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New bat species and records for the Adriatic Islands Vis and Biševo (Croatia)

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Abstract. The bat fauna of the Adriatic islands is relatively poorly known. Seven species were documented so far on the remote Adriatic islands of Vis and Biševo (Croatia). This study aims to increase knowledge on the bat communities on these islands. Bat echolocations were recorded between 30 April and 11 May 2018 at seven sites showing bat presence. Calls were identified to genus and species level where possible, which confirmed the presence of eight bat taxa on the islands. Three taxa were observed for the first time: *Tadarida teniotis*, *Myotis* sp. and *Nyctalus* sp. Results of this study increase the number of documented bat taxa on Vis from seven to ten and on Biševo from one to six. This study highlights the importance and benefits of utilizing passive acoustic devices at remote locations. Our findings suggest that bat communities and diversity might also be understudied on other islands in the Mediterranean, which could have important implications for bat conservation.

Keywords. Bioacoustics, islands, echolocation calls, bat species distribution, Chiroptera.

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Introduction

Islands represent combinations of unique physical and biological features, such as size and increased population density, reduced species diversity and altered life-histories (Fleming & Racey 2013), all of which impact the species communities living on them. Islands may also be used as stepping stones for dispersal (Biollaz *et al.* 2010; Mifsud & Vella 2019). Bats provide a range of ecosystem services (Kunz *et al.* 2011) and are considered highly relevant indicators of ecosystem changes (Jones *et al.* 2009; Newson *et al.* 2009; Haysom *et al.* 2014). Information on the presence and distribution of bat species on island is important for setting up conservation plans and assessments of (meta)population viability (Mifsud & Vella 2019).

More than 30 bat species occur in the European part of the Mediterranean basin (Davy *et al.* 2007) of which 17 species have been reported from the Adriatic islands (Dulić & Tvrtković 1970; Pavlinić *et al.* 2010). However, the bat diversity on the Adriatic islands of Croatia is relatively poorly known.

The present study focuses on the bat fauna of Vis (including the nearby small islet of Ravnik since in a biogeographical context, a bat can easily cross to the islet) and Biševo, some of the most offshore islands of the archipelago. Dulić & Tvrtković (1970) reported four species for Vis: *Rhinolophus ferrumequinum*, *Myotis emarginatus*, *Pipistrellus kuhlii* and *Hypsugo savii*. Later, *Plecotus kolombatovici* (Dulić 1980), *Rhinolophus hipposideros* and *Miniopterus schreibersii* (Pavlinić *et al.* 2010) were added to the species list of the island (totaling seven species). Only one bat species, *R. ferrumequinum* was reported for Biševo (Pavlinić *et al.* 2010).

In the spring of 2018, we visited the islands to survey the bat communities through acoustic monitoring and visual inspection of the survey sites. This paper describes the bat biodiversity of these islands, including taxa reported for the first time, testing the hypothesis that the use of acoustic monitoring can produce more reliable estimates of bat biodiversity.

Material and methods

Surveys were carried out between 30 April and 11 May 2018.

Study Area

The study area covered three sites on the island of Vis, one on the islet of Ravnik and three on the island of Biševo (Fig. 1; Table 1). The sites represented a variety of habitats (from coastal cliffs to meadows and urban areas, see following paragraphs) and were chosen based on the presence of bats, caves or

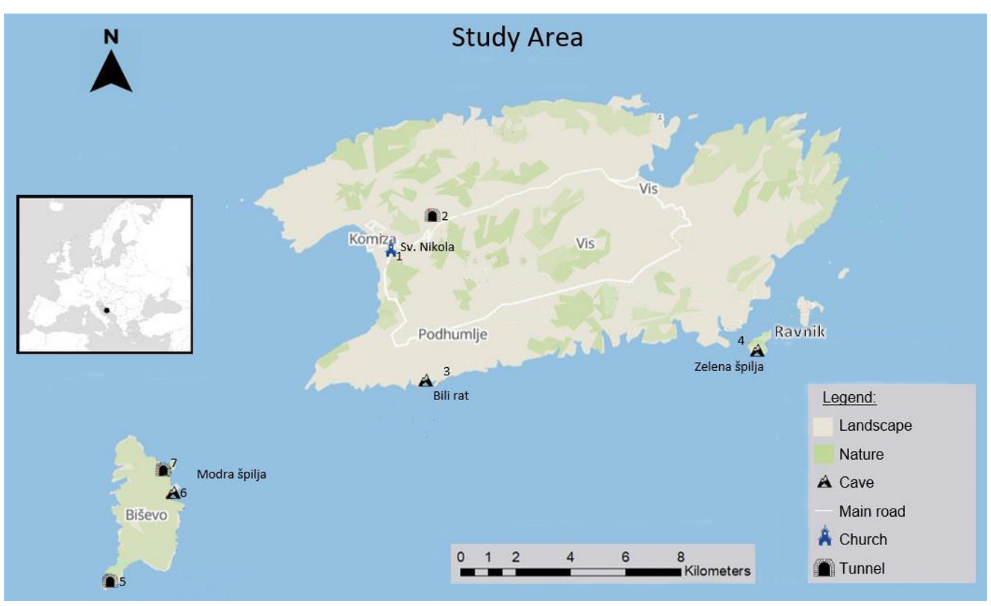

Figure 1 – Study area: the islands of Vis, Ravnik an Biševo. Study sites are indicated with respective numbers (for details see Table 1). Caves, tunnels and the church are shown with pictograms and the main road is visualized in white.

