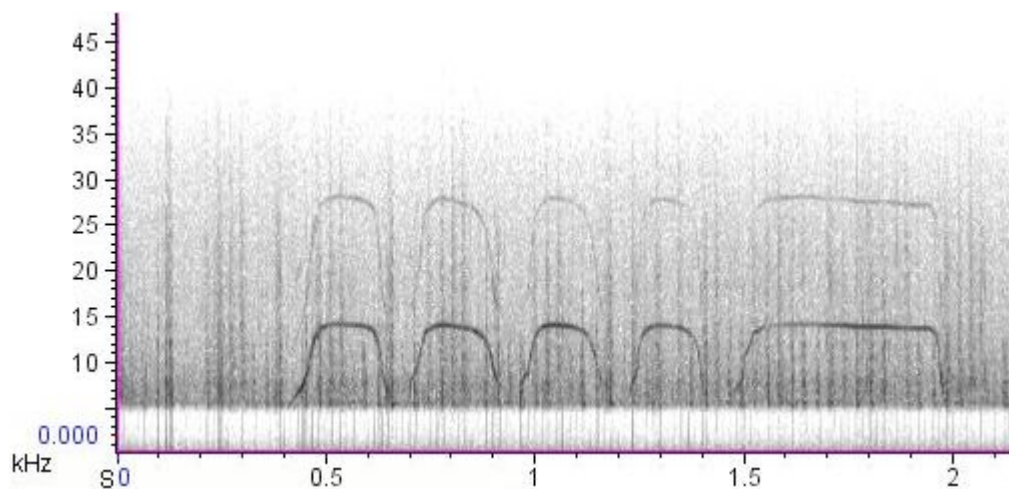


Automated Categorisation of Bottlenose Dolphin (*Tursiops truncatus*) Whistles



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Abstract

Classifying the acoustic repertoire of animal calls is challenging. Previously, human judges have been a commonly used method of classifying call types, which although effective, can be slow and inconsistent. Computer technology is a potential way of standardising thresholds and identifying relevant parameters to make the process of separating calls automated.

An automated categorisation method using dynamic time warping (DTW) and an adaptive resonance theory (ART) neural network, previously tested on captive bottlenose dolphins (*Tursiops truncatus*), was tested on a population of free-ranging bottlenose dolphins.

Twenty hours of tape were analysed and 312 whistles, including multi-loop whistles where basic contours are repeated, were identified. Contours were extracted from all 312 whistles, giving 415 single contour text files of frequency points, with a temporal resolution of 1 millisecond.

When the program was run through 1 iteration, 415 whistles were separated into 90 categories. When these categories were matched visually to an existing catalogue of signature whistles, only 10% of these categories contained correctly grouped whistles.

It is hoped that running the program for multiple iterations will produce more successful results, allowing this methodology to become applicable to population and behavioural ecology studies of free-ranging bottlenose dolphins.

Keywords: acoustic, automate, categorisation.

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Introduction

Communication in Cetaceans

In 1967 Evans noted that the complexity of cetacean vocalisations was only exceeded by the fervour of the research to explain them. Although this still holds true, how cetaceans communicate remains very much uncharted scientific territory. This is due in part to the difficulty of researching marine mammals as opposed to terrestrial mammals, as most marine mammals spend the majority of their life under water. Sound is the best modality for communication under water, propagating huge distances, as opposed to visual communication where sunlight is reduced to 1% of its original strength within 100m water depth (Clarke and Denton 1962). However, cetaceans are capable of making sound without any visual cues. Visual cues, for example bubblestreams, were thought to be related to bottlenose dolphin (*Tursiops truncatus*) whistle production by McCowan and Reiss (1995), however it was pointed out by Janik and Slater (1998) that attributing a whistle to a particular animal, based on an animal producing a bubblestream at the same time, is incorrect. This is because bubblestreams can occur in the absence of whistles, and whistles can occur in the absence of bubblestreams (Fripp 2005).

Consequently, because of the difficulties in researching marine mammals, we know a lot about some species like bottlenose dolphins, but very little about others, like beaked whales (Family *Ziphiidae*). Bottlenose dolphins are one of the most researched marine species with respect to acoustic communication,

with established field sites having been set up in Monkey Mia, Shark Bay, Western Australia (Smolker and Pepper 1999); Scotland (Janik 2000); and Sarasota, Florida (Sayigh *et al.* 1990). Bottlenose dolphins communicate using several different types of sound, including clicks that are used for echolocation, and whistles. Echolocating clicks are frequently used for foraging. The animal makes a click towards a distant object and waits for the echo to return, providing information on the distance, shape and size of the object in question. Bottlenose dolphins can detect a 2.5 cm metal target from about 72 m away using echolocation clicks (Murchison 1980).

Whistles

This study concentrates on dolphin whistles, and in particular, signature whistles. Bottlenose dolphins produce whistles that are narrow-band, tonal signals from 1 kHz up to 24 kHz (Janik 1999). Signature whistles are the most common whistle produced by a dolphin whilst it is in isolation (Caldwell and Caldwell 1965), comprising up to 90% of all whistles produced (Sayigh *et al.* 1990). It was shown by Sayigh *et al.* (1990) that wild dolphin populations, like isolated animals, also monopolise their whistle repertoire with signature whistles. Cook *et al.* (2004) found that approximately 52% of all whistles recorded from wild animals were signature or probable signature whistles. Additionally, Watwood *et al.* (2005) showed results that signature whistles are individually distinctive, whereas variant whistles, all non-signature whistles, are not individually distinctive.

Caldwell and Caldwell (1965) coined the term “signature whistles” when they suggested that animals produce individual stereotyped contours that may function to broadcast the identity of the caller, and its location (Caldwell *et al.* 1990). A number of studies (Sayigh *et al.* 1990, Janik and Slater 1998, Cook *et al.* 2004, Watwood *et al.* 2005) have been carried out into how signature whistles are used, and contact calls seems to be one of the main objectives of signature whistle communication. Recognition signals for species that are mobile and associate with particular conspecifics are a useful medium for preserving group cohesion (Janik and Slater 1998). Other species have individually specific calls, such as the African large-eared, free-tailed bats (*Otomops martiensseni*), upon which a study undertaken in 2001 showed significant inter-individual call variation (Fenton *et al.* 2004). These bats live in groups year round, similar to most bottlenose dolphins. In other cetacean species, for example killer whales (*Orcinus orca*), group-specific dialects are thought to be used to maintain group cohesion (Ford 1991). It is an interesting question as to why some species have common calls per group, and others such as the bottlenose dolphins, have specific calls per individual. It has also been suggested that variations in signature whistles by the same individual could communicate other information and serve other purposes (Caldwell *et al.* 1990, Janik *et al.* 1994).

