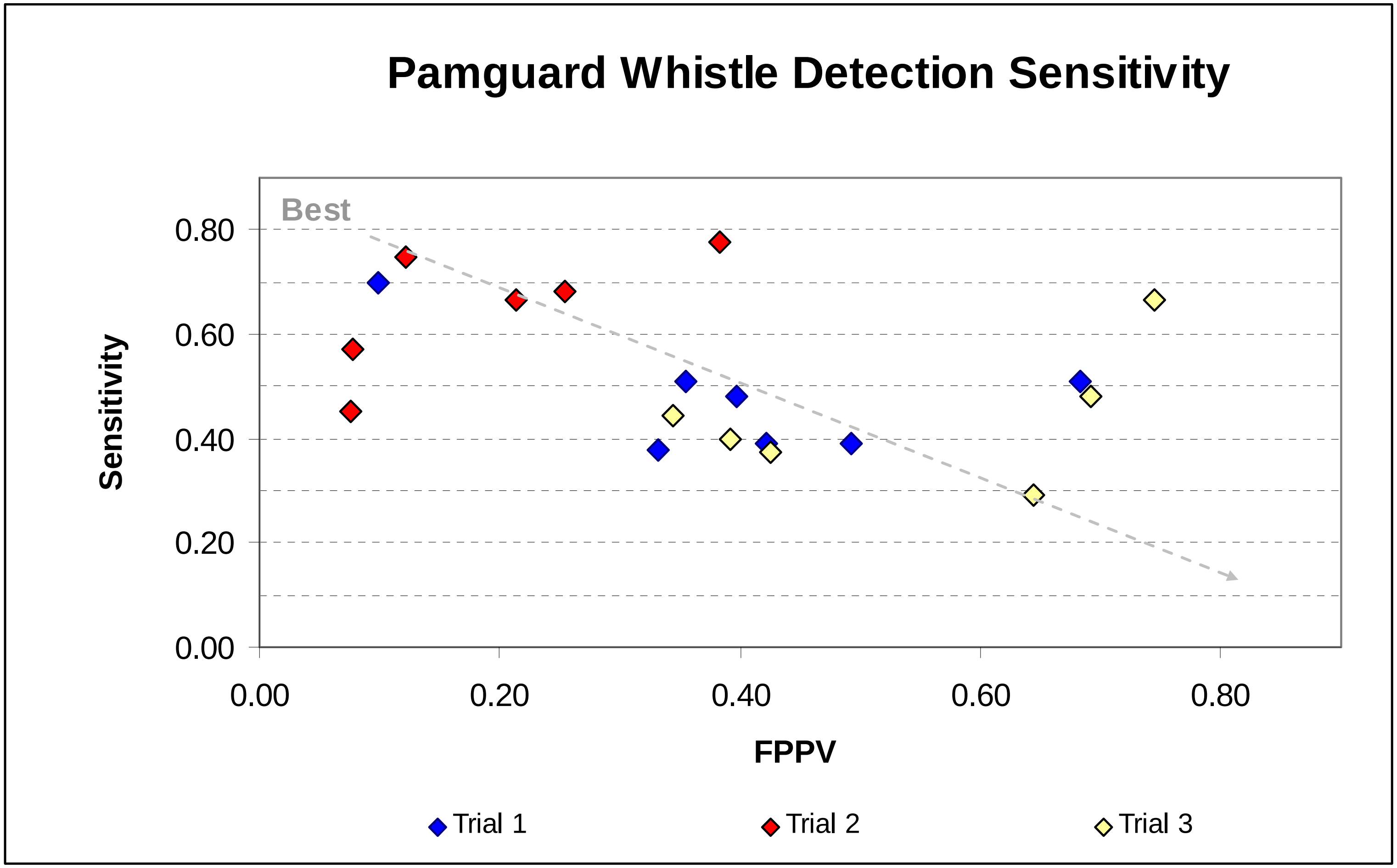

Figure 13. PAMGUARD Whistle Detection Sensitivity. The figure illustrates PAMGUARD whistle detection sensitivity for each subsample file during Trial 1 (blue), Trial 2 (red), and Trial 3 (yellow). The graph is a plot of Sensitivity (true positive rate, expressed as a percentage = a/(a+b), where a = True Positive and b = False Negative) vs FPPV (False Positive Predictive value; expressed as a percentage = c/(a+c), where a = True Positive and c = False Positive).

