Supplementary Material

Manual of the Ficedula Toolbox 1.0

Development and downloading information

The toolbox was developed in Matlab 2013 (The Mathworks Inc.), and can be downloaded from https://github.com/zsebok/Ficedula. The software is open source, and is under GNU General Public License Version 3. In case of any trouble, we are happy to provide any further information (zsebok.s@gmail.com).

Sound analysis possibilities

The toolbox containing several programs offers the following analysis options:

- cutting songs out from recordings (Step 1)
- segmenting songs to syllables (Step 3)
- computer aided manual clustering syllables into syllable groups (Step 5)
- computer aided manual clustering within-individual groups into larger inter-individual groups (Step 8)

The toolbox can be used for the whole analysis from song cutting to clustering or separately for specific steps.

Setting up the program

After downloading and extracting the compressed file, the Ficedula Toolbox folder can be placed in any folder on the computer. No need for additional preparations. The toolbox menu can be loaded with the run of “ficedula.m” file. The menu is structured according to the analysis steps in the same order and with the same numbers as it is in this manual (Figure S1).

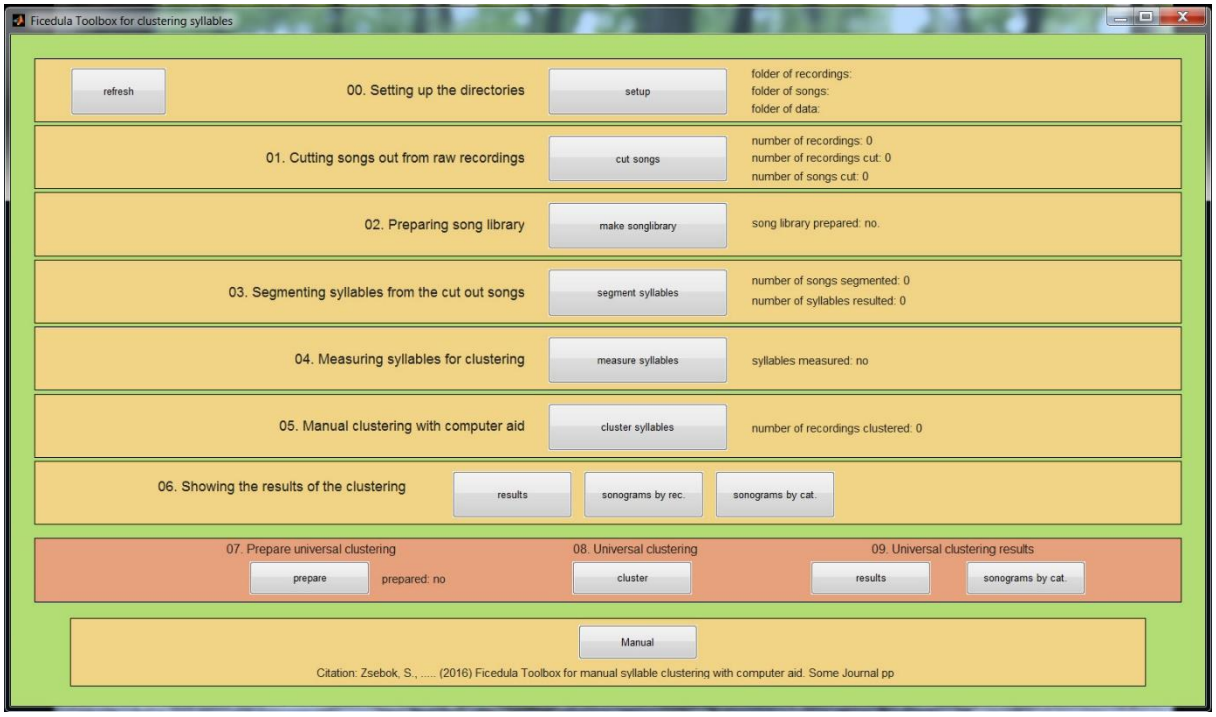

Figure S1. The menu screen of the program.

Step 0. Setting up a new project

- press button “setup” (Figure S1)
- choose the folder of recordings (.wav files)
- choose the folder of songs
- choose the folder of data, where all the results (tables and pictures of sonogram), data files will go

We suggest to create a folder for each project separately containing the three folders (recordings, songs, data). You have to copy your recording files into the recording folder.

