CLICK TRAIN CHARACTERISTICS IN RIVER DOLPHINS IN BRAZIL

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1 INTRODUCTION

It has hitherto been difficult to study the characteristics of click trains of small cetaceans because of the very large volumes of data involved, and we have found no detailed published data on train characteristics or diel patterns in river dolphins. The development of an autonomous click logging device that can run continuously over weeks or months has made this area of study much simpler and we have used such devices (T-PODs, made by Chelonia Limited) to collect data on click trains from Amazon dolphins, the Boto, *Inia geofrennsis,* and the Tucuxi, *Sotalia fluviatilis*. The aim was to provide a first description of the data obtainable in this way, and to make some assessment of the feasibility of long term acoustic monitoring.

2 METHOD

T-POD autonomous click loggers were deployed close to the confluence of the Amazon and Japura Rivers at locations within the Mamiraua Sustainable Development Reserve around 02°S 66°W. In this area of the Amazon basin most of the forested ground is submerged beneath several metres of water for several months each year and Boto sometimes forage within the flooded forest (igapo) while Tucuxi are rarely seen in the forest. Most deployments were at approximately 14m in water 15m deep, close to, or directly beneath, the Projeto Boto Vermelho floating house. Deployments were made for a few days each at the entrance to the reserve at Boca di Mamiraua and in small lakes, also in the flooded forest where the hydrophone was about 2m down in water 3m deep. Deployments within the channels were in unobstructed locations within 30m of the bank or flooded forest. The water was muddy everywhere with in-water visibility usually being less than 10cm and very rarely greater than 1m.

The T-POD system logs only the time of occurrence and duration of tonal ultrasounds filtered in user-determined frequency bands, and depends on a probabilistic train detection and classification algorithm to reject non-cetacean clicks that are logged. Such non-cetacean clicks are logged because various natural sources, especially rain, can produce tonal ultrasounds at a wide range of frequencies, but these only rarely appear as trains by chance. Study of these ‘chance trains’ in T-POD data suggest rates of much less than one per million are mis-classified as being in the most reliable category of cetacean train, designated 'Cet Hi' by the software. The train detection algorithm used was version 3.0 which has click repetition rate limits of 1Hz to 2kHz. Data used here are the number of clicks logged, click rates (mean number of clicks per second in a train, pulse repetition frequency, PRF), and train durations.

Trains identified by the T-POD system are not complete trains as produced by the dolphin but are fragments, typically less than one second long, of trains detected as the sonar beam of the dolphin sweeps across the hydrophone. Train duration is consequently mainly determined by the rate of angular head movement. This causes a lowering of the apparent duration of clicks logged at each end of the detected train as it becomes undetectable. Surface reflection causes duplication of parts, or all, of a few trains. These multi-path duplicates amount to less than 1% of all clicks in trains.

Trains are classified according to how far they differ from chance trains and from boat sonar trains. All trains classified as resembling boat sonars, because they have both very little variation in pulse rate and low pulse rates, are excluded. These comprise less than 0.3% of all trains in this study and are mostly of cetacean origin, but without sufficient inter-click interval variation to reliably exclude a boat sonar as the source. All trains classified as of 'very doubtful' origin are also excluded except in the species specific data analysis. Trains classified by the software as 'very doubtful' show a correlation coefficient with other trains of around 0.92 in this study in respect of distribution through the day and train duration. They have been omitted here because the 1.0 million clicks in the remaining trains is a sufficient number for most of the analysis below, and in noisier environments the 'very doubtful' category of trains becomes substantially less reliable.

Because of the presence of two species some trials of various frequency settings of the T-POD filters were made, with concurrent visual observation, to look for any frequency or bandwidth characteristics of clicks that were distinguishable by the T-POD, and could be used to identify the presence of one or other of the two species. Visual discrimination is easy as only the Boto has a dorsal fin. The visual surveillance was also used to extract subsets of 'one-species train data' that occurred in periods in which one species had been seen and identified with no sighting of the other within 10 minutes.

