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ORIGINAL ARTICLE

The skynet, a new method to capture bats over water

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ABSTRACT

When monitoring bats, the greatest yield in capture rate for survey effort can often be found in riparian and lentic habitats. However, capturing bats over large bodies of water is usually challenging due to the logistics of deploying equipment and extracting bats whilst ensuring the safety of surveyors. We present a novel technique – the "skynet" – as one solution to this problem, allowing fast and safe deployment of a suspended mist net between two anchor points over open water. Preliminary fieldwork in a Croatian scrub-dominated landscape yielded a capture of 22 bats of five species over a 1600 m^2 pond. Our results demonstrate that the method is effective compared to a simultaneous net positioning on the bank of the same water body, which yielded no bats. System design and recommendations for bespoke alterations, alternative equipment options, and future investigations are presented here.

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INTRODUCTION

When undertaking mist-netting surveys for bats, some landscapes present challenges, particularly when they are characterised by a high degree of homogeneity among habitats or a lack of flight corridors and overhanging vegetation (Braun De Torrez et al. 2017). Additionally, mist-netting in open areas can be deleteriously affected by moonlight (Barlow 1999) and wind (Kunz & Kurta 1988), both of which can increase the detectability of mist nets by bats (Braun De Torrez et al. 2017). In such situations, targeted surveys at features of ecological interest to bats (linear features, roosting sites, riparian habitats, water bodies) can prove to be a more effective use of time and resources with regard to survey effort (Kunz & Kurta 1988, Barlow 1999). A number of European species have a documented affinity with riparian and lentic habitats, including *Myotis capaccinii*, *Myotis dasycneme*, *Myotis daubentonii*, and *Pipistrellus nathusii* (Dietz & Kiefer 2014). However, the use of water bodies is not restricted to these species; all bats require drinking water, and most bats will utilise water sources both for drinking and foraging purposes (Korine et al. 2016) and as movement corridors (Lintott et al. 2015). Moreover, the availability of water is directly related to reproductive success in insectivorous bats due to the increased requirements for drinking by lactating females (Adams & Hayes 2008).

While riparian and lentic habitats are among the most productive capture sites (Barlow 1999), trapping bats in mist nets over open water is challenging (Haarsma & van Alphen 2009, Middleton 2017) due to the logistics of access in order to (i) position nets effectively, (ii) extract captured bats quickly, and (iii) ensure the safety of surveyors. The seminal work on mist net design for fieldwork (Kunz & Kurta 1988) presents methods for the deployment of mist nets over shallow ponds and streams accessible on foot and suggests that larger bodies of water can be accessed using rubber rafts. Barlow (1999) suggests the use of tree-climbing equipment and techniques (e.g., slingshot attached to a lightweight throwline) to mount lines upon which nets should be suspended in woodland canopies. In subsequent years, this work has been built on with various innovative designs, including those reliant on what Haarsma & van Alphen (2009) refer to as the "hoist method". Such methods include a square-framed net trap (Middleton 2017), a mechanical gate-like support system that relies on a pivot system for retrieval of bats (Nelson et al. 2012), and complex methods for trapping ducks in mist nets over fast-flowing water (Smith et al. 2015). Systems have also been designed for *in-situ* (i.e., over-water) extraction of birds by utilising deepwater anchors or floating rafts to support nets (Burns et al. 1995), and also for bats utilising static "tubing" net systems (Haarsma & van Alphen 2009). The latter approach has advantages but is hindered by access and safety problems as it relies on surveyors being in the water body either on boats as recommended by Kunz & Kurta (1988) or utilising chest waders and/or floatation devices. For human safety reasons, such *in-situ* methods are not suitable for fast-flowing or deep water, for water bodies containing debris, sharp rocks, or populations of dangerous animals, and those with biosecurity considerations such as the presence of invasive species.