Step 1. Cutting songs out from raw recordings (songcut.m) (Figure S2)

Input files:

- recording files, any length, in .wav audio format

Output file:

- results_songcut.mat, containing the position of the marked songs in the recording

Usage:

- press button “cut songs” in the starting menu (Figure S1), new figure will appear (Figure S2)
- in case you use this program separately from the menu, you have to write the path of recordings manually in the text box appears in the top left
- press “Load path” button
- choose recording by the “File back” and “File forward” buttons
- after pressing “Load file”, the spectrogram of the part of the recording appears. The oscillogram in the bottom shows what part of the recording is shown above.
- you can navigate in the file with the green buttons (“<<<”,”back”,”<” and “>”,”forward”,”>>>”)
- you can zoom with buttons (“zoom to selection”, “zoom out”,”zoom in”)
- listening of the content of the window with button “play”, stop it with “stop”
- to initiate to mark a song, press “mark” button, then use left mouse button to mark the top left corner of the song on the spectrogram, then the right bottom corner with a right mouse click
- to delete a marking, press “delete” button first, then
- to save the markings, press “Save” button

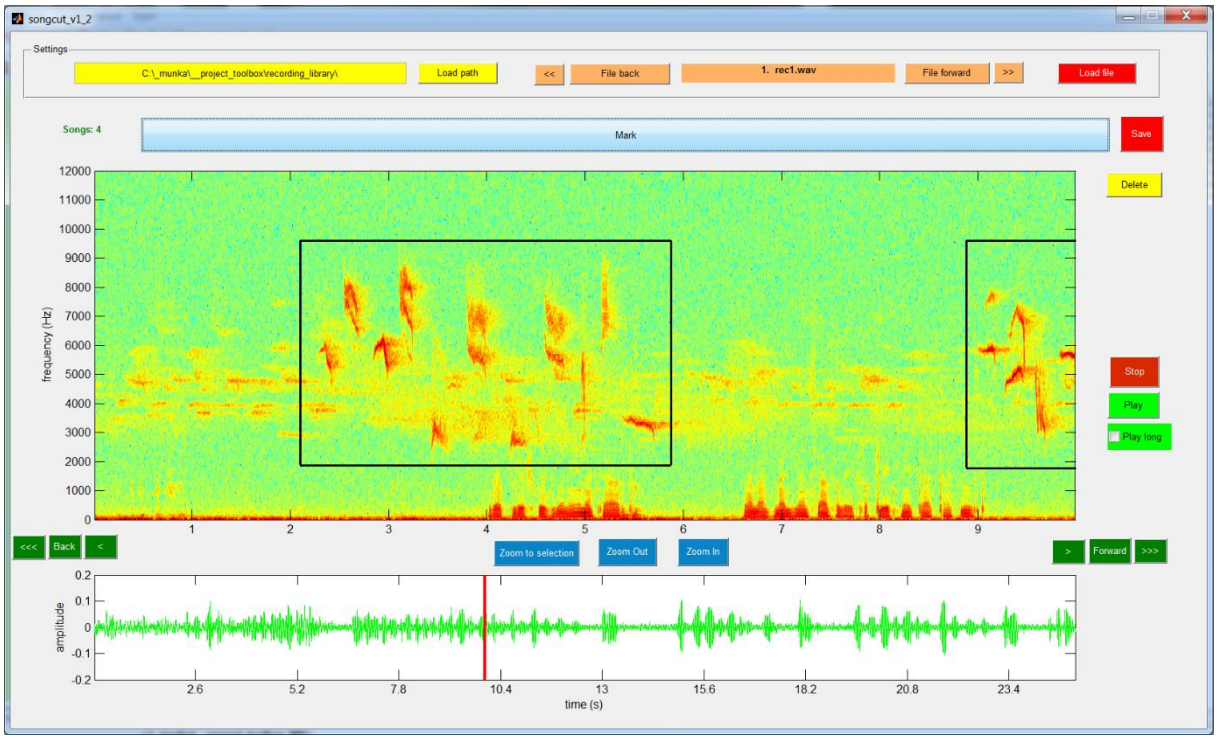

Figure S2. The GUI of the cutting program

Step 2. Preparing song library (make_songlibrary.m) (Figure S1)

Input file:

- results_songcut.mat, containing the position of the marked songs in the recording

Output file:

- song files cut in the folder defined in the project setup, where song files are placed in separate folders by recording

Usage:

- press button “make songlibrary” in the starting menu (Figure S1)
- in case you use other program to cut out the songs from recording, you have to place the song files (.wav format) into separate folders by recording inside the song file folder defined in the project setup

Step 3. Segmenting songs to syllables (segmentation.m) (Figure S3)

Input files:

- song files in .wav audio format, placed in separate folders by recording

Output file:

- results_segmentation.mat, containing the position of the marked syllables in the songs

Usage:

- press button “segmentation” in the starting menu (Figure S1), a new figure will appear (Figure S3)
- very similar to step 1, only differences are mentioned here
- first, you have to select the recording, then the song to load a song file