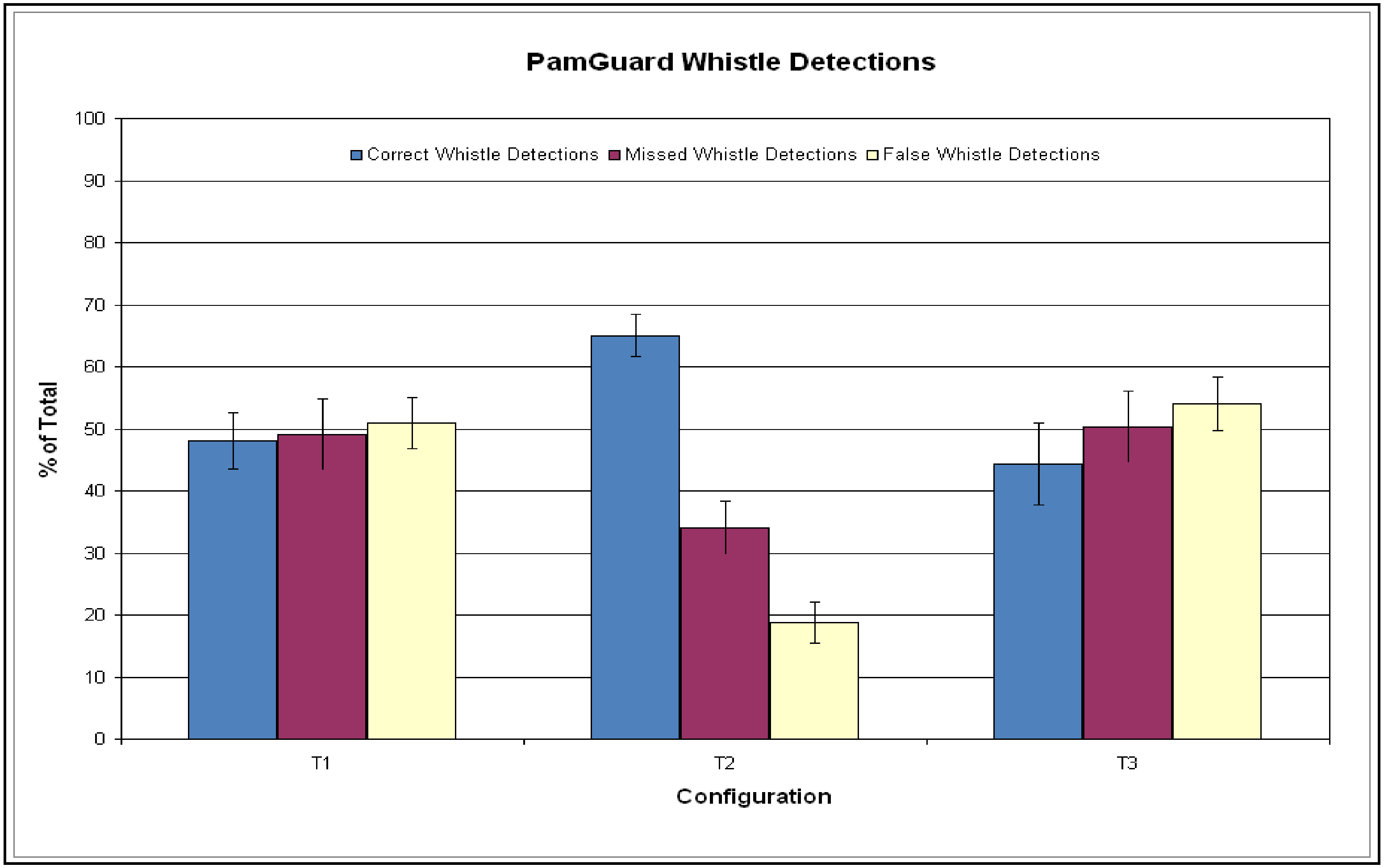

Figure 14. PAMGUARD Whistle Detections (Sensitivity Analysis).
A subset of the sample day was subjected to sensitivity analysis in an effort to evaluate the performance of the three PAMGUARD whistle detection trial configurations. Each file was processed through PAMGUARD Core 1.0 three times each on the following configurations: T1 detector, T2 detector and T3 detector. An observer viewed each file as it was processed and recorded the number of whistles correctly detected, the number of whistles missed, and the number of false detections. The manual whistle count was used to calculate the percent of correct detections (blue) and missed detections (red) for each of the three configurations. The number of total PAMGUARD detections for the trial was used to calculate the percent of false whistle detections (yellow).

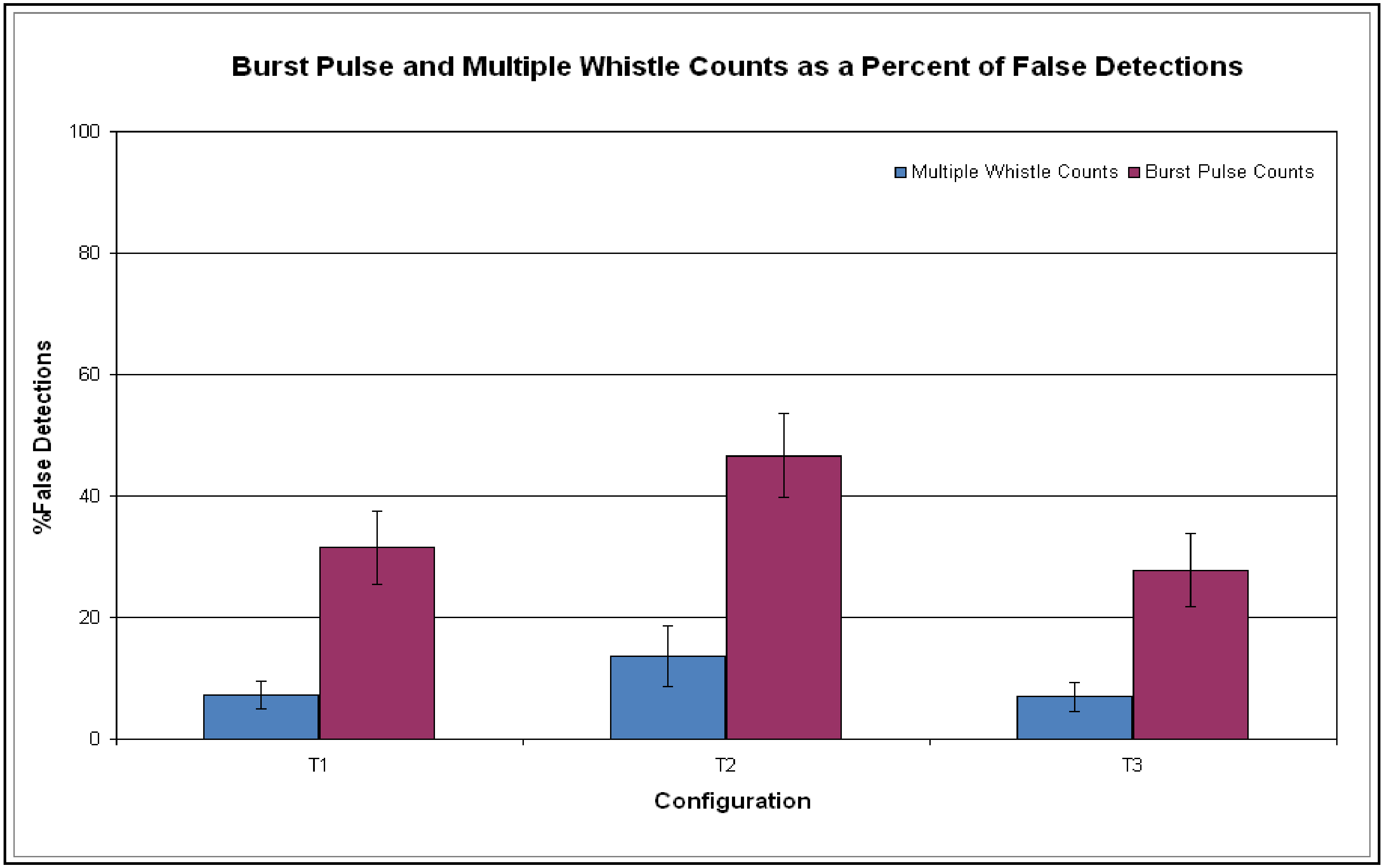

Figure 15. Percent of False detections for Multiple Whistles and Burst Pulses (Sensitivity Analysis).
A subset of the sample day was subjected to sensitivity analysis to evaluate the performance of the three PAMGUARD whistle detection trial configurations. Each file was processed through PAMGUARD Core 1.0 three times each on the following configurations: T1 detector, T2 detector and T3 detector. An observer viewed each file as it was processed and recorded the number of burst pulses counted as whistles and how many times each was counted, and the number of single whistles detected multiple times and how many times each was counted. The total counts by PAMGUARD, taken from the Access databases, were used to calculate the percent of multiple single whistle detections (blue) and burst pulses (red)