One-species encounters were also used to collect click waveforms via a digital oscilloscope at 2 or 5MHz sampling rate. These were analysed using software written for this purpose. Only very loud clicks, exceeding any detected in the absence of dolphins were collected, and no attempt was made to limit this to 'on-axis' clicks. This approach was chosen to obtain a picture of the range of sounds received by loggers or by prey.

The T-POD system has been shown by Tougaard *et al* [1] to detect close to 100% of porpoises, *Phocoena phocoena,* passing over it in shallow water with an effective detection radius of approximately 100m and maximum detection distance of approximately 300m. For bottlenose dolphins, *Tursiops truncatus,* detection rates of 82% of groups seen within 500m of a T-POD (logging alternate minutes only) have been reported by Philpott *et al,* [2]. Higher dolphin detection rates were reported in a study of *Tursiops* around fishing gear by Scali *et al*, [3] who found all visual detections from a fishing boat were also acoustically detected.

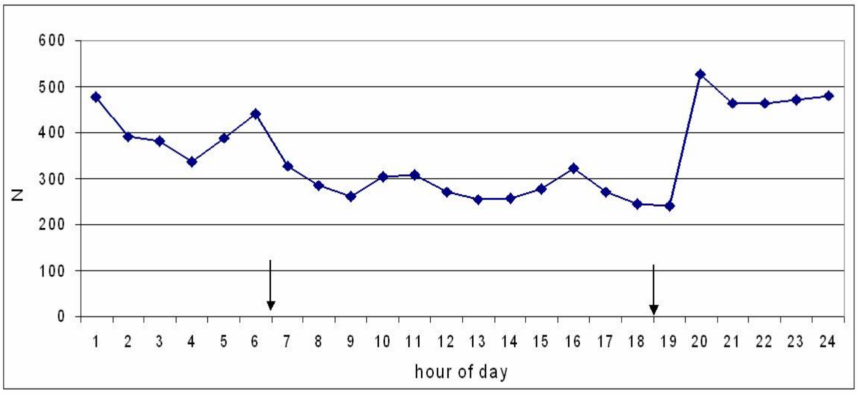
The data collected are time series. An autocorrelation was performed to identify acoustic encounter durations. Applying this to individual data files shows that the value of the auto-correlation coefficient typically falls to less than 2/SqRt(N), an approximation to a 95% confidence level (Chatfield [4]), within 10minutes. This corresponds to visual transit times and indicates a degree of independence between time periods much shorter than 12 hours. On this basis the number of trains has been used in chi squared tests of differences between day and night.

Because of the lack of train data from such species this study was primarily descriptive and no specific hypotheses were under test.

3 RESULTS

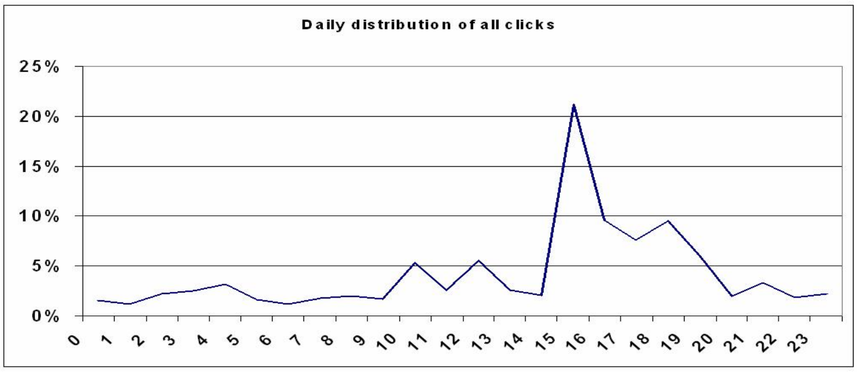
The T-POD logged 9.4million clicks from which the software identified 2.2million clicks in trains. Logged time was distributed evenly through all hours of the day, and took place opportunistically in the years 2002-4, but only in weeks 13-33 and 46-50. Click logging rates were markedly higher during weeks 13-19. The results presented here are from all the data aggregated, but are dominated by data from April and May. The diel patterns found are not evident in the data from November and December. At these times the forest is not flooded.