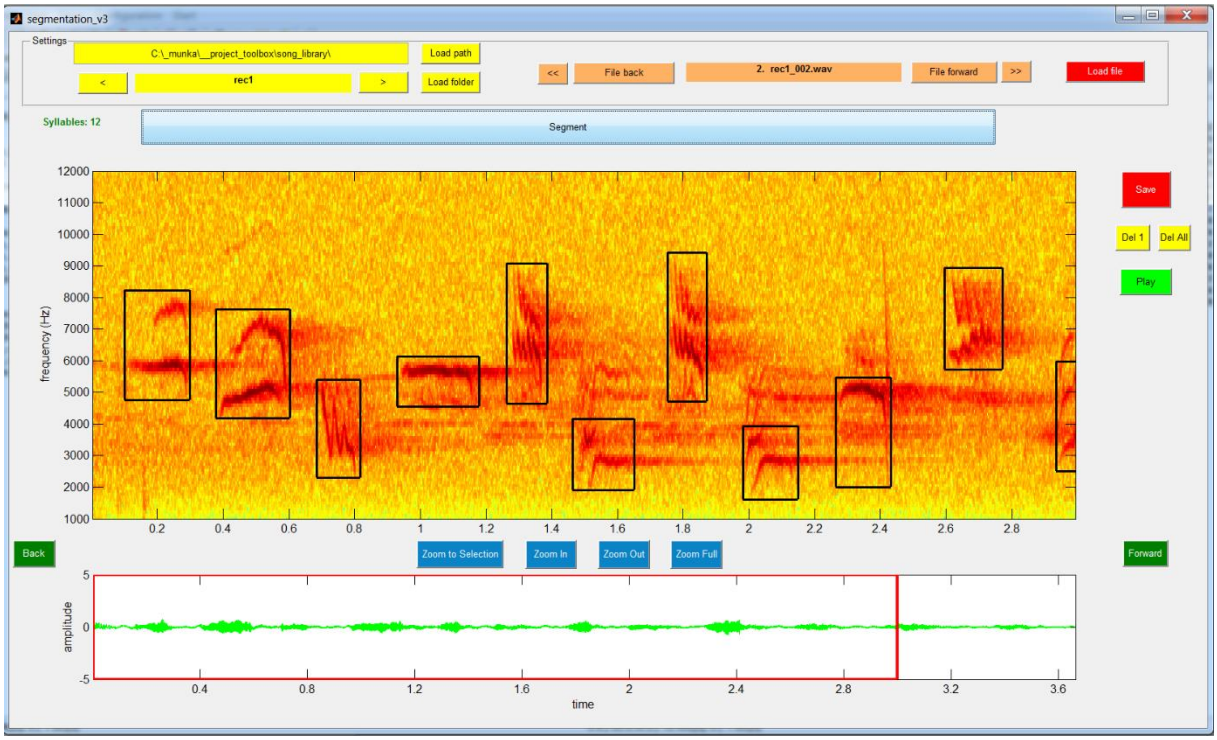

Figure S3. The GUI of the segmentation program.

Step 4. Measuring syllables (ficedula_make_syllable_database.m, ficedula_make_measurements.m) (Figure S1)

Input file:

- results_segmentation.mat, containing the position of syllables in the songs

Output files:

- database_syllables.mat, containing all the syllables in separate rows in a table
- database_syllables_measured.mat, like the previous file supplemented with columns containing the spectral measurements

Usage:

- press “measure syllables” button (Figure S1)
- the measured parameters can be defined in the code of “Ficedula_measurements1.mat” file
- in case you want to use other programs to use in the next clustering step, a database must be prepared like database_syllables_measured.mat, with coloumns specified in the beginning of the code ficedula_make_measurements.m script.

Step 5. Manual clustering with computer aid (csoportositas5.m) (Figure S4)

Input:

- database_syllables_measured.mat, containing the syllable positions and measurements
- inds.mat, containing the name of recordings to process in a randomized order

Output:

- the program save the clustering results into separate files with the name of the actual recording with ".mat" extension

Description of the GUI:

The clustering program's GUI shows windows containing syllables to cluster, the selected syllable, the selected group, the groups ordered according to the similarity to the selected syllable, the groups in their chronological order and the syllables belong to the selected group. All syllables and groups on the GUI are represented by their spectrogram.