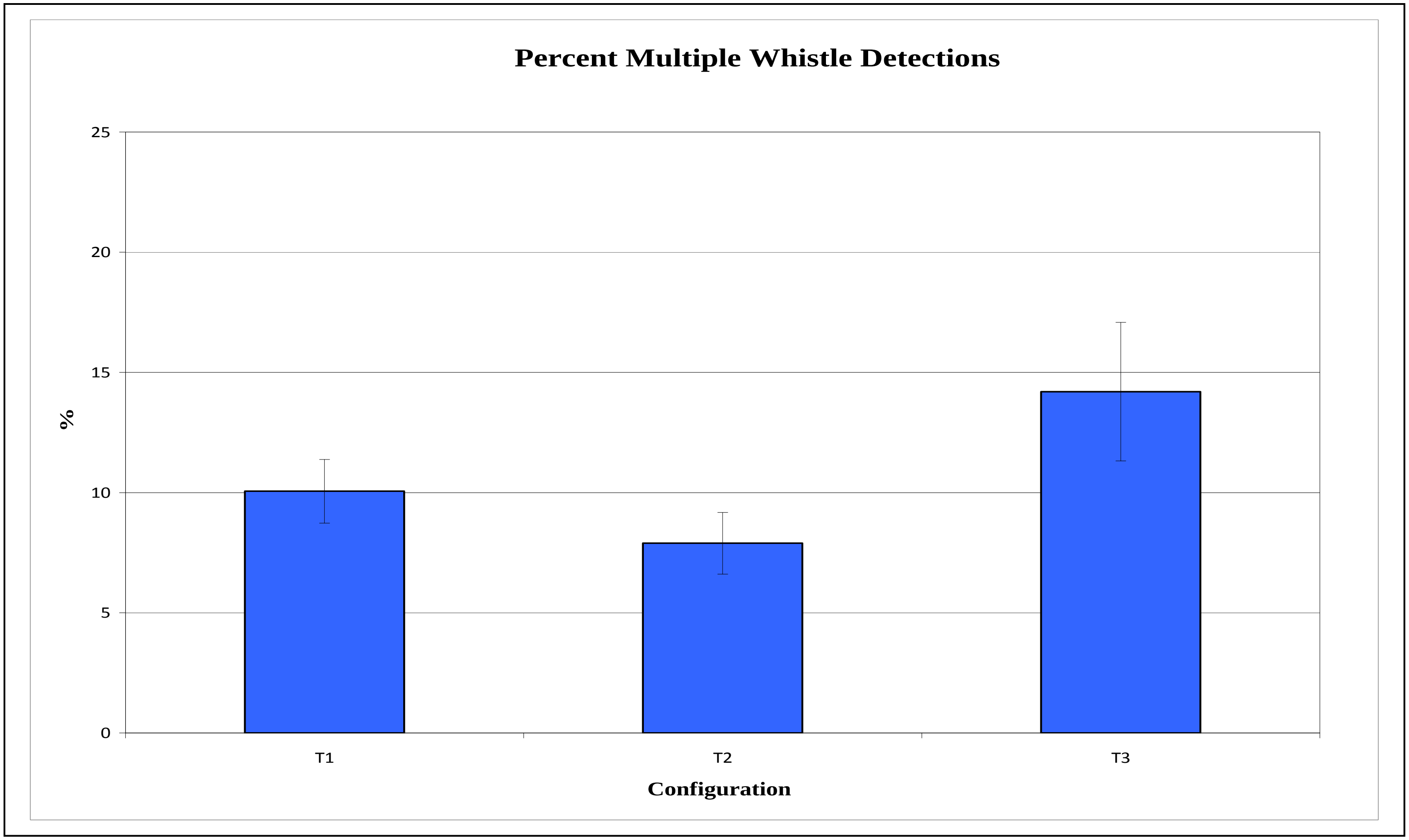

Figure 16. PAMGUARD Percent of Whistle Detections that were Multiple detections of a single whistle (Sensitivity Analysis). A subset of the sample day was subjected to sensitivity analysis to evaluate the performance of the three PAMGUARD whistle detection trial configurations. Each file was processed through PAMGUARD Core 1.0 three times each on the following configurations: T1 detector, T2 detector and T3 detector. An observer viewed each file as it was processed and recorded the number of burst pulses counted as whistles and how many times each was counted, and the number of single whistles detected multiple times and how many times each was counted. The percent of multiple whistle detections for each trial was calculated from the total correct whistled detected for each trial.