3.1 Diel pattern



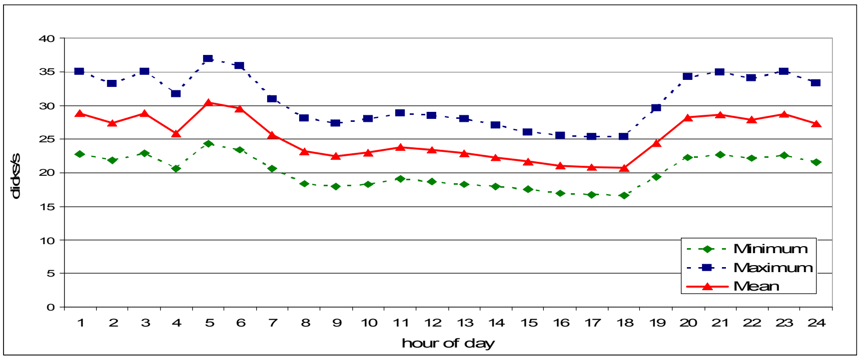
The mean number of clicks logged per hour shows marked variation through the day (Fig 1), with a minimum around 18.00 followed by a sharp rise around 19.00 to a maximum. Day and night rates differ significantly, and are approximately 20% below and 20% above the overall mean.

Fig 1. Daily variation in mean N of clicks logged per hour. N = 1,020,024. The arrows mark sunrise and sunset.



The diel pattern of all clicks, shown in Fig 2, has a strong peak around 4pm and higher values from 10am to 8pm. This corresponds to rainfall, which can be very intense and generates tonal transients that are logged by the T-POD.

Fig 2. Hourly logging rates for all clicks. This includes clicks that are not in trains.



The click repetition rate in trains (Fig 3) show a sharp transition at the same time of day as the click logging rate with a significant day:night difference (ChiSq test $p < 0.0001$).

Fig 3. Mean of highest and lowest click rate in each train, and mean of train click rates/s by hour of day. N = 62,396 trains.

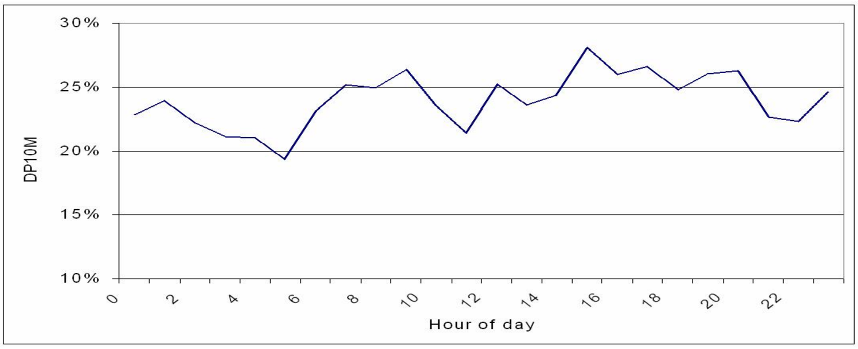
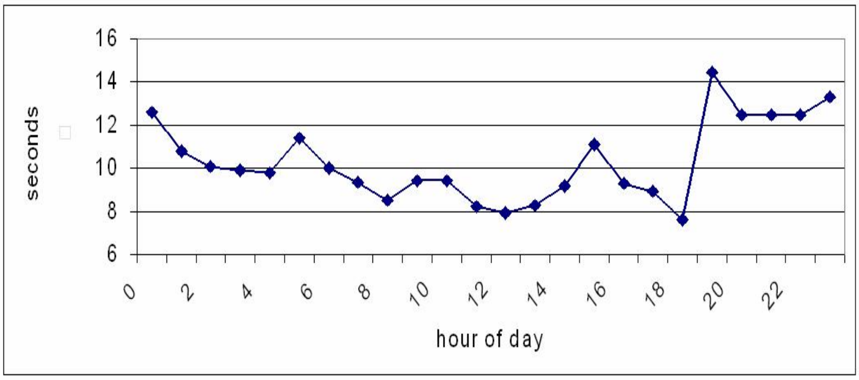