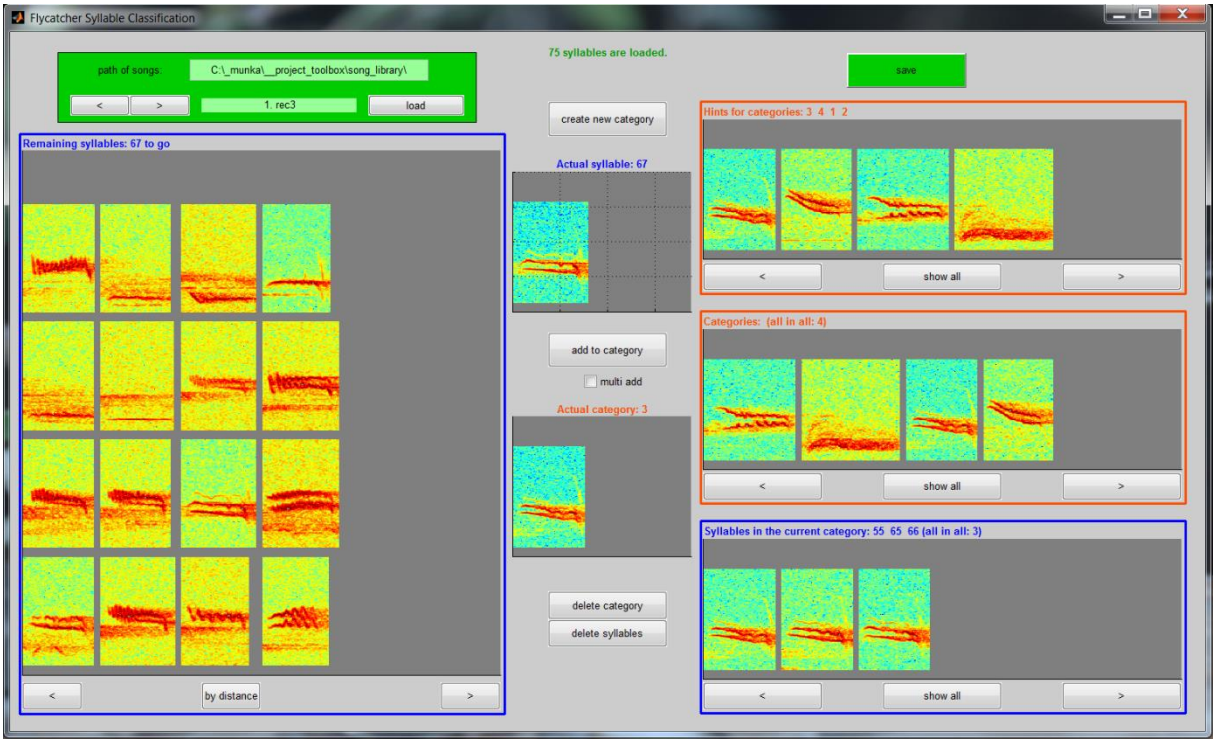

Figure S4. The GUI of the clustering program.

Usage:

- press “cluster syllables” in the start menu to start the program (Figure S1), a new figure will appear (Figure S4)
- path of songs must be specified in the program (e.g.: “c:_munka_flycatcher_songs\”) (Figure S5)

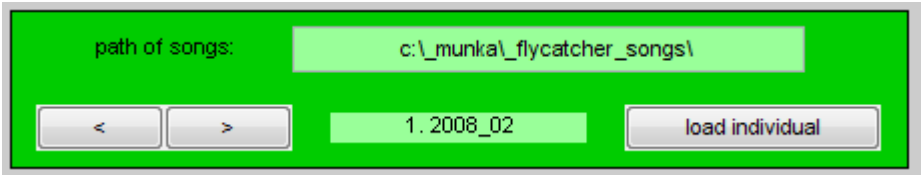

Figure S5. Part of the clustering GUI.

- a recording can be chosen by the arrows, then press “load”
- the left panel shows the syllables to classify (Figure S6)

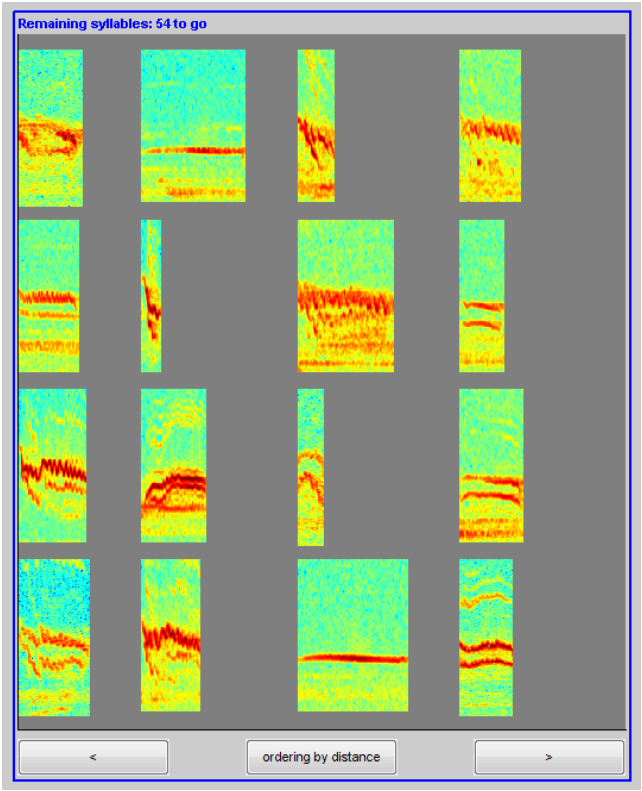

Figure S6. Part of the clustering GUI.

- In case of a syllable is chosen by clicking on it, then, the “ordering by distance” button arranges the syllables from most similar to least similar to this syllable. Otherwise, to the chosen category.
- In the top centre, the actual syllable is visible, below the actual category (Figure S7)

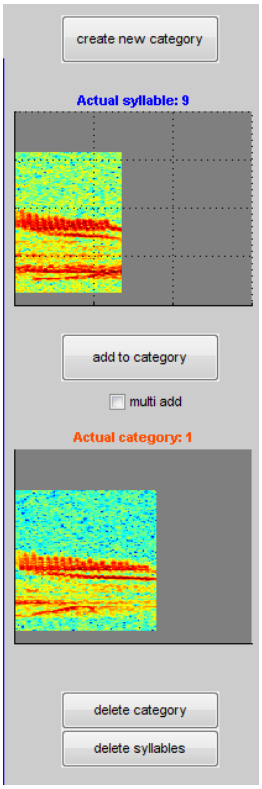

Figure S7. Part of the clustering GUI.