A whistle is made up of a contour which does not change shape, though it may change in duration and/or frequency (Caldwell *et al.* 1972, 1990). This contour is made up of a fundamental frequency, as well as harmonics.

Harmonics are a frequency component of the fundamental frequency, and are

integer multiples or fractions of the frequency of the carrier wave (Gerhardt 1998). This study concentrated solely on the fundamental frequency of a contour.

Some bottlenose dolphins repeat their basic contour when they produce a whistle, and this whistle is known as a multi-loop whistle. It has been recognised that there may be apparent periods of silence between contours. These periods are consistent time intervals and may therefore be thought of as part of the whistle, so a whistle may in fact be made up of a contour plus a specific time interval of silence (Caldwell *et al.* 1990, Miksis *et al.* 2002). This is relevant to non multi-loop whistles as well. Additionally, in a multi-loop whistle, the introductory and terminal loops may be slightly different to the repeated contour in the centre (Caldwell *et al.* 1990).

The most common method used to classify whistle types up until this point has been human classification. A disadvantage of humans classifying different whistle types is that it is hard to know the threshold for categorisation being used, and hard to replicate that threshold. Computer technology may be a way of standardising thresholds and identifying relevant parameters. These parameters could then be used to separate call types and therefore behaviours (Janik 1999), as well as being able to estimate abundance through the separation of call types, and therefore signature whistles. By separating out signature whistles, a count of signature whistles should equate to a count of individuals.

This study intends to follow on from the recent work by Deecke and Janik (in press) that used dynamic time warping (DTW) and an adaptive resonance theory (ART) neural network for categorisation of captive animal whistle contours. The same methodology was used here with free-ranging animals.

Previous Work

Buck and Tyack (1993) used a DTW algorithm to compare signature whistles of the same population of animals whose recordings are the basis for this study. However, their data was recorded when individual dolphins were temporarily captured, therefore making the categorisation exercise somewhat simpler than with wild animals as wild animals also produce a large repertoire of non signature-whistles. Additionally, the whistles obtained in a temporarily restrained situation are likely to be of a higher quality than those obtained in the wild, where other noise sources are present.

Buck and Tyack (1993) concluded that although unmatched contours were altered significantly in time to fit an incorrect category, rather than the correct category, the DTW algorithm did perform adequately. Fripp *et al.* (2005) used the same DTW algorithm that was used by Buck and Tyack (1993), and again the program performed adequately. If there were to be a criticism of this algorithm, it would be that it focuses on dissimilarity rather than similarity, and it alters contours to match in time, but not frequency, where in fact neither time nor frequency are as relevant as the basic shape of the contour (Caldwell *et al.* 1990).

Janik (1999) compared three computer methodologies with human observation in identifying whistle similarities, and found that human observers were still better at categorizing whistles than computers.

Objectives

1. Categorisation of Whistle Types

To show that through the use of computer technology, hydrophone recordings of free-ranging bottlenose dolphins can be automatically categorised into meaningful different whistle types.

2. Abundance Estimates Based on Signature Whistle Categories

To show that these whistle types can help to identify the number of animals present during recording. The technology used in this project should separate call types into different categories. For each signature whistle, there should be a separate category. The number of these signature whistle categories should correlate with the number of individuals present, and these categories should be easy to recognise, as they should have the highest number of contours in them as compared to other variant whistle categories.

Materials and Methods

Data

The data for this research was provided by Laela Sayigh from a long-term study of about one hundred and forty wild bottlenose dolphins in Sarasota Bay, Florida. The animals have been studied since 1970 and therefore are mostly identifiable, with not only sex and age known (Wells 1991, 2003), but also during temporary restraining of most of the individuals in this population, their signature whistles were recorded and catalogued (Sayigh *et al.* 1990). This printed catalogue of signature whistles was used in this study.

Three mother-calf pairs and their associates were recorded for a total of 141.25 h between May and August of 1994 and 1995. Recordings were made with a Panasonic AG-6400 hi-fi VCR that was capable of recording frequencies up to at least 32 kHz. The recordings were taken using two hydrophones with weighted cables that were towed behind a small moving boat (Sayigh *et al.* 1993).

Data Organisation

The recordings detailed above were saved to a total of thirty-nine tapes, with each tape being approximately two hours long in duration. Ten of these tapes were randomly chosen for this study, incorporating fifteen individuals with at least ten signature whistle events each.

For each recording there were three channels used. Two hydrophones placed a metre apart from each other made up channels 1 and 2. Channel 3 was used for commentary, where verbal comments describing group composition, mother-calf distance, calf's nearest neighbour, activity, location and group size were recorded at five minute intervals, throughout these focal follows (Cook *et al.* 2004). The commentary files were converted from wav to mp3 files at a bit rate of 96 kbps, using freeware software, Switch, version 1.05. The files were listened to using Windows media player software, and the time, animal identification (id) code and group size were noted.

To extract the whistles from the recordings, the tapes were processed using CoolEdit Limited Edition, both listening to and viewing the spectrogram on the screen. Fifteen seconds of recording time was displayed on the screen at a time, showing frequencies from 0 to 24 kHz (FFT length: 512).

The original dataset provided an index file that included details of whistles at counter intervals on the tape. A tape counter relates to the relative amount of tape that has passed through a tape recorder, and does not always correlate to absolute time. This index file therefore predicted how many whistles should be contained within each tape, as well as ids of animals present during the recordings. However, as there was no way to correlate the counter intervals to time, the tapes were reanalysed, noting whistle times with respect to the duration of the tape. Therefore in this analysis, some whistles identified in the original index file may have been missed, or some whistles may have been identified that were not identified in the original index file. It would be

extremely difficult to recreate the original data index spreadsheet to reproduce the exact same number of whistles, as human behaviour cannot be reproduced exactly, even if the same person redid the analysis, as some of the whistles were quite faint.

The ten tapes held approximately one thousand whistles as detailed in the original index file. To reduce the dataset, half of the whistles of each tape were chosen to analyse. To do this, the random number generator in Microsoft Excel (=randbetween) was used. If the original data file suggested that a tape had 62 whistles in it, then the formula (=randbetween(1,62)) was used. This formula was copied 31 times to get half the number of whistles. Where the formula provided duplicates, e.g. 20 and 20, the second 20 was made to be 21. If the tape had an odd number of whistles, i.e. 141, the number of whistles to be analysed would be rounded upwards, therefore giving 71.