This study proposes a design for an over-water mist net system (the "skynet") utilising simple and cost-effective equipment to create a tensioned line from which the net can be suspended and manoeuvred, facilitating the effective capture of bats flying over water and their quick and safe extraction on land. This method differs from the above in that it entirely eliminates the need for fieldworkers to enter the water, allowing for trapping over deep or fast-flowing water bodies (without the associated health and safety risks) or in areas with biosecurity considerations. In addition, a comparative assessment of the efficacy of the suspended skynet with a simultaneously deployed terrestrial mist net (with supplementary acoustic monitoring) was undertaken, based on preliminary data from three surveys.

MATERIALS AND METHODS

Study site

The study site was a 45 m-diameter, 1600 m^2 area rural pond in the village of Kistanje, Šibenik-Knin County, Croatia (43.978276, 15.955261) on a plateau west of the Krka Gorge at approximately 250 m.a.s.l. This area experiences a hot-summer Mediterranean climate, *Csa* on the Köppen-Geiger system (Peel et al. 2007), with temperatures at Knin averaging 23 °C in July and 5 °C in January (Krka National Park Authority 2021). Precipitation averages 1078 mm per year, with most falling between October and February (Krka National Park Authority 2021). The immediate surroundings of the study site include areas of rough pasture, with the wider landscape largely comprising rough Mediterranean scrub (*Juniperus oxycedrus, Carpinus betulus*, and *Quercus cerris*). Prior records of Chiroptera for this study site and its immediate surroundings include three species (*Myotis emarginatus, Myotis nattereri, Pipistrellus kuhlii*), which were captured during two-hour mist-netting surveys on 10 and 13 July 2021. These surveys were done using a standard 6 × 2.4 m mist net, which was placed perpendicular to the water's edge. The species list for the nearby Krka National Park comprises a total of 23 extant species comprising 19 species of Vespertilionidae, three species of Rhinolophidae, and one species of Molossidae (Hamidovic et al. 2015), with the majority of species records attributed to sites within the Krka Gorge and nearby cave and mine systems (Marguš 2010).

Suspended net design

The system was built around a tensioned rope that spanned the target water body. Here we present some guidelines to set and deploy the skynet:

1. A rope was anchored on one side over the water with a termination knot (i.e., a bowline knot tied around a tree), while the other end on the other side was also terminated through a climbing belay or descending device. Using this device, the rope can be pulled through to remove the slack and create a tensioned line (TL), much like a zip-line (Fig. 1a). This can be achieved in its most basic form by simply using a carabiner and an Italian hitch, but the use of a specialist climbing device (Fig. 1a, 2a) is recommended for ease of use and better tension. Additional tension can be added to the system utilising mechanical advantage in a 3:1 haul (Fig. 2c) or "Z-haul" and pulling through the remaining slack. This is especially recommended when the distance being spanned is greater than 10 m as a tighter rope reduces the drop in the rope when weighted by the net and poles.

2. Once the TL was in place, the net and poles were attached. For this trial study, two Eurocor 6 m telescoping fishing poles (Cormoran, Gröbenzell, Germany) were used, which were extended up to a height of 215 cm. Purpose-built telescopic poles for mist-netting exist, such as Ecotone 3.4 m telescoping mist net poles (Ecotone, Gdynia, Poland). However, any sturdy support (telescopic or fixed-length) suffices and may be used to reduce equipment costs.

3. Weights were also added to the bottom of the poles to ensure that they hung vertically and were less likely to be affected by wind. Whilst the tensioned ropes and weights mitigate the effects of wind on the skynet somewhat, the skynet is more susceptible to wind movement than a net attached to fixed poles, particularly if the poles are lightweight. For this study, additional stability was achieved by securing rocks to the base of the poles using duct tape. However, a more permanent weight solution could easily be fashioned. Heavier poles (e.g., Ecotone telescopic mist net poles) would not require weights. Notwithstanding, as with any trapping study, the use of mist nets in moderate-to-high winds is not recommended (Collins 2016) as it can affect capture rates (Barlow 1999).