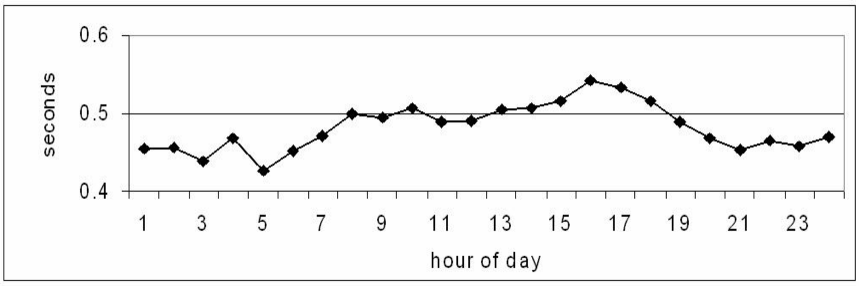
Fig 4. Percentage of 10 minute periods with detections (DP10M) for each hour of the day.



The daily variation in rate of detection of dolphins (i.e. presence/absence), measured as the fraction of ten minute periods in each hour with a detection, Fig 4, does not correlate with the number of dolphin clicks logged (Spearman correlation coefficient –0.25).

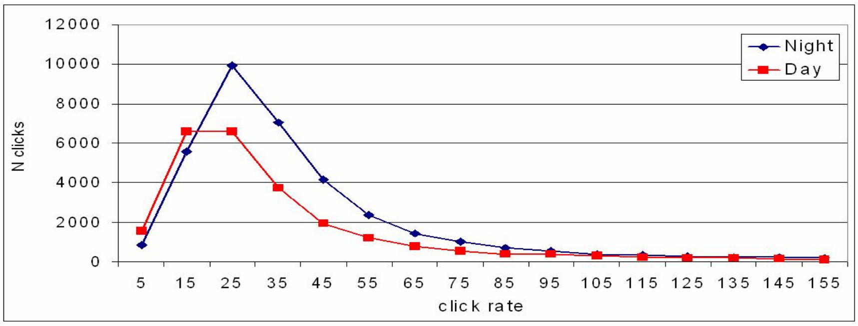
Fig 5. Aggregated train duration by hour of day. N = 62,396 trains.

If the change in number of clicks logged was entirely due to the change in click rate the duration of trains logged would be constant, but Fig 4. show that it also rises at night.



Contrastingly the diel pattern of mean train durations (Fig. 6) shows a non-significant rise from 0.44 seconds at night to 0.51 seconds during daytime.

Fig 6 Daily variation in the mean duration of trains logged. N= 62,396 trains



An examination of the distribution of mean click repetition rates of trains by night and day (Fig 7) suggests that click rates above 30/s are relatively more common at night and rates below 30/s are more common by day. This difference is not statistically significant.

Fig 7. Distribution of mean click rates within trains by night and day. N= 62,396 trains.

Trains with mean click rates above 200/s constituted 7.8% of trains at night and 5.2% during the day.

3.2 Train characteristic differences between *Boto* and *Tucuxi*

The 'one-species' data sets showed very high percentages of clicks classified as in trains: 41% of all clicks logged in Boto encounters and 27% of all clicks in Tucuxi encounters. These are very high figures when compared with marine deployments and indicate that few of the clicks logged are 'noise' in the sense of being non-cetacean in origin. In view of this the species analysis includes trains of all the classifications generated by the software. No night time data are available as we were unable to identify single-species encounters at night.

Train durations:

Species	*N trains*	*Mean duration*	*99% CI*
Boto	2432	0.49s	0.46-0.51s
Tucuxi	1097	0.76s	0.71-0.82s

Click rates:

The slowest click rate logged in trains was 2.7/s for Boto and 1.6/s for Tucuxi, while the highest click rates logged showed little difference at 780/s and 800/s respectively. Fig 8 shows the incidence of click rates for each species up to rates of 100 clicks/s.