Once a whistle was heard or seen on the screen, that section of the spectrogram was copied and saved as a smaller wav file encompassing a few seconds, and never greater than ten seconds in length. Software used later in this analysis had a limit, and would not accept files greater than ten seconds in duration. Whistles have been cited generally as not being longer than 3.6 seconds (Evans and Prescott 1962). Where there were multi-loop whistles, the entire section of the spectrogram containing the loops was saved as one file. At this stage, one of the tapes was discarded due to too much background noise, therefore leaving nine tapes.

The data was run through “Beluga”, a contour extraction program written in Matlab by Volker Deecke of University of British Columbia. Three hundred and twelve small wav files containing both single whistles and multi-loop whistles were saved from CoolEdit and loaded individually into Beluga. In Beluga, the contour area was selected (as shown in Fig. 1), and the program attempted to automatically trace the contour within the selected rectangle area. Beluga uses a noise to ratio mechanism to trace a contour, tracing the loudest noise within the area that has been selected.

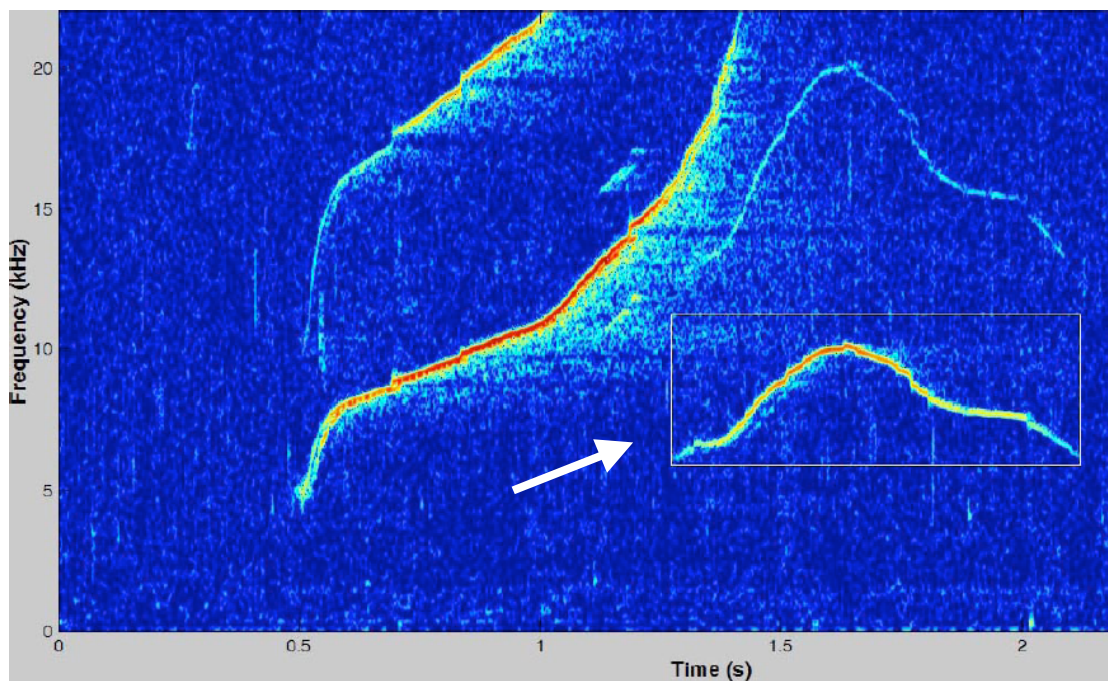


Figure 1: A contour selected for tracing within Beluga.

If the contour was not traced exactly (as shown in Fig. 2), manual edits were made by selecting the small incorrect section and reinitiating the trace (as shown in Fig. 3). This is effectually narrowing the frequencies in which the program is searching for sound, as the frequencies searched are limited to those in the selected rectangle area.

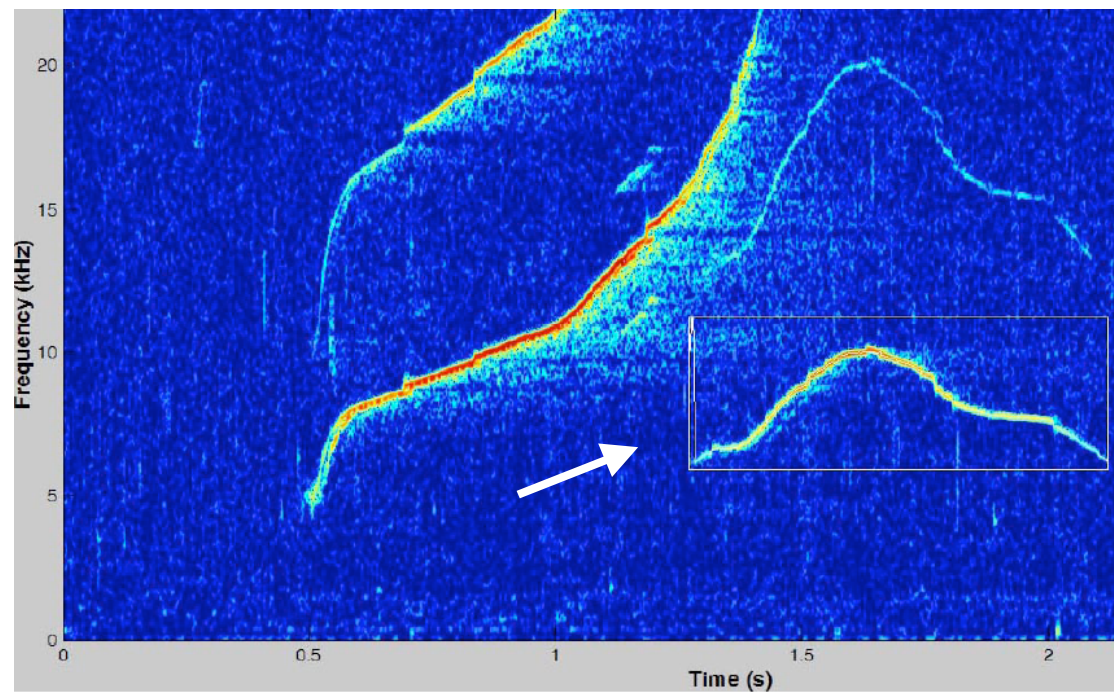


Figure 2: Showing how a contour in Beluga has not been traced correctly at the beginning of the contour.