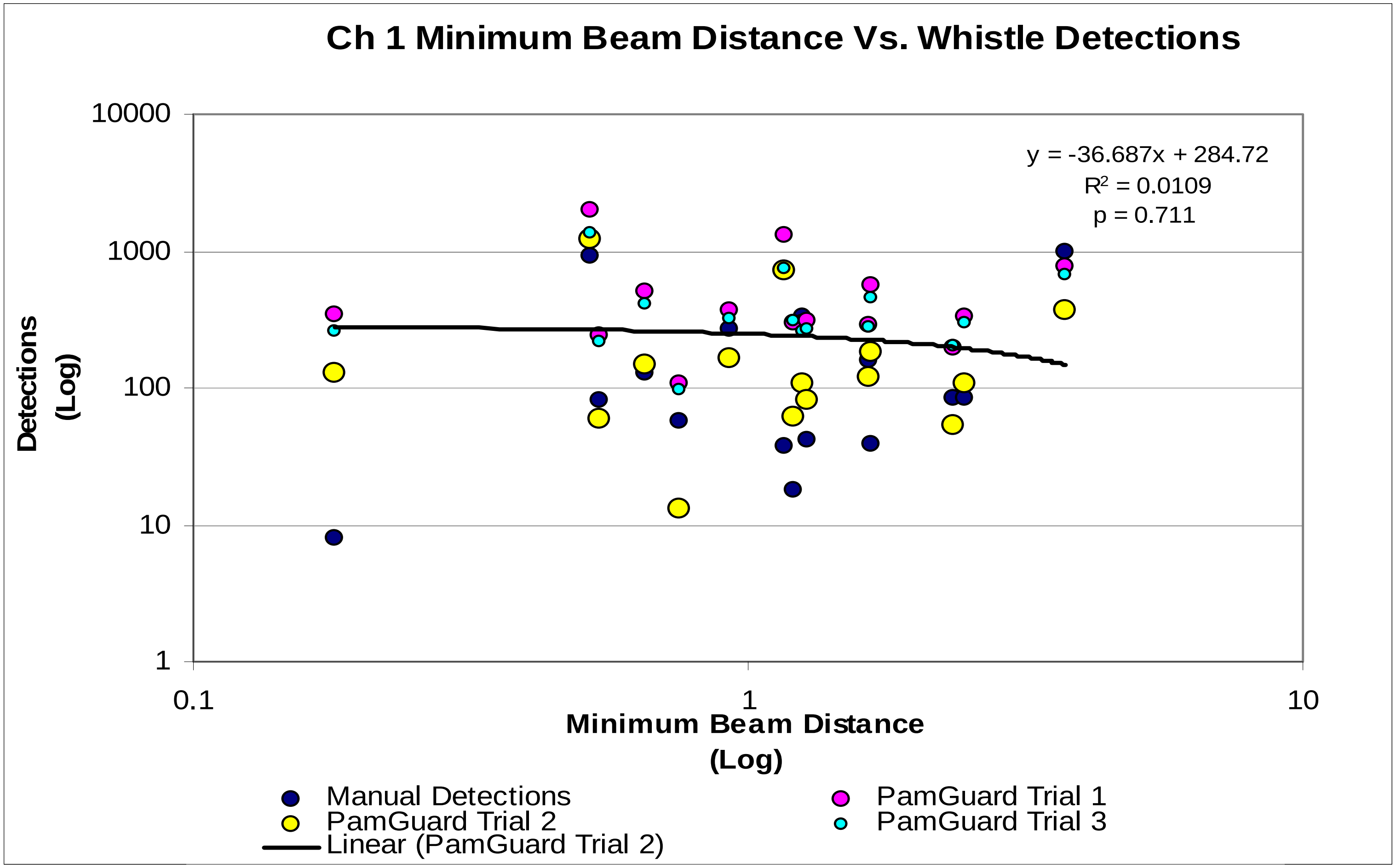

Figure 17a. Channel 1 Minimum Beam Distance Vs. Whistle Detections.
The log values of minimum beam distance estimated from visual encounters that occurred within each 30-min sampling period are plotted against the log whistle detection values. for each detection trial run on Channel 1 recordings. The linear trendline for PAMGUARD Trial 2 is plotted. Manual Detections are from Channel 4. *Regression line appears curved because it is plotted in logarithmic space.

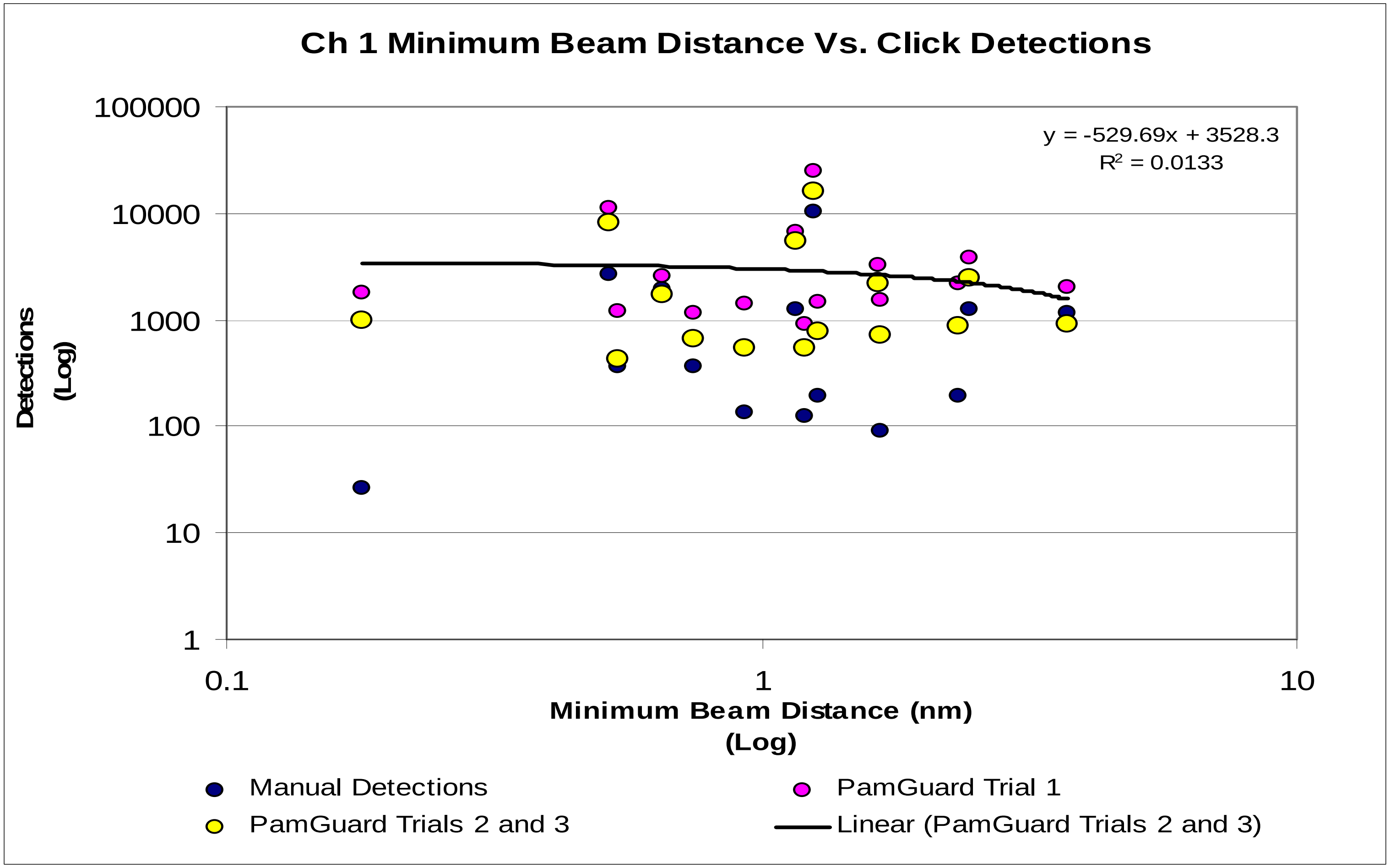

Figure 17b. Channel 1 Minimum Beam Distance Vs. Click Detections.
The log values of minimum beam distance estimated from visual encounters that occurred within each 30-min sampling period are plotted against the log click detection values for each detection trial run on Channel 1 recordings. The linear trendline for PAMGUARD Trial 2 is plotted. Manual detections are from Channel 4. *Regression line appears curved because it is plotted in logarithmic space.