The higher percentage of non-train clicks in the Tucuxi data might have the effect of reducing the detectability of low click-rate trains from this species, but the actual finding was of more low click-rate trains from this species.

Fig 8. Mean click rate in trains of all classes from one-species logging periods

3.3 Click rate and pitch

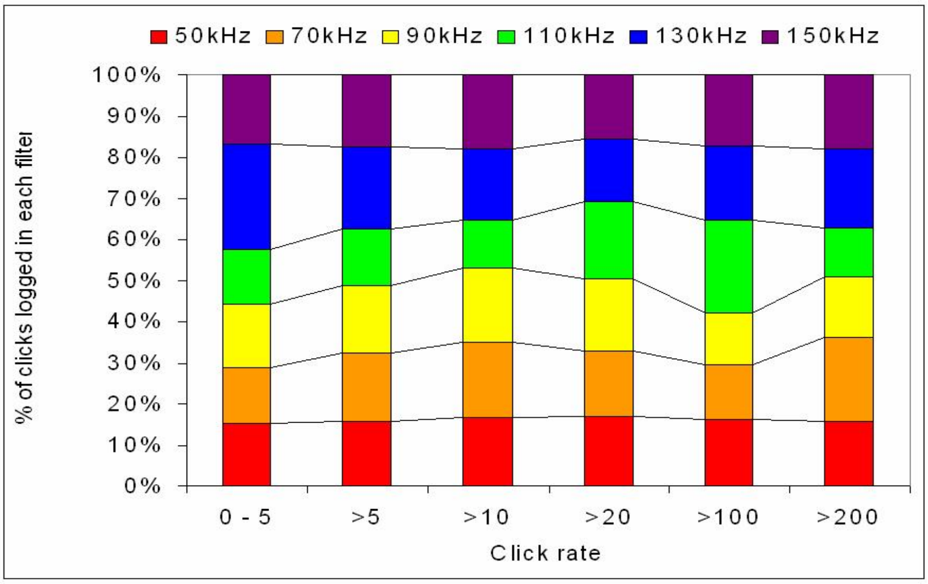


Fig 9 shows that click rates show little correlation with their dominant acoustic spectral frequency as indicated by the POD filter frequency settings at which the click was logged. This analysis used only the two highest classes of train classified by the T-POD.exe software.

Fig 9. Click rates in trains detected at different frequencies (N of clicks = 233,778) The frequencies shown are the centre frequency of the T-POD target frequency filter.

3,627 click waveforms were collected from identified species and analysed. This showed 105kHz as the most prevalent spectral peak of received unimodal Boto clicks, in contrast to 135kHz from Tucuxi. Bimodal clicks were more frequently recorded from Botos, as were lower modes in the spectrum, most frequently around 50kHz. However very few clicks could have been confidently identified, in isolation, to one or other species.

4 DISCUSSION

The fraction of clicks identified by the software as being in trains is exceptionally high in most of these data with 85% deployments giving 10% to 48% of clicks as being in trains in contrast to marine deployments for *Tursiops truncatus* in which classification rates of 1-5% are more typical. (Ingram and Englund *pers. comm.)* The high classification rate effectively represents a high signal:noise ratio, and indicates that such rivers are unusually favourable for static acoustic monitoring techniques as they are acoustically quiet and also have few boat sonars and high densities of dolphins.

The most significant features of the data gathered are:

- A sharp increase in echo-location activity around dusk, with a sustained higher rate through most of the night was found in April and May.
- Many more slow click-rate trains were logged from Tucuxi than from Boto.

4.1 Diel pattern

A significant difference was found between night and day, with an abrupt rise in the number of clicks logged, the click rate in trains, and in the aggregated duration of trains that is sustained through the night. This change could be due to dolphins moving from the forest to the river at night, but the presence of animals in any ten minute period is not lower by day in the river, and the change must be mainly due to a behavioural change rather than redistribution.