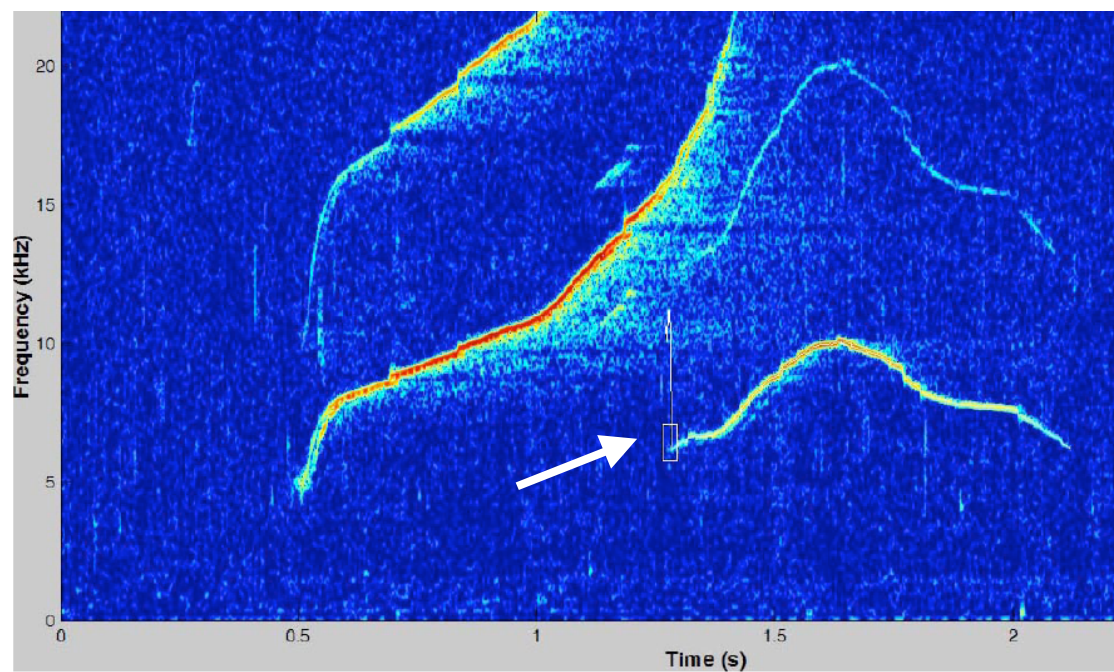


Figure 3: Showing the re-selection of the area requiring editing in Beluga; a narrower frequency range has been selected by drawing a smaller rectangle, so the contour will definitely be the loudest noise.

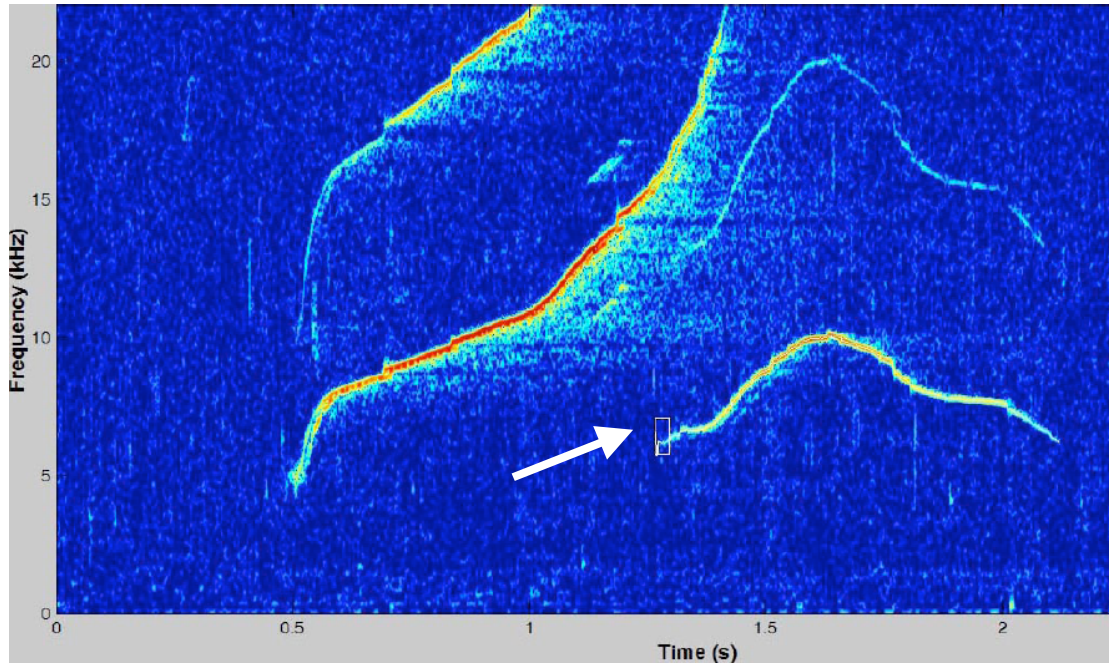


Figure 4: *Showing that Beluga has correctly traced the contour at the beginning, post-editing.*

Fig. 4 above shows that the beginning of the contour post-editing, remained in line with the frequency range of the originally selected contour.

When a wav file was loaded into Beluga that contained a multi-loop whistle, the entire section was highlighted initially to see if Beluga could trace all the loops as one whistle. If Beluga could not complete the trace between contours, then each contour was extracted separately, and considered separate whistles in the analysis.

Once the trace of the contour was complete, it was saved as a contour (ctr) file. Four hundred and fifteen ctr files were produced in all. The ctr files were then opened individually in Matlab and resaved as text (txt) files. These txt files contained a numeric record of every frequency point of the contour, with a temporal resolution of 1 millisecond.

ARTwarp is a program also written by Volker Deecke that compares contours up to a set similarity percentage (vigilance parameter) that can be specified by the user. In this case, 96% was chosen, in keeping with the parameter value used by Deecke and Janik (in press). ARTwarp places contours that are at least as similar as the set vigilance parameter, into the same category.

Where a contour matches an existing category, the contour is added to that category and the reference contour for that category is recalculated as an average of all the contours contained within that category. Where a contour does not match any of the existing categories reference contours, or is the first contour being analysed, a new category is created and that contour becomes that category's reference contour. The program iterates through all the contours, opening the contours in a random sequence for each iteration, until it achieves the same categorisation network for two consecutive iterations.

Some changes to the original program were made. The variable that manages how many iterations are possible was originally set to 100.

However, due to the amount of time the program takes to run, for this study the dataset was only run through one iteration, and therefore the variable was reset to one. Additionally, the maximum number of categories was hard-coded to 56, and this was modified to equal 415 to allow if necessary, one category per contour. Finally, the program added as the last data point in the txt files, the length in seconds of the contour. This manifested itself graphically in adding a trailing tail to each contour, joining the last frequency

data point to a point on the x axis directly below the last frequency, indicating the duration. Therefore I removed the last data point in each contour file.