4. The mist net was set up using standard protocols (Barlow 1999), with the short lengths of masking tape being used to fix the shelves of the net in place at desired points on the poles. Securing the loops on the poles in this way is recommended in order to keep them in place when tension is not complete (i.e., during deployment and retraction of the net). An alternative method to achieve this is to utilise small plastic toggles on each loop. To increase capturing efficacy whilst mitigating the risk of drowning bats trapped in the lower pockets of

the net (Kunz & Kurta 1988, Barlow 1999), the loop of the lowest shelf was positioned at a minimum of 40 cm above the base of the support poles to allow the base of the poles to be positioned as close to the surface of the water as possible (based on test weight objects of 50 g; when trapping in areas with a possibility of larger bats, this may need to be increased).

5. A series of hitches was then formed using 5-mm guy rope, allowing the surveyors to hang the poles vertically from the TL using carabiners (Fig. 1b, 2c). This process could be streamlined by using poles with an eyelet at the top through which a carabiner could be directly attached to the TL.

6. Another rope was attached, using clove hitches, to the top and the bottom of the pole and equalised at a central point using a knot (Fig. 1c). In this study, an alpine butterfly knot was used for this purpose, but a simple overhand knot would suffice.

7. Finally, into the equalised point, a longer guy rope was attached with a secure knot (Fig. 1d), though another carabiner could also be used here as an alternative. It is this rope that later allows the net to be extended over the water and returned back to land for the extraction of bats. This entire process was repeated with the other pole before clipping the poles to the TL. A carabiner was used here, but a pulley could be added to increase the efficiency of moving the net across the TL.

To deploy the skynet, two people are required (one at either end of the setup in order to maintain tension). For the retrieval and extraction of bats, three people are recommended (one at either end of the setup and a third to extract the bat). The net was pulled out across the water using the guy rope on the opposite side of the water body from where the assembly took place. Once the net was in the desired location over the water, the guy ropes were tied off to surrounding vegetation, rocks, stakes, or other forms of support, to maintain the tension in the net as if it were being used normally (Fig. 1a, 2e). When a bat was captured in the net, the process was repeated in reverse: guy ropes were untied, and the net was pulled back towards the shore and the bat handler(s). Once the bat was removed, the net was reset across the water following the same steps above. The process of retrieval and re-deployment in this study took less than two minutes (plus extraction time), although the time required would be variable with different lengths of net and rope. A full list of equipment required for the deployment of the suspended skynet is presented in Table 1.

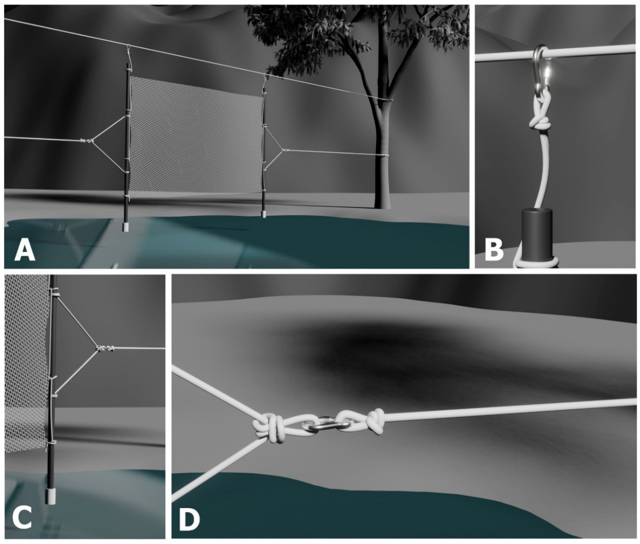

Fig. 1 - The skynet design. **A.** Overview of the skynet *in-situ* (over-water). **B.** Attachment to tension line. **C.** Attachment of poles to lateral lines. **D**. Knotwork of lateral lines.