- By clicking on the actual syllable, it shows both the actual syllable and the chosen category in the same axes, and plays both syllables.
- “create new category” button creates a new, empty category
- “add to category” puts the actual syllable into the current category
- if the box “multi add” is checked, then after clicking on the syllables in the left window, the syllable is automatically added to the actual category.
- after pressing “delete category” you can choose one category from the middle right panel to delete
- by pressing “delete syllables” you can delete multiple syllables from the bottom right panel with left mouse button, and finish it with the right mouse button.
- on the top of the right (“Hints for categories”) you can find the categories in order from most similar to least similar to the actual syllable (Figure S8)

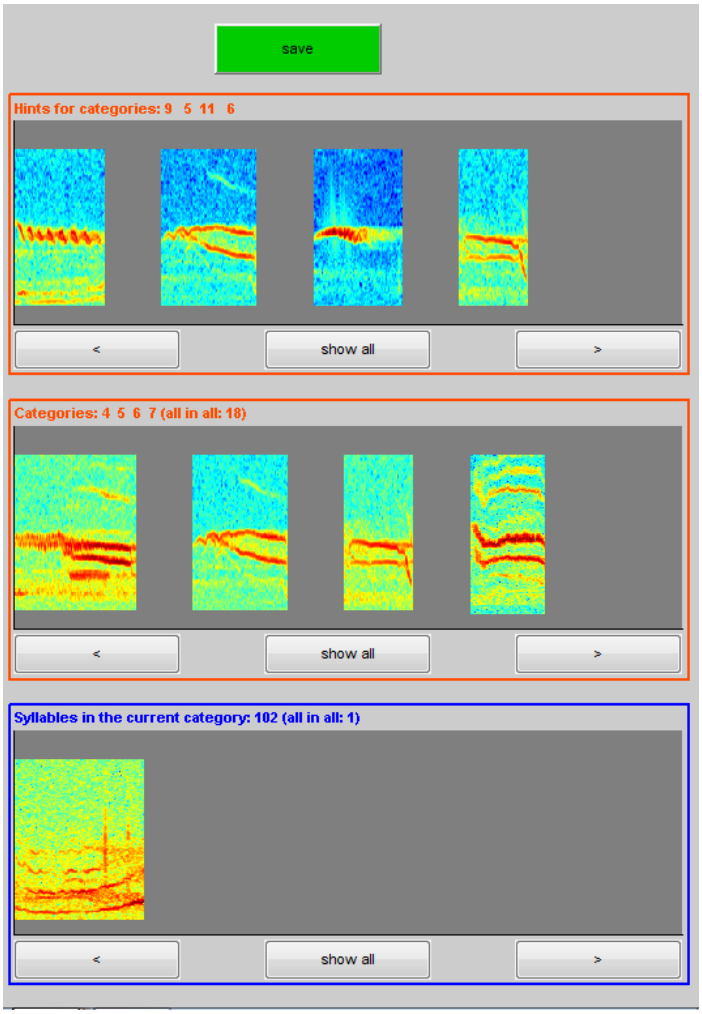

Figure S8. Part of the clustering GUI.

- in the middle of the right, the categories are shown in historical order
- on the bottom of the right, the syllables in the actual category are shown
- pressing “show all” buttons on the right, you will see all the categories or syllables related to that window – in case of categories you can select them too as actual category.
- use the “Save” button on the top right corner to save your work before changing individual or closing the program.

Step 6. Generate results of clustering (Figure S1)

Input files:

- “.mat” files (with the name of the recording) containing the categorization results

Usage and Output files:

- by pressing “sonograms by cat” button: “ficedula_sonograms_by_category.m” generate image files about the syllable sonograms in the “by category” folder
- by pressing “sonograms by rec” button: “ficedula_sonograms_by_recording.m” generate image files about the syllable sonograms in the “by recording” folder
- by pressing “results” button:
    - “results_categorized.mat” – categorization results in table format
    - “ficedula_make_summary_song.m” generates “summary_on_songs.csv” and “summary_on_recordings.csv” files with the basic acoustic parameters on song and recording level

Step 7. Prepare universal clustering (Figure S1)

Input files:

- “results_categorized.mat” containing the syllable categorization data

Output files:

- “database_syllables_measured_univ.mat” containing the position and measurement data what Step 8. necessitates
- “database_syllables_measured_univ_allinfo.mat” similar as the previous file but contains also all syllable data what Step 9 needs

Usage:

- press the “prepare” button

Step 8. Universal clustering (csoportositas5.m) (Figure S4)

Input files:

- database_syllables_measured_univ.mat containing the data representing the syllable groups

Output files:

- “universal.mat” containing the categorization results

Usage:

- press the “universal cluster” program (Figure S1), a new figure will appear (Figure S4)
- see step 5.