Once ARTwarp had completed, there was a list of contours assigned to each category. As some categories only contained one contour, the first contour of each category was chosen to compare to the printed signature whistle catalogue. In order to do this, the wav file underlying the contour was opened using Raven software, version 1.2, and visually compared to the printed signature whistle catalogue containing the signature whistles of the Sarasota Bay population of dolphins. The reason the visual match was done with the underlying wav file was because the contour file may just have been a single loop extracted from a multi-loop whistle, and therefore would definitely not match to any of the signature whistles in the printed signature whistle catalogue. The catalogue lists signature whistles with the animals id beside it. The Raven software window was adjusted to represent as similar as possible a picture to those in the catalogue, displaying up to three seconds along the x axis, and up to 30 kHz along the y axis. Using visual comparison, the wav file on the screen was blindly matched to the catalogue, using a similarity index.

Similarity Index	Description of Similarity
3	Definite match
2	A likely match
1	Similar, but unlikely to be the same
0	No match

For each wav file on the screen, the printed signature whistle catalogue was visually iterated through once, so even if a signature whistle in the catalogue appeared similar to the whistle on the screen, the matching search continued to see if there were any more catalogue signature whistles that were also similar. Up to two catalogue animal ids could be noted down where necessary.

To concentrate on the most meaningful results, for those categories that scored a two or a three in the similarity index, further analysis was carried out. Each contour within these ARTwarp categories was compared to the index and/or commentary tapes (behavioural observation data) to ascertain whether the animal id chosen from the printed signature whistle catalogue that visually matched to the first contour in each ARTwarp category, known from here on in this text as the 'match animal', was in fact present during the time of recording of each subsequent contour in the category.

Nb. There were ten animals noted as being present in the behavioural observation data, whose signature whistles were not detailed in the catalogue.

Results

When ARTwarp was run through 1 iteration, the program grouped the 415 contour files into 90 categories. The analysis is divided into stages below, as the dataset being analysed is reduced in each stage.

Stage 1

The dataset was reduced by discarding all those categories with a 1 or a 0 similarity index. Using the similarity index described previously, 22 of the resulting 90 ARTwarp categories had a similarity index of 2, and two categories had a similarity index of 3, as shown in the frequency distribution histogram (Fig. 5) below. Therefore 24 of the ARTwarp categories (27%) were used for further analysis, as described in Stage 2 below.

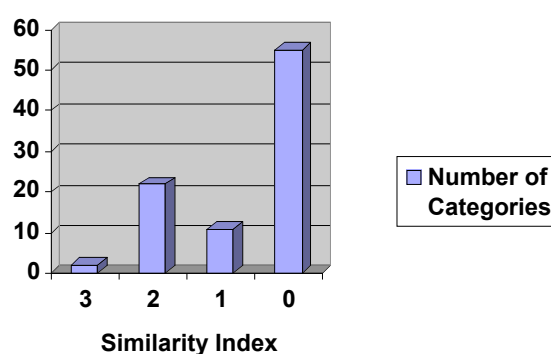


Figure 5: Histogram of frequency distribution across the similarity index scale.

Stage 2

To ascertain whether the match animal was present during each contour within each of the remaining 24 categories, the behavioural observation data was reviewed. Fifteen of these categories contained no contours that had the

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match animal present during recording. Two of these categories had a combination of the match animal being present or absent, in one case being present 86%, and in the other being present only 27%. Seven of the categories however, had 100% of their contours being recorded at a time with the match animal present, and these seven categories were used for further analysis in Stage 3.

Stage 3

For the next stage of analysis, all the contours contained within each of the remaining seven categories were analysed visually to see if they all truly matched the signature whistle of the match animal. Two match animal ids were listed more than once across categories. Match animal FB25 was listed three times in categories 59, 71 and 89. The signature whistle for this match animal was a multi-loop whistle containing two contours. The **_2** at the end of a contour name (in Table 1 below) indicates the second loop of a multi-loop whistle.

Table 1: Summary of the 7 categories with 100% contained contours having the match animal present. Boxes highlighted the same colour and with bold text, represent contours from the same multi-loop whistle.

Catalogue ID (‘match animal’)	% Time Present (all recordings)	Category	Contour 1	Contour 2	Contour 3
FB25	37	59	94r13_74_13_877.ctr		
		71	95r11_97_22_557.ctr	95r11_97_22_557_2.ctr	
		89	94r13_74_13_877_2.ctr		
FB63	40	61	95r11_34_42_727_2.ctr		
		90	95r11_34_42_727.ctr		
FB65	17	23	95r10_107_50_054.ctr	95r10_107_52_709.ctr	95r9_101_24_200.ctr
FB75	76	50	94r13_87_50_672.ctr		

Category 71 shown below in Fig. 6 interestingly contains both contours of match animal FB25, and they look quite different to each other. However,

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category 59 contains the first contour of FB25's multi-loop whistle and category 89 contains the second contour and although these two contours have been split across two categories, they actually look a lot more similar to each other (see Fig. 7 below) than the two contours represented in category 71 (see Fig. 6 below).