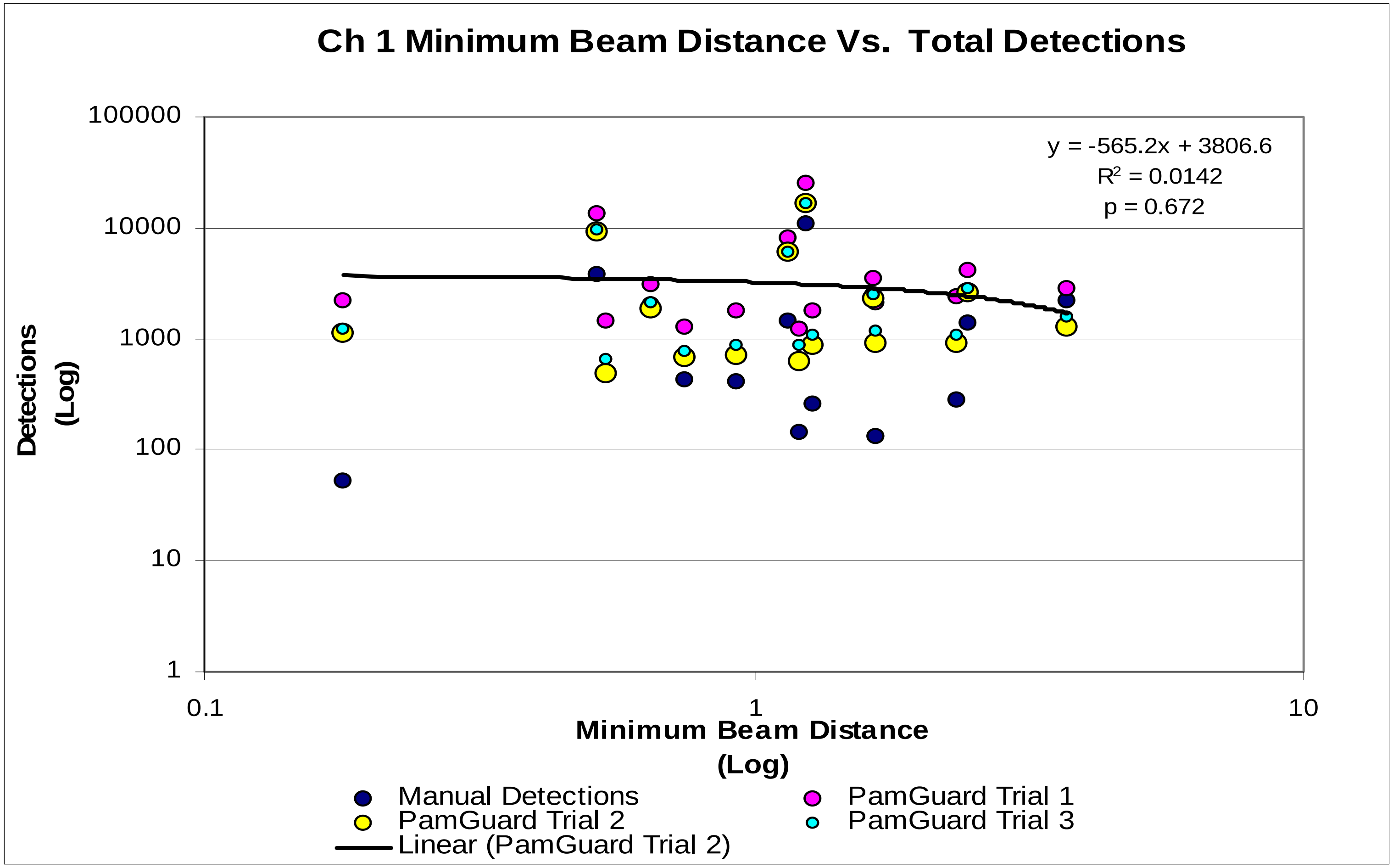

Figure 17c. Channel 1 Minimum Beam Distance Vs. Total Detections.
The log values of minimum beam distance estimated from visual encounters that occurred within each 30-min sampling period are plotted against the log click and whistle detection values for each detection trial run on Channel 1 recordings. The linear trendline for PAMGUARD Trial 2 is plotted. Manual detections are from Channel 4. *Regression line appears curved because it is plotted in logarithmic space.