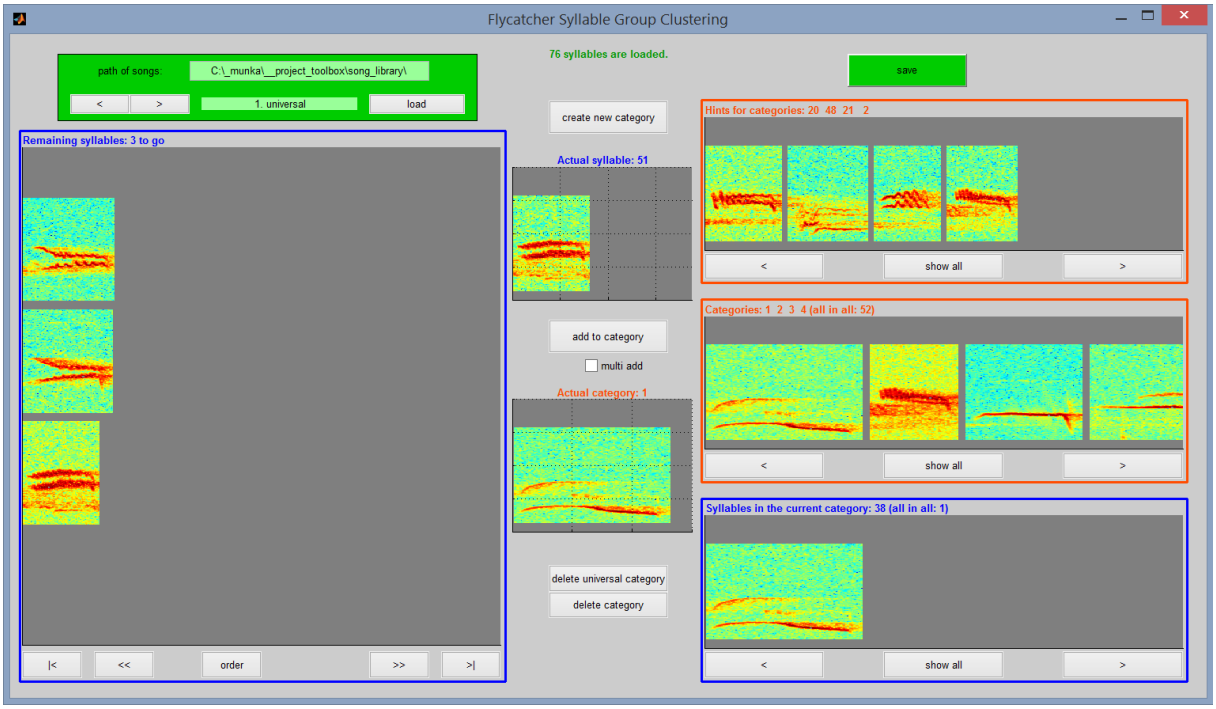

Figure S9. The GUI of the universal clustering program

Step 9. Generate universal clustering results (Figure S1)

Input files:

- “universal.mat” containing the categorization results

Usage and Output files:

- “results_categorized_univ.mat” – categorization results in table format
- by pressing “results” button: “ficedula_sonograms_by_category_univ.m” generate image files about the sonograms in the “by univ category” folder
- by pressing “sonograms by cat” button: “ficedula_make_summary_univ.m” generates “summary_on_universal_categories.csv” file with the frequency table by individuals and universal categories

Example analysis for the Ficedula Toolbox

For demonstrating the utility and the usage of the toolbox, we provide a little example. We prepared three short recordings containing several songs from our collared flycatcher recordings (rec1-rec3 in wav format in the "recording_library" folder). According to the instructions in the manual, we processed the three recordings and we show now the results generated by the toolbox. The example can be downloaded from https://github.com/zsebok/Ficedula. Download the folder named "Ficedula_Toolbox_example".

00. Setup of the working directories

First, you have to set up the directories in the program. Choose the subfolders

- _data_folder\
- _recording_library\
- _song_library\

According to that, 3 new files will appear in the main folder containing the path info.

- lastpath_data.mat
- lastpath_segment.mat
- lastpath_songcut.mat

01. Cutting the songs from the recordings

After cutting, four, five, and five songs were cut out respectively. Automatically a "results_songcut.mat" will be generated _data_folder.

Press "Refresh" button in the main menu to update information about the project.

02. Making song library

The songs cut out can be found in "song_library" folder, in the subfolders named after the recordings. The results can be found in the "songlibrary.csv" file (Table S1) and in "songlibrary.mat" file.

Table S1. Cutting results.

orig_filename	songfile	start (s)	end (s)
rec1.wav	rec1_001.wav	2.2867	5.7521
rec1.wav	rec1_002.wav	8.9698	12.5376
rec1.wav	rec1_003.wav	14.8488	17.3271
rec1.wav	rec1_004.wav	19.3427	22.9616
rec2.wav	rec2_001.wav	0.41515	3.9902
rec2.wav	rec2_002.wav	10.0592	12.9324

rec2.wav	rec2_003.wav	18.5718	21.2988
rec2.wav	rec2_004.wav	25.5149	29.9746
rec2.wav	rec2_005.wav	34.0779	38.6106
rec3.wav	rec3_001.wav	4.7181	10.2378
rec3.wav	rec3_002.wav	14.74	18.5782
rec3.wav	rec3_003.wav	23.4784	26.6367
rec3.wav	rec3_004.wav	30.6669	33.986
rec3.wav	rec3_005.wav	36.0998	40.1793

03. Segmenting the syllables from the songs

After segmentation, "results_segmentation.mat" is generated in struct format.