TABLE 1

Location (nr.), coordinates, type of site, sampling duration (nights) and corresponding dates.

Island	Location number	Coordinates	Site type	Sampling duration	Date
Vis	1	43°2′26″ N, 16°5′45″ E	Church area	3 (4 detectors)	(1–3rd May)
	2	43°2′50″ N, 16°6′36″ E	Tunnels	2	(3–4th May)
	3	43°0′30″ N, 16°6′45″ E	Cave system	2 (2 detectors)	(1–2nd May)
Ravnik (Vis)	4	43°0′56″N , 16°13′27″ E	Cave system	1	(8th May)
Biševo	5	42°57′20″ N, 15°59′54″ E	Tunnels	2	(7–8th May)
	6	42°58′51.8″ N 16°01′19.6″ E	Cave system	2	(7–8th May)
	7	42°59′16″ N, 16°1′16″ E	Tunnels	1	(7th May)

tunnels. When placing bat recorders (as explained further; during daytime), all sites were explored and any visuals of bats were recorded. Tunnels and the church were accessed on foot (sites 2, 5, 7 and 1, respectively). The sea caves (site 4 and 6) were accessed by boat. Crevices at site 3 were too narrow to investigate thoroughly. Sites are described in detail below.

Three sampling sites on Vis

1) The area around Sv. Nikola (St. Nicholas) church, Komiža (Vis). The church is located on a small hill, surrounded by multiple lantern poles used to light the building and the hill at night. Almost every night, bats could be seen feeding on the many insects that were attracted to these lights. The bell tower and an old storage room in the church were investigated during daytime, but no bats were seen at that time. Bat detectors were placed on four locations around the hill, always directed towards open areas: towards the graveyard, a field, an open meadow and a meadow below a bridge. Multiple trees and shrubs were present in this area.

2) Abandoned military tunnels, slightly east of Komiža at the end of a sidetrack of the eastern main road (Vis). Bats were observed here whilst exploring during daytime. The entrance opens at the bottom of a cliff and this corridor leads to several large rooms. A small tunnel leads outside the back and a steep upwards, cave-like tunnel leads to two holes opening high up in the cliffside (a drop of at least 30 m and 40 m, respectively); a detector was placed at the lower one, facing outwards. The area below contained deciduous trees and relatively dry meadows.

3) Two spots with openings in the rock. Both were located in the eastern arm of the sea inlet leading to Pritisčina public beach (south of Podhumlje). One bat recorder was placed at a shallow and relatively large rock indent, which reaches the sea on the northern side. A substantial crevice led further into the rock. Another detector was placed near several rather big holes, which were present in the cliffs on the southern side of the inlet-arm. Both detectors were in close proximity of the sea and the direct surroundings had limited vegetation.

One sampling site on Ravnik

4) The "Zelena Špilja" (English: Green Cave) is located on the island Ravnik. It is found at the most southwestern part of the islet and its entrance faces southeast. It is a rather large sea cave, which can be entered by boat. The bottom of the cave does not reach above the water level. It is a large single cavity, and the ceiling shows many edges and notches where bats might cling to and hide themselves. It was difficult to place a bat recorder inside the cave. Therefore, a bat recorder was instead placed outside above the cave entrance, in an area covered with dry shrubs.

Three sampling sites on Biševo

5) Abandoned underground military tunnel-complex at the most south-western part of Biševo. The tunnel openings surface at sites which were originally used to station military artillery. Entrances are located in dry habitat with many shrubs and few trees. A relatively large bat flew through the tunnels. A detector was placed at a dead end of a corridor, at an opening reaching a steep seaside cliff with limited vegetation (+10 m above the sea surface at that time).

6) The "Modra Špilja" (English: Blue Cave) is located in the bay of Balun, on the eastern side of the island. This dark sea cave has large inside cavities and is often visited as a touristic attraction. There was no possibility to place a recorder at the cave entrance. A bat recorder was instead placed above the cave in an area containing many shrubs.

7) A short tunnel, near the northern tip of the west side of Bay of Balun. Some substance resembling bat guano was found at the end. Only a single tree and very limited vegetation was present in the rocky environment. A bat detector was placed at the entrance and faced the seaside cliffs at 20 m distance.

Recording and analysis

Bat vocalizations were automatically recorded between 6 p.m. and 7 a.m. (13 h) – monitoring the whole night from dusk till dawn – with Petterson D500X ultrasound bat detectors (frequency range: 500 kHz; trigger level: 30; input gain: 45; HP filter: on). Bat detectors were placed during daytime and directed towards open spaces to ensure maximum exposure to passing bats. Each location was monitored for one to three nights between April 30th and May 11th (Table 1). At the moment of detector placement, there were relatively low wind speeds and warm temperatures.