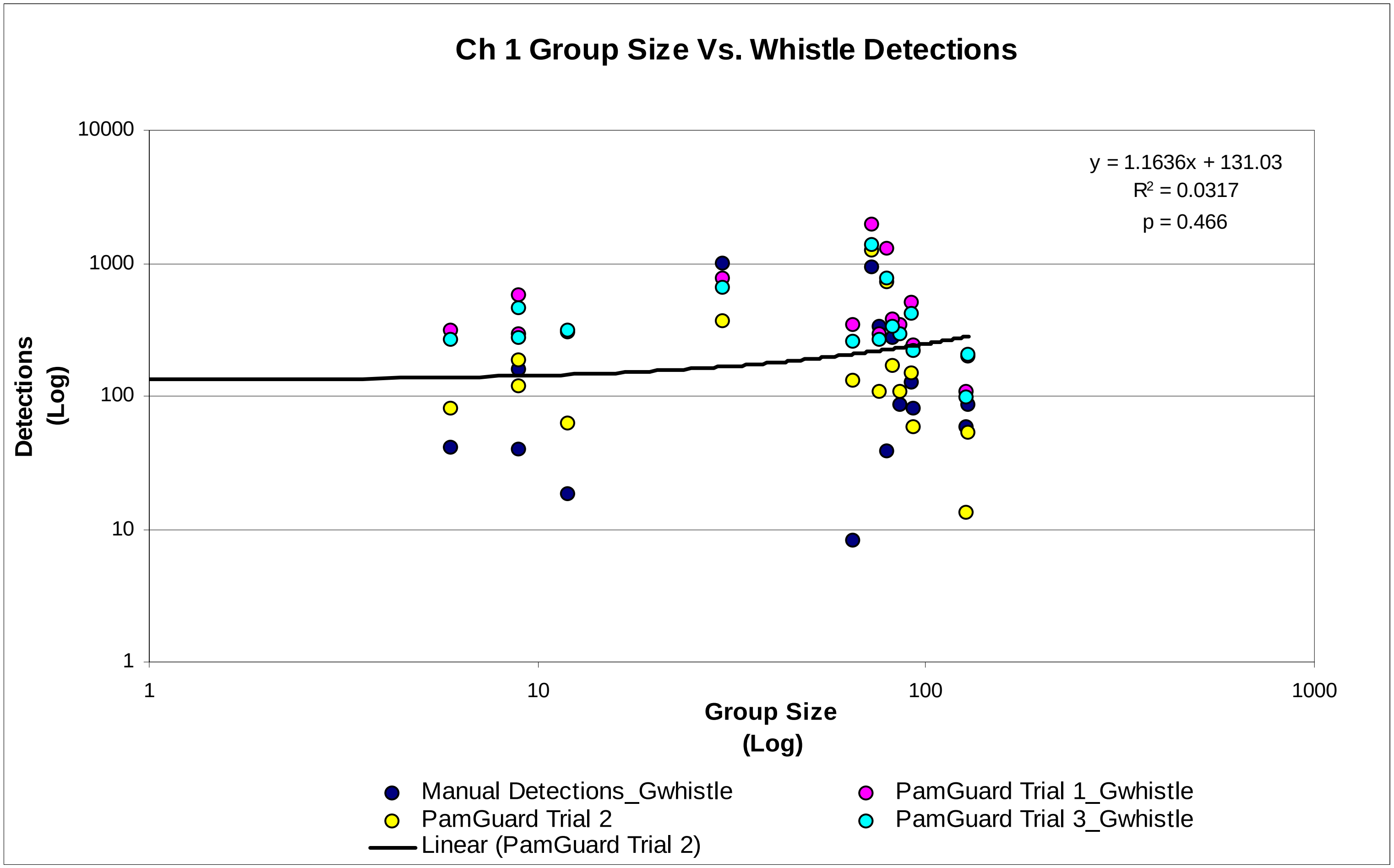

Figure 18a. Channel 1 Group Size Vs. Whistle Detections.
The log values of mean group size estimated from visual encounters that occurred within each 30-min sampling period are plotted against the log whistle detection values for each detection trial run on Channel 1 recordings. The linear trendline for PAMGUARD Trial 2 is plotted. Manual detections are from Channel 4. *Regression line appears curved because it is plotted in logarithmic space.

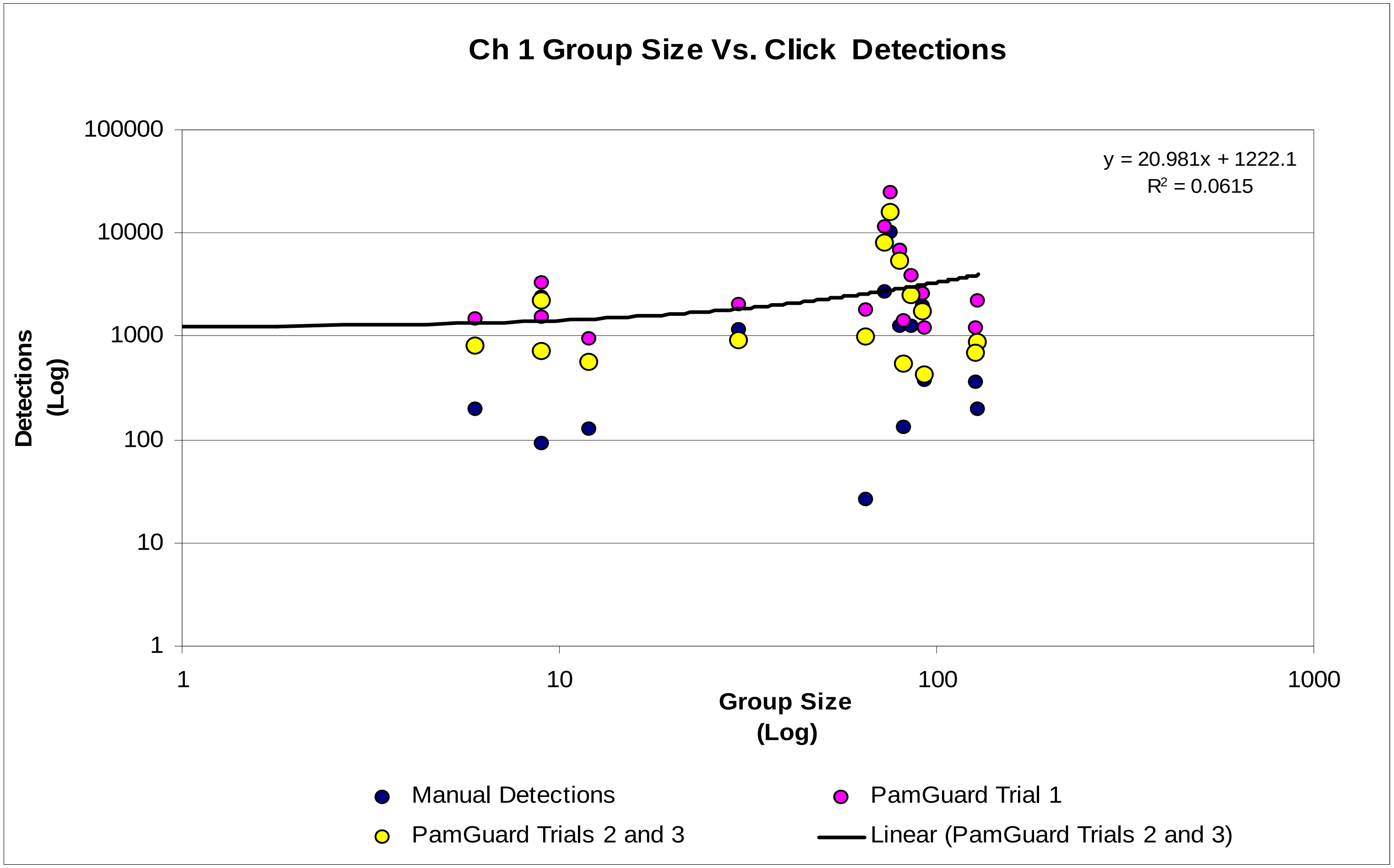

Figure 18b. Ch1 Group Size Vs. Click Detections.
The log values of mean group size estimated from visual encounters that occurred within each 30-min sampling period are plotted against the log click detection values for each detection trial run on Channel 1 recordings. The linear trendline for PAMGUARD Trial 2 is plotted. Manual detections are from Channel 4. *Regression line appears curved because it is plotted in logarithmic space.