Press "Refresh" button in the main menu to update information about the project.

04. Measure syllables

The results files are: "database_syllables.mat" and "database_syllables_measured.mat", latter one is containing the acoustic measurements for each syllable in cell format. The latter file is also the input of individual clustering. Additionally, "inds.mat" file is generated containing the recordings names in randomized order that is determine the order of recordings in clustering.

05. Within-individual clustering

In clustering, separated files are generated for each recording (rec1.mat, rec2.mat, rec3.mat).

Press "Refresh" button in the main menu to update information about the project.

06. Showing the results of the clustering

Pressing "results" – generating "results_categorized.mat" file in cell format. Also "summary_on_recordings.csv" (Table S2) and "summary_on_songs.csv" (Table S3) files are generated.

Table S2. Summary of within-recording clustering results on recordings

recording	number of syllables	repertoire size	number of songs	song interval (mean ± SD)	song duration (mean ± SD)
rec1	42	17	4	5.7 ± 1.1	3.4 ± 0.5
rec2	62	24	5	8.4 ± 1.1	3.7 ± 0.8
rec3	75	35	5	7.8 ± 1.9	4.6 ± 0.8

Table S3. Summary of within-recording clustering results on songs

songfile	rec.	num. of sylls	versatility	meas_1 mean	meas_2 mean	meas_3 mean	…	meas_5 max
rec1_001.wav	rec1	11	9	0.19	5283	5097	…	7680
rec1_002.wav	rec1	12	7	0.19	5042	5072	…	6720
rec1_003.wav	rec1	8	4	0.20	4949	4860	…	6720
rec1_004.wav	rec1	11	7	0.21	5158	5071	…	6816
rec2_001.wav	rec2	13	11	0.20	5199	4970	…	7104
rec2_002.wav	rec2	10	8	0.21	5097	5213	…	7296
rec2_003.wav	rec2	9	7	0.21	5456	5749	…	8064
rec2_004.wav	rec2	15	8	0.22	4987	5005	…	7488
rec2_005.wav	rec2	15	11	0.21	5246	5005	…	7104
rec3_001.wav	rec3	19	12	0.20	4991	4719	…	7392
rec3_002.wav	rec3	15	12	0.19	5352	4851	…	7104
rec3_003.wav	rec3	12	10	0.21	5226	4840	…	6336
rec3_004.wav	rec3	12	10	0.20	5520	4992	…	7200
rec3_005.wav	rec3	14	8	0.21	5221	4978	…	7392

Beside of the tabulated data, sonograms of all the categories with their representative syllables (first syllable in each category) can be generated (Figure S10) with buttons “sonograms by rec.” and “sonograms by cat.” Respectively. The results can be found in the “data_folder”.

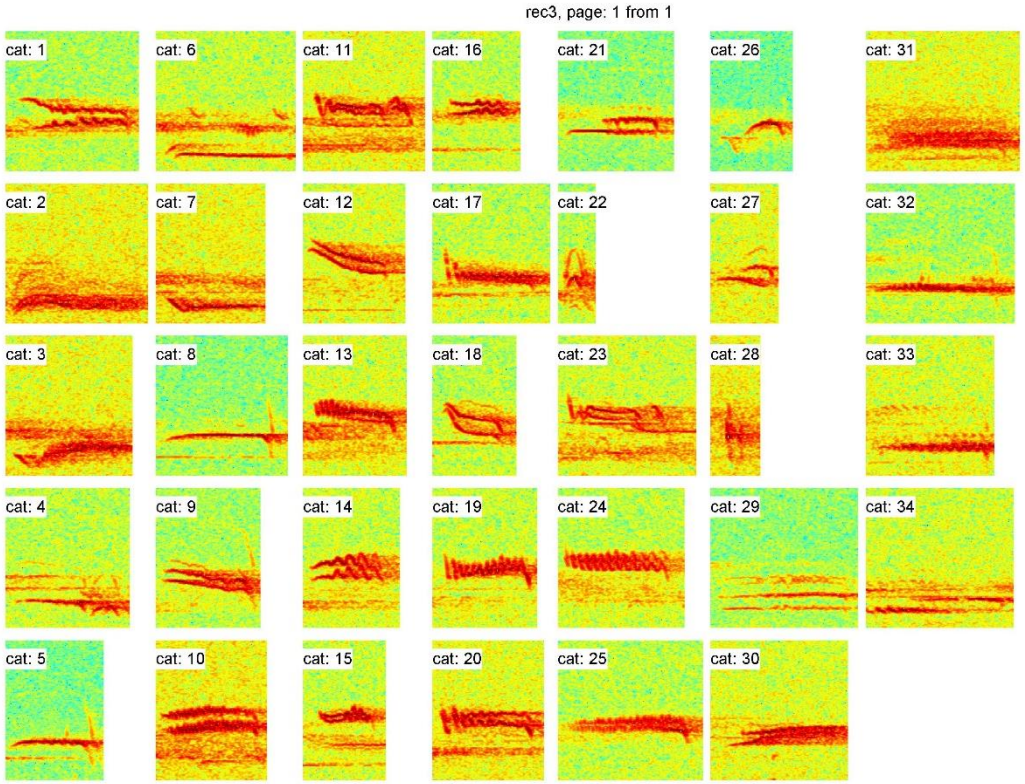

Figure S10. Sonograms of all the categories from the third individual after clustering.