Recordings were identified using Sonobat (version 4.5.0 Universal) (Szewczak 2015) software. Only recordings with clear bat vocalizations were used for identification. Recordings that were unclear or could not be identified are still included in the estimated total number of recordings per site. Identification was based on a variety of characteristics: call frequency parameters (end frequency, critical frequency, frequency of max energy), shape, duration, repetitivity and alternation (Russo & Jones 2002; Obrist *et al.* 2004; Papadatou *et al.* 2008; Russ 2012; Jansen & Limpens 2014; Barataud 2015). Recordings are available from the authors upon request.

Results

In total, 1656 bat echolocation sequences were recorded at the surveyed sites. Most were recorded at the Sv. Nickola church (site 1) and the nearby military tunnel complex (site 2). Vicinities of other sites showed much fewer vocalizations in relation to sampling intensity. No calls were recorded by the northern bat detector at site 3. In the same location, all calls were recorded by the southern detector. Few calls were recorded on Biševo.

Visual observations only provided limited information, which is why the main focus of the current study lies on the acoustic recordings. Relatively large bats with light-colored fur on the underside were

TABLE 2

Distribution of bat species recorded at survey sites in this study, over Vis and Biševo. Total recordings are the total number of recordings made at a given site and thus also include recordings that could not be assigned to any of the shown taxa. * = reported for the first time on an island. Numbers represent recordings for which correct identification is sure. At site 2, there were at least 100 recordings for *T. teniotis* as well as 100 for *N. noctula*/*lasiopterus*, the latter being surely underestimations since distinction between these two species is not always possible.

Island and location	Total species	Total recordings	*Rhinolophus ferrumequinum*	*Pipistrellus kuhlii*	*Hypsugo savii*	*Plecotus sp.*	*Miniopterus schreibersii*	*Tadarida teniotis*	*Myotis sp.*	*Nyctalus noctula/ lasiopterus*
Vis	**8**	**1828**	**15**	**573**	**219**	**14**	**273**	**> 301***	**2***	**> 100***
1	4	777	–	386	1	–	254	199	–	–
2	7	1033	15	187	211	14	17	> 100	–	> 100
3	5	18	–	–	7	–	2	2	2	–
Ravnik (Vis)	**1**	**1**	–	–	–	–	–	–	**1***	–
4	1	1	–	–	–	–	–	–	1	–
Biševo	**6**	**37**	**3**	**10***	**3***	**3***	–	**6***	–	**1***
5	5	20	2	9	1	3	–	3	–	1
6	4	4	1	1	1	–	–	1	–	–
7	2	3	–	–	1	–	–	2	–	–

Figure 2 – Photographs of *Plecotus* sp. (left) and *Rhinolophus* sp. (right) at site 2 (military tunnels). (© Frederik De Wint).

hunting on flying insects around the church (site 1). They produced low frequency vocalizations audible with the naked ear and therefore might have been *Tadarida teniotis*. Another large bat was flying in the tunnels of site 4. Four roosting individuals were found in the tunnels of site 2 (three *Plecotus* sp. and one *Rhinolophus* sp.; Fig. 2).

In total, vocalizations of eight bat taxa were recorded in this study, three of which had not yet been recorded in the research area (Table 2).

Previously documented species

1. *Rhinolophus ferrumequinum* (Schreber, 1774) (Appendix Fig. 1)

This species produces typical high frequency 'Constant Frequency (CF)' calls which can easily be distinguished from other *Rhinolophus* species (Barataud 2015). The global and national conservation status are "Least Concern (LC)" (Piraccini 2016) and "Near Threatened (NT)" respectively (Tvrtković 2006).

2. *Pipistrellus kuhlii* (Kuhl, 1817) (Appendix Fig. 2)

There is a small overlap with the call frequency range of *H. savii* (Barataud 2015) but call frequency ranges in our recordings were higher than the overlapping zone (end frequency 34.4–42.2 kHz). A rather large frequency overlap exists as well with *P. nathusii*. Luckily, social calls were also recorded which confirmed presence of *P. kuhli* (Russo & Jones 1999). The global and national conservation status is "Least Concern" (LC) (Tvrtković 2006; Juste & Paunović 2016b).

3. *Hypsugo savi* (Bonaparte, 1837) (Appendix Fig. 3)

There is a small overlap with the call frequency range of *P. kuhlii*, but the calls of *H. savii* we recorded were lower than this overlapping zone (Barataud 2015). The global and national conservation status of this species is "Least Concern" (LC) (Juste & Paunović 2016a; Tvrtković 2006).

4. *Plecotus* sp. (Appendix Fig. 4)

Our recordings of individuals match the echolocation of *P. austriacus* and *P. kolombatovici* which cannot be distinguished based on the current available knowledge (Dietz & Kiefer 2016; Wilson & Mittermeier 2019).