As PODs do not detect whole trains as produced by the animal but only fragments of trains as the sonar beam sweeps across the POD the shorter trains found here by night suggest the dolphins are turning their heads faster at night. An alternative cause for shorter trains could be the production of quieter clicks, which would then only allow detection over a smaller angle for an animal at the same distance and would also decrease the detection range. Fig 7 shows that at dusk the prevalence of all click rates above 30/s rises.

The simplest explanation of these observations is that one or both species of dolphin feeds more actively at night, producing faster click trains and faster head movements, but without any substantial redistribution of animals out of the river channel and into the forest.

Carlström [5] reported the detection of more trains at night with a lower mean inter-click interval in a study of porpoises, *Phocoena phocoena*, using T-PODs near the sea bed in 40m of water, and Cox *et al* [6] made similar observations using a simpler click logging system deployed nearer to the surface. A plausible explanation of these patterns would be that a significant proportion of prey have greater success in avoiding capture by small cetaceans during daylight, leading to cetaceans concentrating their foraging effort on night time, but this mechanism is less plausible in the muddy waters studied here.

4.2 Inter-species train differences

The preponderance of very slow trains detected from Tucuxi was unexpected. It has been shown, above, that it is not a spurious finding from noise impairing the detection of slow trains.

If slow trains from the Boto were more irregular they might not be recognized by the train detection algorithm. However the very high proportion of clicks, in comparison with other species and locations, that are found to be in trains is against this, as is comparison of the proportion of trains classified as doubtful or very doubtful. These categories include less regular trains, but comprise 81% of slow (<20clicks /s) Boto trains and 98% of Tucuxi trains.

If the rotational velocity of head movement in Boto was higher this would allow only shorter sections of a train to be logged as the sonar beam scans across the hydrophone, and would thereby reduce their detectability. This would cause train lengths from Boto to be shorter, and a significant difference is found in this, and is in the expected direction, with Boto trains averaging 0.49s, Tucuxi 0.76s or 55% longer. While this must contribute it appears inadequate to explain a more than six fold difference in the number of trains logged at less than 10 clicks per second.

The largest deviation from uniformity in the relationship between click pitch and rate, (see Fig 9) is the strong representation of 130kHz clicks in the slowest click rate class, which is consistent with the bias towards both 130kHz and slow trains in the Tucuxi.

As far as these data can take us it does appear that there is an actual species difference with Tucuxi producing many more slow click rate trains. It is not clear from these data whether Boto 'replace' slow trains with silence or with faster trains. Possible explanations that give a species-specific benefit for silence instead of slow trains are:

1. To maximise passive sensory performance in hearing a noise-making prey of interest to Boto only.
2. To minimise detectability by prey. e.g. if only Boto have a prey species that can hear their clicks. The difference in click spectrum founds indicates an alternative explanation, that silence may be preferred to slow trains by Botos because their clicks may be more audible to some prey.
3. Low click rates may have a communication role in the Tucuxi only.
4. The Tucuxi, may need to avoid entering the forest and use slow rates to build up a more distant map of the waterways.
5. Silence rests the click production organs, which might be more stressed in Botos due to higher source levels, lower frequencies or both.

Slow trains, rather than silence, might be preferred to faster trains if :

6. If shoaling fish are preferred prey for Tucuxi only and could be detected at ranges above 75m this species would gain an advantage from using trains slower than 10clicks per second.
7. a reduced echo-location energy budget is more beneficial to a smaller dolphin.

4.3 Feasibility of acoustic monitoring

It would be useful to be able to distinguish species from POD data. The waveform data showed distinct differences between the species, with Boto using lower frequencies more often than Tucuxi and showing greater variability in click characteristics, but there was no basis on which an individual click of any type detected can be confidently ascribed to one or other species. Train characteristics also showed no absolute difference between species. A composite index based on both features would have potential for distinguishing the species, but a system that logged acoustic parameters of individual clicks could have much greater discriminatory power.

Compared to most marine monitoring, the Amazon has much lower noise levels, few boat sonars and very convenient mooring sites that allow easy servicing with minimal risk of losses of monitors to trawling or theft. This project has demonstrated that the Amazon is highly suitable for long term acoustic monitoring of cetacean densities.

END

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