07. Prepare between-individual clustering

Two new files will be generated in cell format: “database_syllables_measured_univ_allinfo.mat” and ”database_syllables_measured_univ.mat”. The latter one is the input of between-individual clustering.

08. Between-individual clustering

In the clustering, the data is saved in “universal.mat” file.

09. Clustering results

By pressing “results”, a file named “results_categorized_univ.mat” can be generated containing all information in cell format. The data are summarized in the “summary_on_universal_categories.csv” file (Table S4).

Also, the sonograms of all the syllables ordered in the universal categories can be saved (Figure S11) by pressing “sonograms by cat.” button. All the sonograms can be found in the “sonograms” subfolder inside the “data_folder”.

Table S4. Summary of between-recording clustering results.

	cat1	**cat2**	**cat3**	**.**	**.**	**cat54**	**sum of categories**	**sum of syllables**
rec1	0	0	2	.	.	0	14	42
rec2	4	1	2	.	.	0	22	62
rec3	4	0	4	.	.	1	32	75
sum of individuals	2	1	3	.	.	1		
sum of syllables	8	1	8	.	.	1		

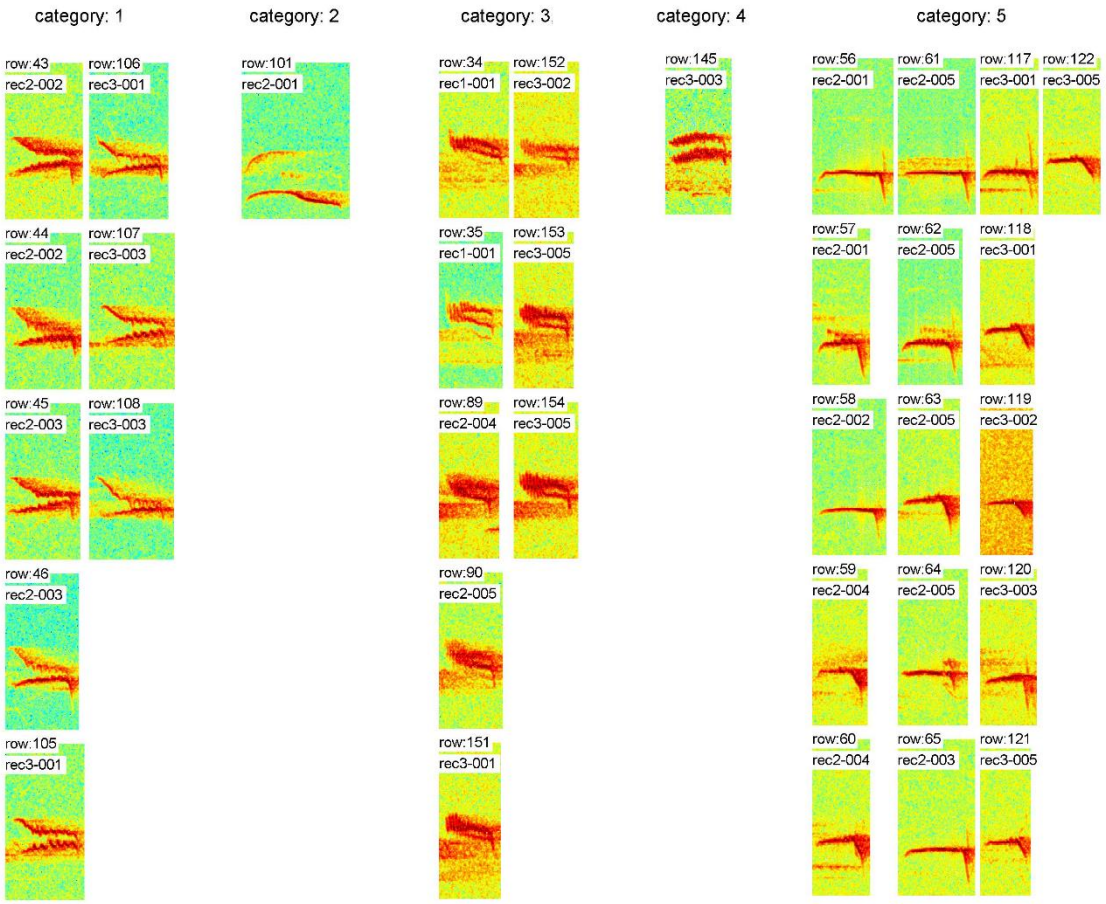

Figure S11. Sonograms of the syllables belonging to the first five universal categories.