5. *Miniopterus schreibersii* (Kuhl, 1817) (Appendix Fig. 5)

Social calls of this species were recorded in this study, which were necessary to discern this species from *P. pipistrellus* and *Pipistrellus pygmaeus* (Russo & Papadatou 2014). The species conservation status is "Vulnerable" (VU) on a global scale, which is nearly identical with Europe as the main distribution range covers this continent (Gazaryan *et al.* 2021). It is "Endangered" (EN) in Croatia (Tvrtković 2006).

Newly documented species

6. *Tadarida teniotis* (Rafinesque, 1814) (Appendix Fig. 6)

The very low frequency calls are characteristic for this species in Europe (Zbinden & Zingg 1986; Barataud 2015; Jamault *et al.* 2018). Flat 'Quasi Constant Frequency (QCF)' calls presented end frequencies between 9.5–12 kHz. Steep and higher frequency calls are more difficult to discern since they overlap with frequency ranges of *Nyctalus* spp. (Barataud 2015). *Tadarida teniotis* has been documented earlier on the islands of Šolta and Korčula (Kolombatović 1887; Dulić & Tvrtković 1970). We have recorded this species at more locations than any of the other observed species. The global and national conservation status is "Least Concern" (LC) (Tvrtković 2006; Benda & Piraccini 2016).

7. *Myotis* sp. (Appendix Fig. 7)

Myotis emarginatus is the only species of *Myotis* reported to occur on Vis (Pavlinić *et al.* 2010). One of our recordings could have been produced by this species. However, the other two recordings show characteristics that differ from those published for *M. emarginatus* (Russo & Jones 2002; Papadatou *et al.* 2008; Barataud 2015) and belong to a different yet unreported *Myotis* sp. However, the available knowledge as well as our data concerning the acoustics of *Myotis* are not sufficient to ensure correct identifications to the species level.

8. *Nyctalus noctula/lasiopterus* (Appendix Fig. 8)

This is the first time a species of *Nyctalus* is recorded on the islands. The observed end frequencies (ranging up to 20.6 kHz) are higher than the end frequency range of *T. teniotis* calls (Barataud 2015; Chris Corben personal communication). The steep calls (bandwith > 5 kHz) are indicative of echolocation by *Nyctalus noctula* or *N. lasiopterus* produced in clutter (Barataud 2015). Our recordings also contain sequences with alternation of 'high' and 'low' calls, which is indicative for *Nyctalus* spp. Further identification to the species level was not possible.

Discussion

With the exception of *Rhinolophus hipposideros* and *Myotis emarginatus* (Pavlinić *et al.* 2010), all bat species that were known to occur on Vis have been recorded in this study. In addition, we report the presence of previously undocumented species on Vis (*T. teniotis*, unknown *Myotis.* sp. and *Nyctalus* sp.), Ravnik (*Myotis* sp.) and Biševo (*P. kuhli*, *H. savii*, *T. teniotis*, a *Nyctalus* sp. and *Plecotus* sp.) which brings the total to ten bat taxa on Vis, one on Ravnik and six on Biševo.

Plecotus kolombatovici is the only species of the genus that has been reported on Vis, observed in abandoned military tunnels and also caught with mist nets above lakes (Tvrtković 2006). Dulić & Tvrtković (1970) mentioned *P. auritus* (not to be confused with *P. austriacus*) for other islands in the Adriatic archipelago. However, Tvrtković *et al.* (2005) reviewed the observations of all species of *Plecotus* in Croatia and concluded that *P. auritus* does not occur on Croatian islands. They also stated that only *P. kolombatovici* is found on Croatian islands, a species described after the publication of Dulić & Tvrtković (1970). It is therefore most likely that our recordings are produced by *P. kolombatovici.* The lowland, coastal and regional characteristics of the studied islands also better suit the known ecology, habitat and geographical distribution of *P. kolombatovici* than those of *P. austriacus* (Tvrtković *et al.* 2005). The unknown *Myotis* sp. recordings show end frequencies around 30 kHz, while those of *M. emarginatus* have been reported to end around 38 kHz (Barataud 2015), 41.2 kHz (Papadatou *et al.* 2008) or 42.6 KHz (Russo & Jones 2002), respectively. In addition, the call frequency bandwidth and duration are rather short and long, respectively, compared to those of *M. emarginatus*. The call sequences point in the direction of *Myotis daubentonii* or *Myotis capaccinii* (Van De Sijpe 2011; Barataud 2015), but might also include another *Myotis* species.

We recorded three taxa that have previously not been reported by bat surveys, namely *T. teniotis*, *Nyctalus* sp. and *Myotis* sp. On the other hand, we could not confirm the presence of two species reported by previous studies: *R. hipposideros* and *M. emarginatus* (Pavlinić *et al.* 2010). This might be due to the deployment of different sampling techniques (e.g., trapping versus acoustic monitoring), but also different timing (period of the year) of the surveys.