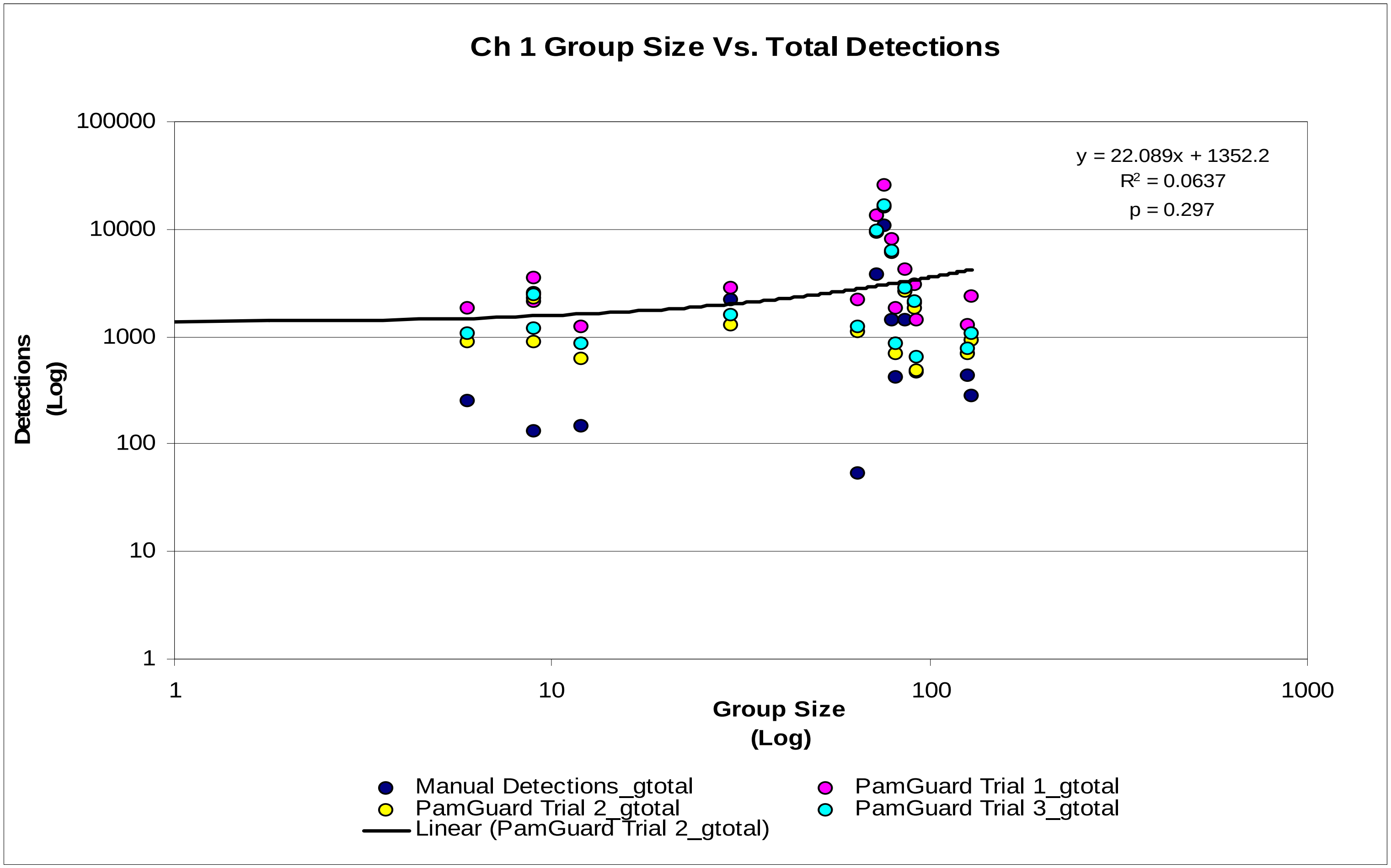

Figure 18c. Channel 1 Group Size Vs. Total Detections.
The log values of mean group size estimated from visual encounters that occurred within each 30-min sampling period are plotted against the log click and whistle detection values for each detection trial run on Channel 1 recordings. The linear trendline for PAMGUARD Trial 2 is plotted. Manual detections are from Channel 4. *Regression line appears curved because it is plotted in logarithmic space.