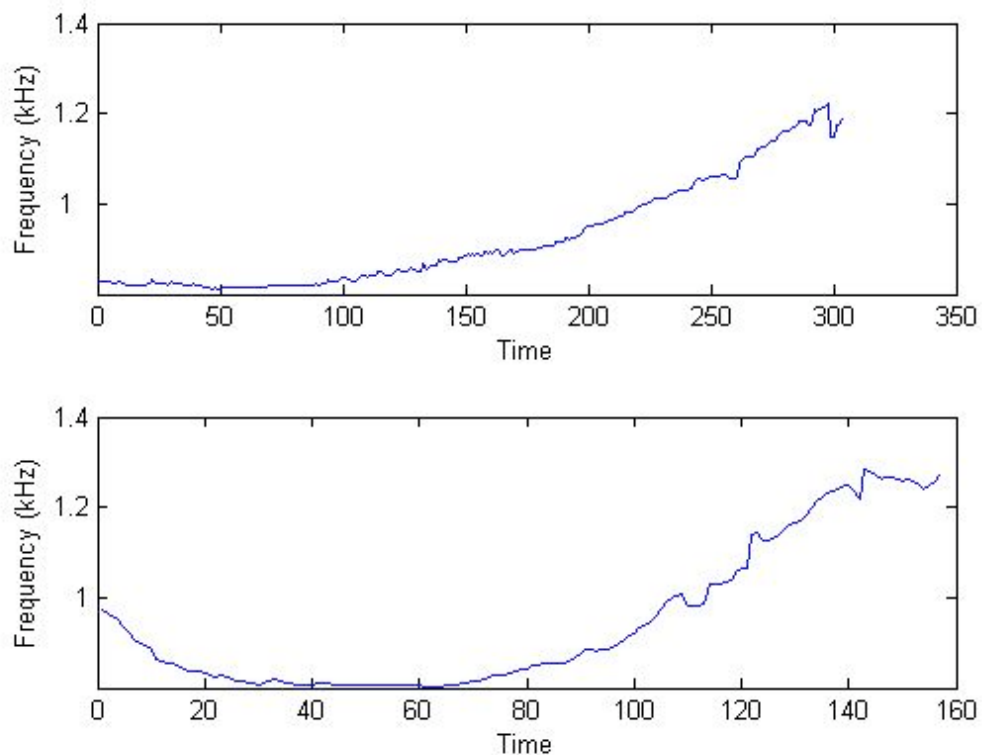


Figure 6: Category 71 containing both contours from the multi-loop signature whistle of match animal FB25, contours 1 and 2 are top and bottom respectively.

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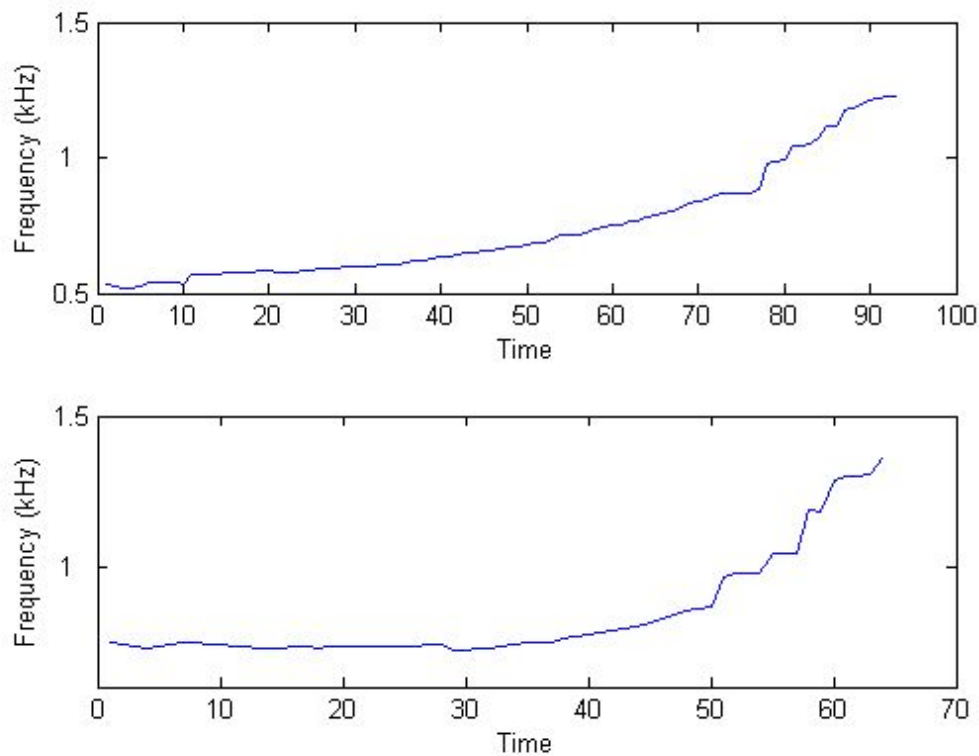


Figure 7: *Categories 59 (top) and 89 (bottom), which contain one of each contour of the multi-loop signature whistle of match animal FB25, contours 1 and 2 are top and bottom respectively.*

The match animal FB63 was listed across two categories, 61 and 90, and again its two contours of its two looped multi-loop whistle were split across the two categories.

Category 50 contained a single looped whistle that visually matched the match animal FB75.

Category 23 was matched to a non multi-loop signature whistle match animal, FB65, and contained 3 contours within its category that visually matched this whistle, as seen in Fig. 8 below.

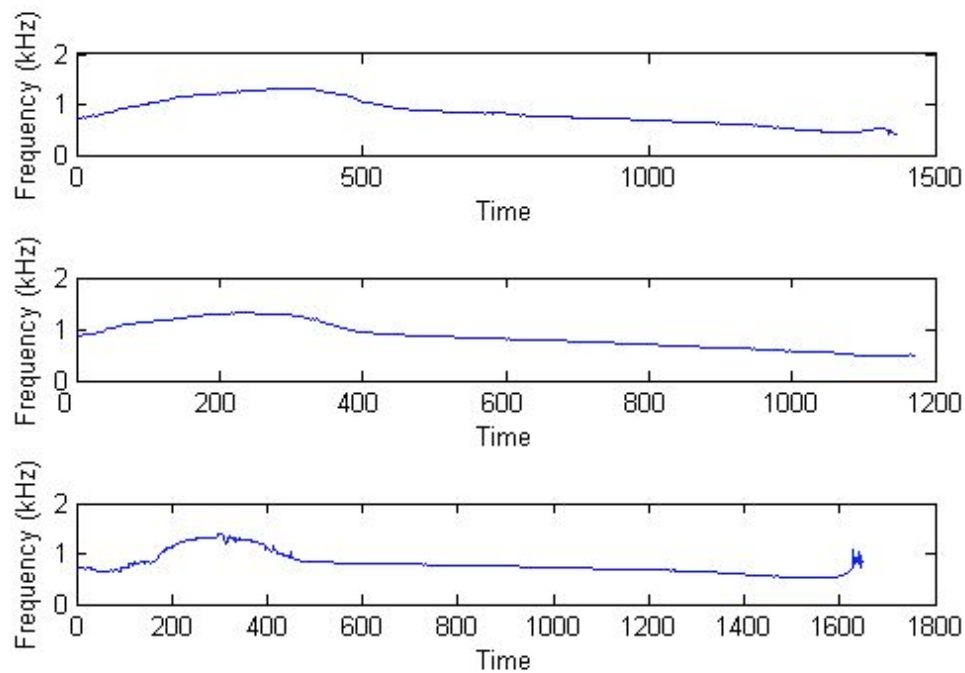


Figure 8: *Category 23 containing three contours that appear visually similar to match animal FB65’s signature whistle in the printed catalogue.*

Table 1 also shows that the animals were not all present equally. To thoroughly test an automated methodology, one would need an equal amount of recording time with each individual in the same circumstances, so as the neural network is not weighted discriminately, but this is simply not feasible with free-ranging animals.

Discussion

Categorisation of Whistle Types

Potential for Human Error

Although previous work has shown that human categorisation works well (Janik 1999), it is still not ideal for a study to mix computer categorisation with human categorisation for a true test of automated categorisation ability.