Most likely, *T. teniotis* was overlooked during previous capture-based studies due to its behavior. *Tadarida teniotis* tends to fly and forage on high altitude (Rydell & Arlettaz 1994). Such species are often missed by standard capture methods and are more commonly observed through acoustic monitoring (Kalko *et al.* 1996; O'Farrell & Gannon 1999).

Our results indicate that the bat fauna on Biševo comprises a subset of the diversity on Vis. This is expected since smaller, adjacent islands further away from the mainland tend to hold similar yet less diverse bat species assemblages (Meyer & Kalko 2008). Judging by the lack of bat survey data from Biševo, it is furthermore likely that this island had been severely understudied. Only one species (*R. ferrumequinum*) has been reported by a previous study (Pavlinić *et al.* 2010) whilst we observed six.

Our results illustrate the need to update the knowledge of the bat community composition on the Adriatic islands, preferably by incorporating acoustic monitoring. Other smaller, relatively undisturbed remote islands in the Mediterranean might also be inhabited by a larger variety of bat species than presently known.

Additional research on the Adriatic islands could extend known distribution ranges of a variety of bat species. It is also possible that these islands act as a contact zone between many separate cryptic lineages found in Italy and the Balkans (Bogdanowicz *et al.* 2015; Çoraman *et al.* 2019), which should be further investigated.

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Appendix

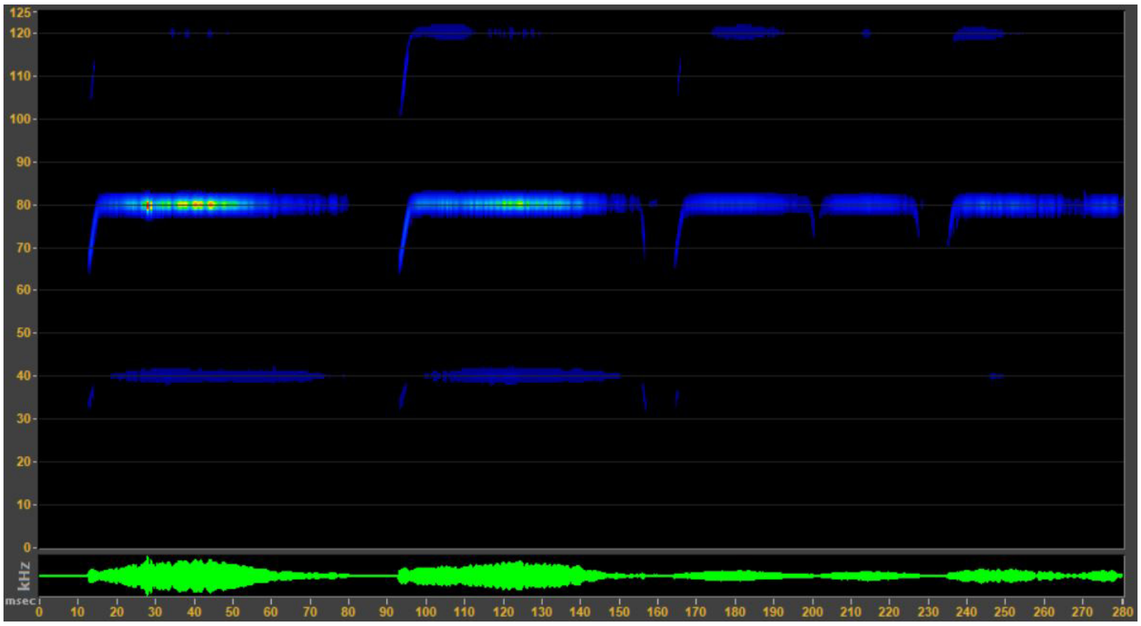

Figure 1 – *Rhinolophus ferrumequinum* (site 5, selection view).