Fig. 2 - Photos of the skynet as trialled by the authors. **A.** Use of a Petzl basic as the rope grab in a 3:1 haul system to tension the TL. **B.** Petzl gri gri used to remove slack and maintain tension on one side of the TL, attached to the tree behind via a carabiner and nylon climbing sling. **C.** Knotwork attaching a pole to TL. Clove hitch secures guy rope to pole; carabiner is clipped to TL and through a figure-of-8 on the bight. **D.** Surveyors attaching a pole to tension line. **E.** Suspended net in position over the pond. **F.** Orientation of suspended and terrestrial nets.

Field test survey design

In order to perform a preliminary assessment of the efficacy of the suspended skynet compared with a land-based standard net, a total of four mist-netting surveys were undertaken between 27 July and 3 August 2021. Surveys commenced at sunset and lasted for three hours, with equipment deployment consisting of two 6 × 2.4 m monofilament Ecotone mist nets: the first (the skynet)

Table 1 - Kit list for the suspended skynet, with descriptions, alternative materials, and approximate costs in Euros in the UK.

Item	Description	No.	Option 1 (Budget)	Approx. Cost.	Option 2 (Standard)	Approx. Cost.	Purpose
Semi-static rope	≥9 mm diameter; at least as long as width of water body + 5 m	1	Standard abseiling rope or semi-static rope	€1.78 p/m, e.g., 30 m = €53.40	As per Option 1	€53.40	Used for creating a tensioned line on which the net hangs; a dynamic rope is also an option but more difficult to tension
Descending device	Device used to catch a falling climber when rock climbing	1	Petzl gri gri or similar	€ 53.48	As per Option 1	€53.48	Allows the slack to be taken in and out of the TL easily; maintains the tension in the rope
Rope grab	Device which can grip onto the rope	1	Simple Prussik loop	5 m €5.10	Toothed device, (e.g., Petzl basic)	€41.60	Facilitates 3:1 haul system to more effectively tension the rope
Climbing sling	High-strength nylon or dyneema sling	1+	Standard climbing sling	€ 6.70	As per Option 1	€6.70	For wrapping around anchor points to connect ropes or devices
Carabiner	Gated metal clip for climbing or rigging, accessory carabiners are not appropriate	5	Basic snapgate or screwgate carabiners	6.50 each × 5 = €32.50	Carabiner with integrated pulley (e.g., DMM revolver, x2 to hang net)	27.10 each x2 = 54.2 + (3 × 6.50) = €73.70	Net hangs on TL from these and is used to connect devices to slings or rope
Guy ropes	Smaller diameter rope. At least as long as the width of the water body	1+	DIY store accessory cord	(20 m) €20.15	As per Option 1	(20 m) €20.15	Used to suspend poles and to manoeuvre net over water and for retrieval, can also be used to suspend the poles from the TL
Throwline	Thin rope or string to which a weight can be attached		String	€2	Arborist throw line with storage bag and weight sack	€34.38	It may not always be necessary but it can be useful to get the rope from one side of the water to the other
Poles	Standard mist net kit	2	Telescoping fishing poles	€11.87	Telescopic mist net poles (e.g., Ecotone)	€85.00	Supports the mist net
Mist net	Standard mist net kit	1	Bat mist net (e.g., 6 × 16 mm net)	€62.50	As per Option 1	€62.50	For trapping the bats
Tape or toggles	Masking tape or string-pull toggles. Generally standard mist net kit	1	Masking tape	€2.00	Toggles on net loops	€5.00	Secures net shelves in place when the net is not fully tensioned (i.e., while moving it over the water)
				€ 249.70		€ 435.91	

suspended over the water as centrally as access would allow, and the second one (the terrestrial net) perpendicular and adjacent to the water's edge on the west side of the pond. The terrestrial net was positioned to replicate the aspect and height of the skynet as much as the topography of the bank would allow (Fig. 2f).

This deployment equated three net hours per survey as per Pereira et al. (2009) and Hughes et al. (2020). Nets were monitored continuously as per Barlow (1999), so that bats could be extracted immediately upon capture. Bats were processed away from nets, handled and measured according to standard methodology (Kunz 1988, Barlow 1999) and identified using available keys (Dietz & Kiefer 2014).