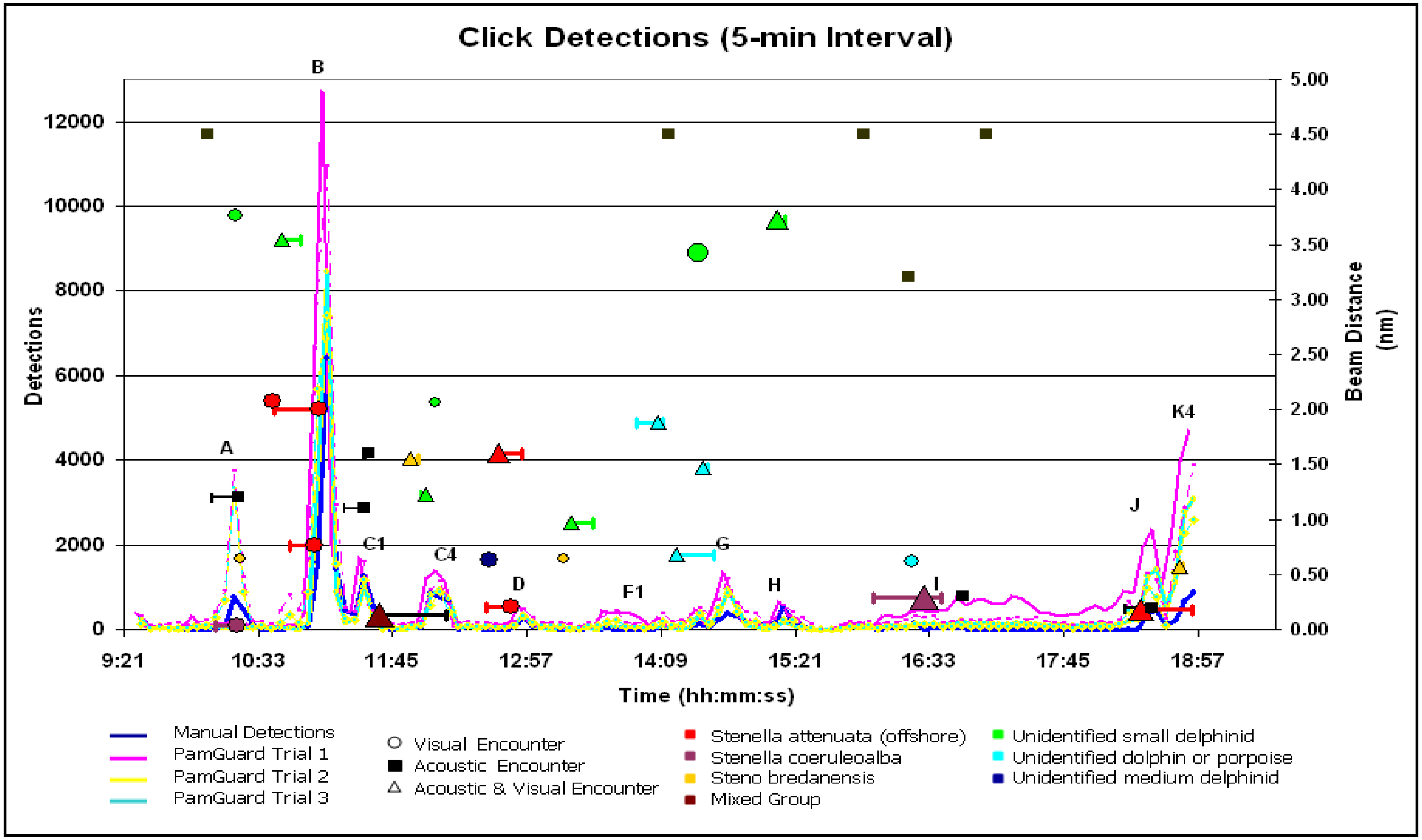

Figure 19a. Channel 1 and Channel 4 Peak Click Detections (5-min interval) that correspond to Visual and Acoustic Encounters

The five-minute sampling interval analysis for all trials resulted in recognition of detection peaks for clicks detected on Channel 1 (dotted lines) and Channel 4 (solid lines). Manual detections (blue), PAMGUARD Trial 1 detections (pink), PAMGUARD Trial 2 detections (yellow) and PAMGUARD Trial 3 detections (teal) are plotted with time along the x-axis and number of detections along the left y-axis. Each significant detection peak is labeled alphanumerically. Peaks were temporally associated with visual detections (Table 2). Visual only encounters (circles), acoustic only encounters (squares) and joint visual and acoustic encounters (triangles) are plotted as a function of time (x-axis) and minimum beam distance (right y-axis).* Manual detection values shown for Channel 4 only.

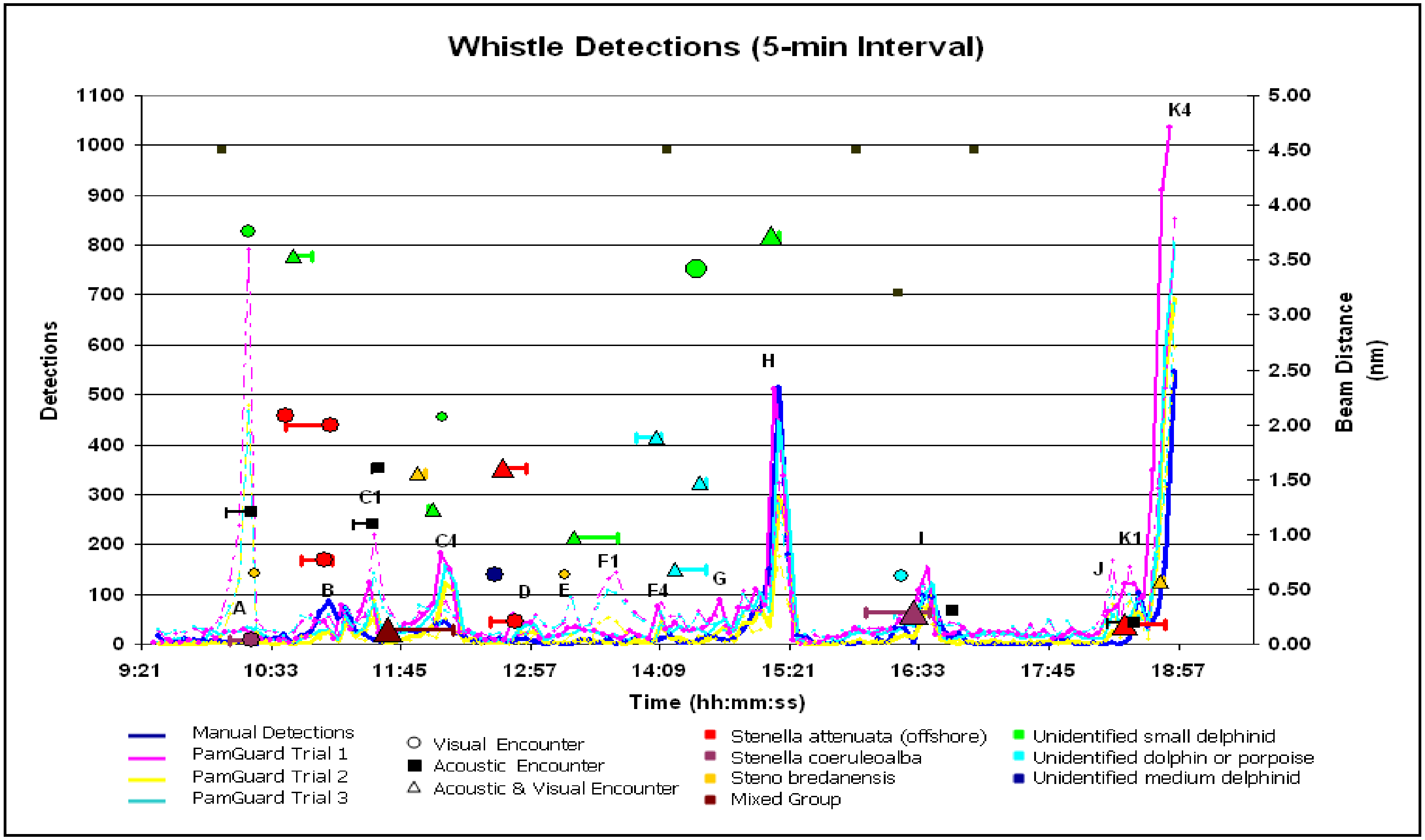

Figure 19b. Channel 1 and Channel 4 Peak Whistle Detections (5-min interval) that correspond to Visual and Acoustic Encounters.

The five-minute sampling interval analysis for all trials resulted in recognition of detection peaks for whistles detected on Channel 1 (dotted lines) and Channel 4 (solid lines). Manual detections (blue), PAMGUARD Trial 1 detections (pink), PAMGUARD Trial 2 detections (yellow) and PAMGUARD Trial 3 detections (teal) are plotted with time along the x-axis and number of detections along the left y-axis. Each significant detection peak is labeled alphanumerically. Peaks were temporally associated with visual detections (Table 2). Visual only encounters (circles), acoustic only encounters (squares) and joint visual and acoustic encounters (triangles) are plotted as a function of time (x-axis) and minimum beam distance (right y-axis).* Manual detection values shown for Channel 4 only.

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