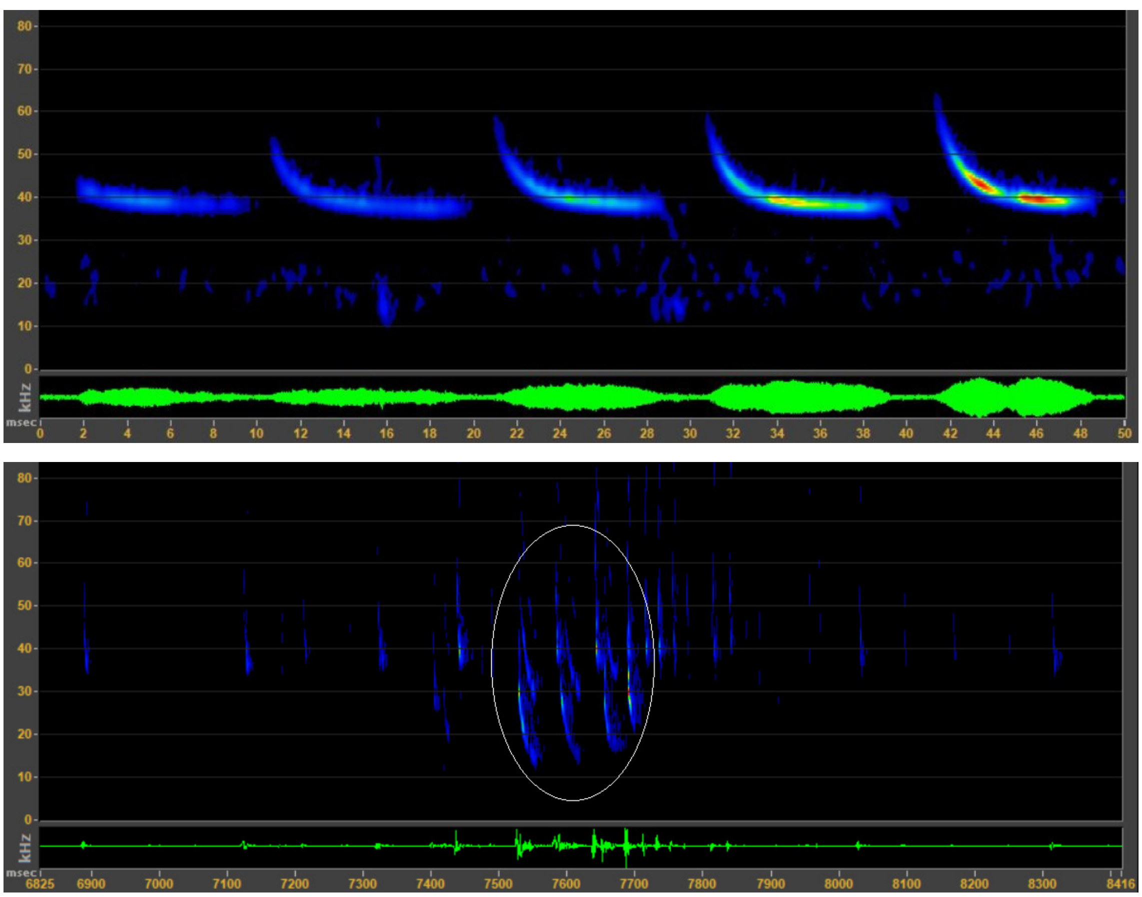

Figure 2 – *Pipistrellus kuhlii* (site 1, selection view) and its social calls (site 2, realtime view).

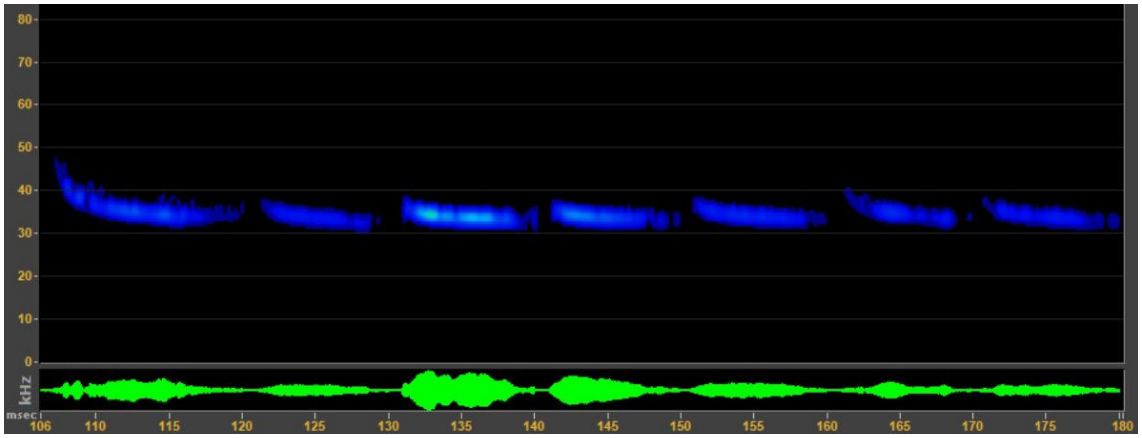

Figure 3 – *Hypsugo savii* (site 3, selection view).

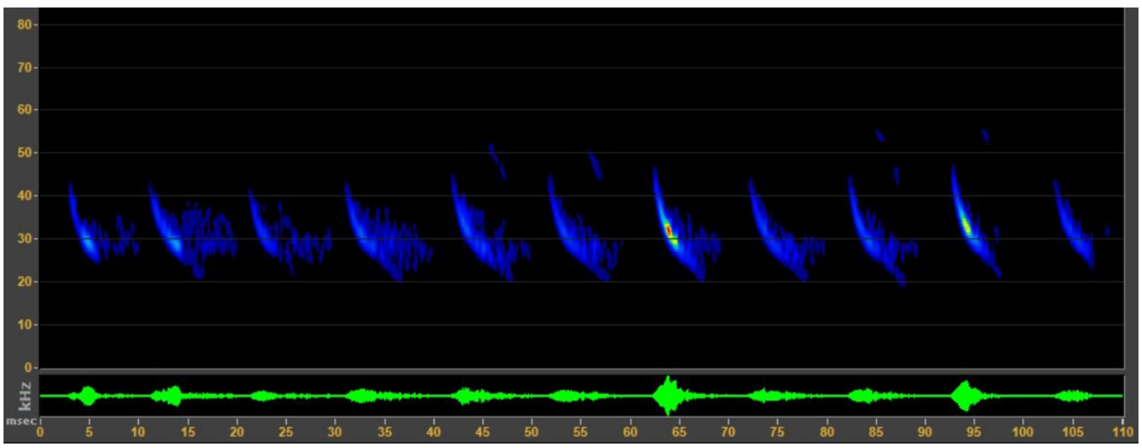

Figure 4 – *Plecotus* sp. (site 5, selection view).