Human interaction for this study enters throughout the project, possibly not giving the computer software a consistent, standard dataset to truly be tested with. Firstly, during the actual follows of the animals, it is possible that an animal's whistle was recorded, but that individual was not seen by the observers on the boat. This would greatly influence the second stage of the analysis whereby the behavioural observation data is cross-referenced for all the contours contained within a category of a similarity index of 2 or 3, to check whether the match animal is present. Secondly, the contour extraction program, Beluga, allows for too much human input and therefore, error and lack of standardisation. A possibility to consider here would be to have a variable that measures the human's editing ability, similarly to line transect observer ability. Finally, the interpretation of the results used human visual matching capabilities to match wav files on screen, to photocopied spectrogram printouts contained within the printed signature whistle catalogue. For consistency I would recommend including an electronic version of the printed signature whistle catalogue into the dataset, to get a true comparison using the same automated algorithm that has compared all the whistles. One thing to consider here in addition, is that the catalogue,

and/or the recorded wav files, may have contained cut off signature whistles that did not completely match visually to the human eye.

Multi-loop Whistles

At a very basic level of multi-human discrepancy, individuals could be placed into two camps with regards to multi-loop whistles, a 'splitter' or a 'lumper', as noted by Caldwell *et al.* (1990). However, Tyack and Sayigh (1997) state that even if the animal has a variable number of contours within a signature whistle, as long as the repetition is of the same contour and with consistent time intervals between each contour, this classifies as a signature whistle. This means that the technique of extracting each contour separately for a multi-loop whistle is a method that could still give us a category containing the core of an animal's signature whistle. For example, if the whistle had been extracted as an entire multi-loop whistle, that whistle would have been placed into one category, and if the multi-loop whistle had been split into three contours, those three contours would also be saved into only one category, as the three contours were identical. In theory this should hold true regardless of whether the number of contours in an animal's multi-loop whistle varies or not. As long as the contours are the same, they will always be put into the same bucket.

This method of splitting up multi-loop whistles into separate contours would therefore provide more consistent results if the number of loops does indeed vary, rather than comparing an entire multi-loop whistle as a whole whistle. For example, if in one instance the multi-loop whistle had two contours, and in

another, three contours, these two whistles would be placed into two separate categories; whereas if the contours were split out, all contours would still be contained in one category. However in some cases with animals that repeat their contour, the introductory and terminal loops may be slightly different to the repeated contour in the centre (Caldwell *et al.* 1990). Therefore the introductory, central and terminal contours belonging to the same animal's signature whistle may be put into three different categories, depending on the stereotypy of the introductory and terminal contours.

Perhaps a solution would be to take only the second contour of a multi-loop whistle for comparison, therefore removing the introductory and terminal loop differences as well as reducing human effort and computer time by reducing the number of contours overall. This solution may not be relevant with a multi-loop whistle made up of only 2 loops. Additionally, Buck and Tyack (1993) noted that even central loops may not be as stereotypical as previously believed. Therefore I would suggest one method would be for all multi-loop whistles to be pushed through a piece of software that does a subset of what ARTwarp does in averaging out the contours in its categories to produce a reference contour, and in this case produce a vanilla central loop contour for comparison.

Decreasing Runtime

Time wise this methodology needs refining, as this process is still taking longer than human effort would at this stage, which defeats the purpose somewhat. With respect to the ARTwarp software, there are a number of

modifications and different ways to use the program that could enhance the runtime:

- Reduce the resolution of the whistle contours, so for example modify the temporal resolution from 1 millisecond to 10 milliseconds. This will result in reducing the amount of processing required for the DTW algorithm.
- Turn off the graphical display.
- Lower the vigilance parameter, which will result in creating fewer categories.
- Use only a subsample of whistles to create a core network that can then be used to classify call types.

Abundance Estimates Based on Signature Whistle Categories

In captivity, bottlenose dolphin calves develop their signature whistles at approximately six months old (Caldwell and Caldwell 1979). Wild calves of one year of age have stable signature whistles developed, which can remain stable for up to twelve years (Sayigh *et al.* 1990). Therefore there is a possibility that acoustic monitoring may miss some very young animals in an abundance estimate. However, the same problem occurs with photo-id studies, as few young animals have marks, and actually signature whistles are developed at a younger age than marks.

Caldwell *et al.* (1990) also note that a change in the ontogeny of signature whistles occurs early on in the development stage, with an increase in the number of contours produced as part of a whistle, and increased frequency

variation with age. However, once stable, they found that animals had not changed their signature whistle for up to eighteen years. Therefore again, abundance estimates of younger animals may be harder to obtain correctly. Again, a similar problem exists with mark changes in photo-id studies. The solution is to obtain samples frequently enough to keep track of these changes.

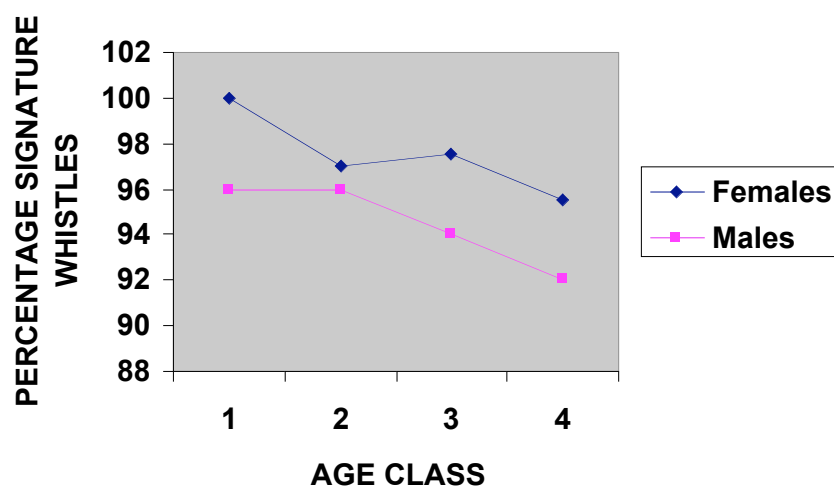


Figure 9: Graph showing percentage of signature whistles used by varying age classes (Caldwell *et al.* 1990)

Caldwell *et al.* (1990) showed that as age class increases, the production of signature whistles decreases, as shown above in Fig. 9. Adult males whistle less than females and/or young males. This will also bias abundance estimates somewhat.

Smolker and Pepper (1999) conclude that male alliances converge their whistles so they are as acoustically similar to each other as they are to themselves. This was also found by Watwood *et al.* (2004), where male

dolphins were in close relationships that they would have similar, converged whistles. This would therefore result in under-estimating abundance.