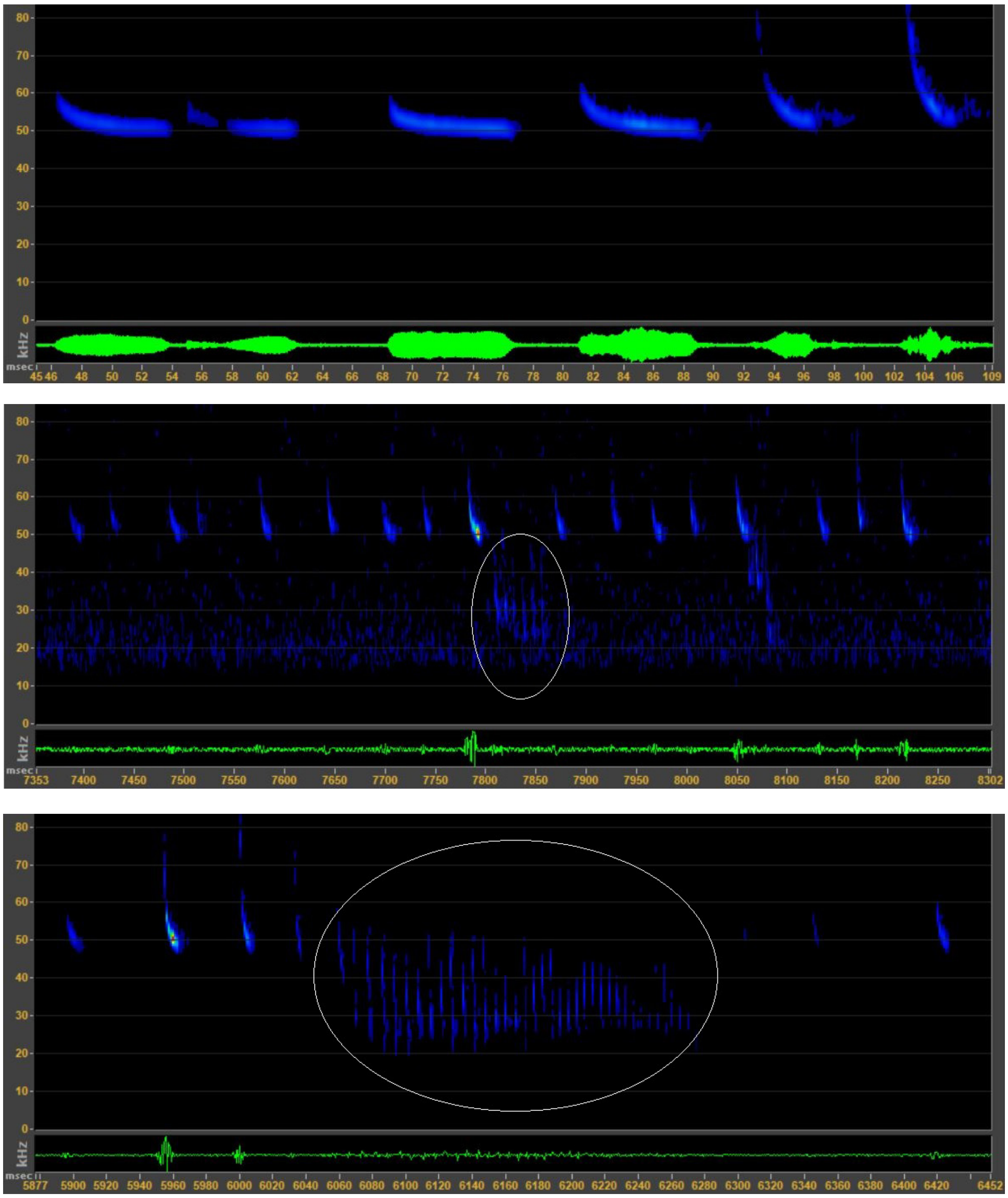

Figure 5 – *Miniopterus schreibersii* (site 1, selection view) and social calls indicated (site 1, realtime view).

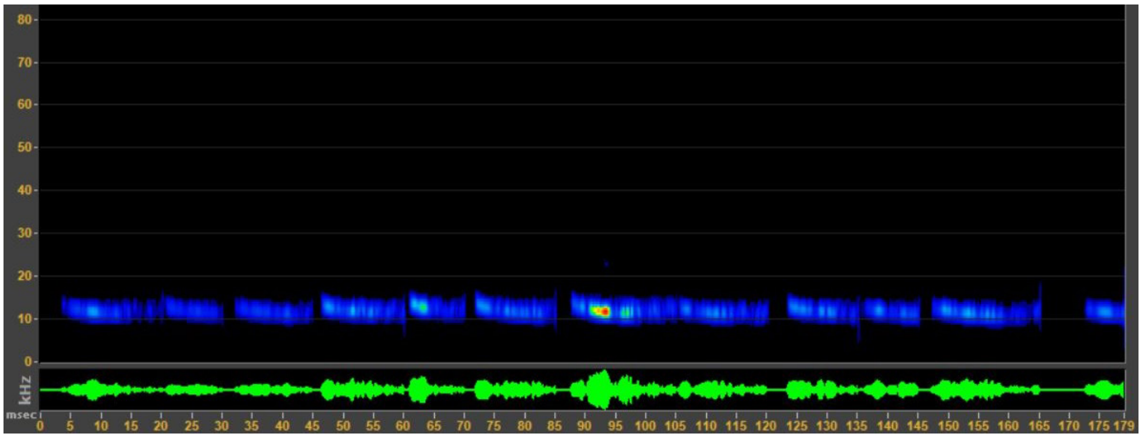

Figure 6 – *Tadarida teniotis* (site 1, selection view).

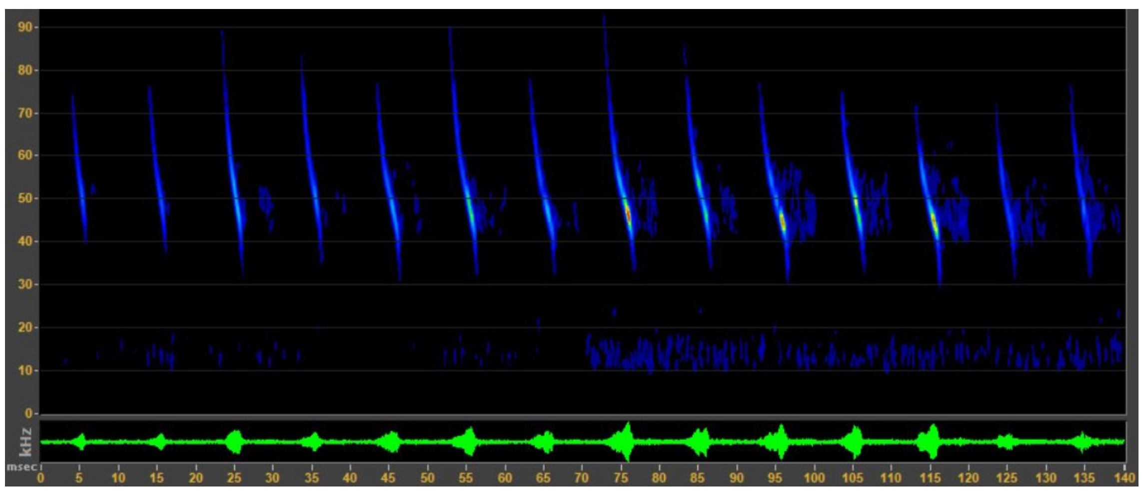

Figure 7 – *Myotis* sp. (site 3, selection view).

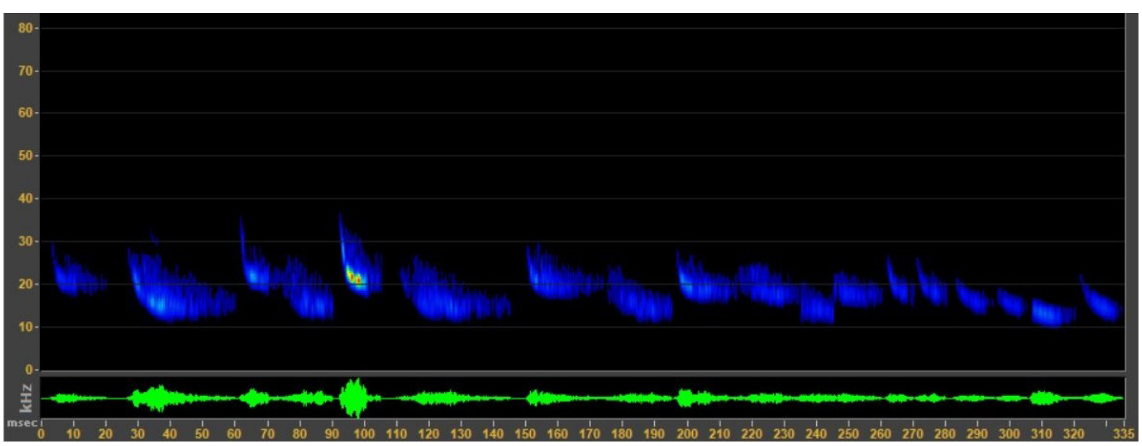

Figure 8 – *Nyctalus* sp. (site 5, selection view).