Another consideration is that if signature whistles are to be used as contact calls, there may be situations where announcing or concealing presence, location and identity may be preferred (Janik and Slater 1998).

It is worth noting that Smolker and Pepper (1999) found no individually specific whistle type, although they do contradict themselves by then saying that the most common whistle type of each animal changed considerably over a four-year period.

The copying of signature whistles that occurs both in captivity and in the wild (Janik and Slater 1998), means that abundance estimates could under-estimate the number of animals present, assuming that the animal being copied is present, and the animal doing the copying does not produce its own signature whistle during the abundance estimate collection period. However, Sayigh *et al.* (1990) suggested that variant whistles could in fact be copies of the signature whistles of other animals. If these other animals are not in the group, and an animal is making its own signature whistle as well as a copied one of an animal not present, abundance estimates will be an over-estimation.

Future Work

It is not understood how dolphins perceive whistles, and whether for example a 4 loop whistle holds more information than a 3 loop whistle, or whether

multi-loop whistles are just perceived as repeated initial contours and hold no more information, regardless of how many loops, than the initial contour.

Perhaps the introductory contour holds some information as to how many contours will follow? As varying results from separate studies with different methods of categorising whistles evolve, we need to understand how dolphins themselves categorise whistles (Tyack 2000), to work towards some standardisation of categorisation, whether it be automated or human categorisation.

Dolphins are clearly able to recognise whether a signature whistle is from its originator, or a copier, therefore more research into the differences of a true and copied signature whistle should be undertaken. More investigation into the details of individual's development of signature whistles would help us categorise not only the whistles, but be able to tell sex and age class of individuals. For example, juvenile males adopt their signature whistles to be similar to their mothers, whereas juvenile females ensure their signature whistle is distinctive from their mothers (Sayigh *et al.* 1990, 1995).

Using signature whistles as a count of the presence or absence of an individual has the potential to provide much higher resolution data on animal abundance than achieved by other methods to date. Van Parijs *et al.* (2002) used acoustic recordings in conjunction with visual group size observations to correlate the mean number of calls for a set time period, with group size. Although this method resulted in adequate abundance estimates, it was only useful when group sizes were less than nine. However, in order that the

signature whistle methodology become refined to achieve accurate abundance estimates, several problems need to be accounted for and overcome, including whistle changes by age class and copying whistles.

Abundance estimates could be calculated using the mark-recapture protocol, but instead of the mark being an individual's id photograph, it could be an individual's signature whistle. This would have its own problems to address, such as the fact that if the hydrophone is only in one place, some animals will be missed. Perhaps the best application for automated whistle categorisation is to estimate abundance by using a remote bottom-mounted hydrophone system. This has numerous benefits, including conservational and financial. Animals are not harassed by research boats, which consume valuable resources, i.e. Petrol. Although the survey area would be geographically limited, a bottom-mounted hydrophone is a 24-hour monitoring device, and would not be limited by weather.

For future testing of this methodology, some thought should be given to how to develop signature whistle catalogues without temporary restraint. As localisation techniques advance, and are applied in areas where individuals are photo-identified, identifying which wild animal has produced which sound should become easier. However, the advantage of temporary restraint is that in isolation, a dolphin rarely produces anything other than its signature whistle, therefore ensuring the accuracy of the catalogue.

Conclusions

The results of this study showed that using the neural network categorisation methodology with free-ranging bottlenose dolphins was not as successful as when tested on captive animals (Deecke and Janik, in press). This is in part due to the fact the categorisation algorithm was only run through one iteration. The classification is only considered stable once all whistles are consistently assigned to the same categories in two consecutive iterations. The hope is that the program would have improved results if it had been left to iterate as required.

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Appendix I

Convert2txt program written in Matlab to convert ctr files to txt files required for ARTwarp program

```
DATA = dir('C:\Program Files\MATLAB704\whistles\*ctr');
DATA = rmfield(DATA,'date');
DATA = rmfield(DATA,'bytes');
DATA = rmfield(DATA,'isdir');
dat = {};

for f = 1:size(DATA,1);
    load(DATA(f).name,'-mat');
    fcontour = fcontour';
    dlmwrite([num2str(f,'%03.0f') '.txt'],fcontour);
    dat{f,1} = num2str(f,'%03.0f');
    dat{f,2} = DATA(f).name;
end
```

Appendix II

Modified Convert2txt program

```
DATA = dir('C:\MATLAB701\whistles\*ctr');
DATA = rmfield(DATA,'date');
DATA = rmfield(DATA,'bytes');
DATA = rmfield(DATA,'isdir');
dat = {};

for f = 1:size(DATA,1);
    load(DATA(f).name,'-mat');
    fcontour = fcontour';
    dlmwrite([num2str(f,'%03.0f') '.txt'],fcontour(1:(max(size(fcontour))-1)));
    dat{f,1} = num2str(f,'%03.0f');
    dat{f,2} = DATA(f).name;
    dat{f,3} = fcontour(max(size(fcontour)));
end
```

Appendix III

Ids present per tape, a combination from both the original index file and the commentary files

YEAR	REEL	ID	YEAR	REEL	ID
1994	2	FB571	1995	9	C652
1994	2	FB111-CLLA	1995	9	FB65
1994	2	FB90			
1994	2	FB39	1995	10	C652
1994	2	FB29	1995	10	FB65
1994	13	FB131	1995	11	FB155
1994	13	FB79	1995	11	FB122
1994	13	FB75	1995	11	FB101
1994	13	FB62	1995	11	FB90
1994	13	FB59	1995	11	FB65
1994	13	FB39	1995	11	FB63
1994	13	FB38	1995	11	FB60
1994	13	FB25	1995	11	FB48
1994	13	FB20	1995	11	FB26
1994	13	FB17	1995	11	FB25
			1995	11	FB1
1994	24	C652-V			
1994	24	FB122	1995	13	C391
1994	24	FB90	1995	13	FB132
1994	24	FB68	1995	33	FB131
1994	24	FB65	1995	33	FB92
1994	24	FB63	1995	33	FB65
1994	24	FB48	1995	33	FB62
1994	24	FB26	1995	33	FB59
1994	24	FB24	1995	33	FB39
1994	24	FB9	1995	33	FB34
1994	24	FB7	1995	33	FB02
1994	24	FB6			
1994	36	FB175			
1994	36	FB122			
1994	36	FB90			
1994	36	FB75			
1994	36	FB65			
1994	36	FB36			
1994	36	FB11			
1994	36	FB10			
1994	36	FB8			
1994	36	FB2			
1994	36	FB1			