To assess the efficacy of the skynet design, we also used an EchoMeter Touch 2 Pro full-spectrum bat detector (Wildlife Acoustics, Maynard, Massachusetts, USA) for the duration of each survey to gauge general bat activity levels. Due to the abundance of Orthoptera in the surrounding area, the detector was set to trigger at levels above 20 kHz. Manual analysis of acoustic recordings was done using BatExplorer PRO software (Elekon AG, Luzern, Switzerland), utilising reference call information (Middleton et al. 2014, Barataud et al. 2020, Russ 2021).

RESULTS AND DISCUSSION

During the four surveys, a total of 22 individual bats of five species in four genera were captured using the suspended skynet: 12 *Pipistrellus kuhlii*, four *Myotis nattereri*, three *Eptesicus serotinus*, two *Hypsugo savii*, and one *Myotis blythii*. No bats were captured in the terrestrial net. The catch at this study site over the four surveys represents 22% of the known species assemblage of Krka National Park (Marguš 2010, Hamidovic et al. 2015). Analysis of acoustic recordings determined the presence of at least two additional species not captured in nets (Table 2): *Miniopterus schreibersii* and *Rhinolophus ferrumequinum*. Due to the cryptic nature of the acoustic calls of some species groups, it is possible that additional species were recorded in the immediate surrounds of the study site which cannot be confirmed by acoustic analysis. For example, *M. blythii* and *M. myotis* are both present within Krka National Park (Marguš 2010) but cannot reliably be separated by acoustic analysis alone. As such, calls of these species were attributed to *M. blythii/myotis* (Table 2). Additionally, the 20 kHz minimum trigger setting would have reduced the likelihood of recording some species. For example, *Nyctalus noctula* and *Tadarida teniotis* are high-flying, open-space foragers and are therefore also unlikely to have been caught in our mist nets (Braun De Torrez et al. 2017). Additionally, some species known to be within the Krka area exhibit particularly quiet (e.g., *Plecotus kolombatovici*) or directional (e.g., *Rhinolophidae*) echolocation and have a low detection rate.

Limitations and future improvements

As with many techniques, the skynet has certain limitations, as it requires a higher degree of technical deployment skills compared to non-suspended mist-netting surveys, and it requires additional specialist though widely available equipment. The requirement to retract the net for extraction of bats and then re-deploy it affects sampling duration. However, this is also the case for several standard methods of mist-netting, such as the use of double-high or triple-high mist-netting systems, which require lowering for extraction of bats and then re-positioning. The length of time required for retraction and re-deployment of the skynet in this study (less than two minutes excluding extraction time) is comparable to that of a triple-high mist net system which also requires two people to lower/raise but is variable—dependent on the length of net used and the length of the supporting ropes. There are also limitations in the length of the net that can be deployed, as the amount of tension required to ensure that nets do not sag increases with the length of the net. In addition, the width of the water body suitable for deployment is determined by the amount of rope available. Again, the tension required for the TL increases with rope length. As a general rule, we recommend using the skynet design with (*i*) anchor points no more than 50 m apart and (*ii*) nets no longer than 9 m.

The general design of a suspended apparatus for capturing bats could be modified to suspend a harp trap over a water body. Care must be taken here to ensure that all anchors and ropes are rated to appropriately support the weight of the trap used. The guy rope system could also be improved with a series of pulleys to create a continuous loop. This would allow the movement and tensioning of the net to be completed by a single surveyor from one side of the water body.

Surveying bats over open water

In drier habitats, such as homogenous scrub or in karst where water sources are rare, lotic and lentic features are vital for bats (Blakey et al. 2018), providing not only essential drinking water but a concentration of prey species for insectivorous bats (Razgour et al. 2011, Korine et al. 2016, Salvarina 2016). Bat activity is greater in lentic habitats surrounded by an arid landscape, with the importance of wetlands increasing with surrounding aridity (Blakey et al. 2018) and pond size (Razgour et al. 2010).

Capturing bats over open water is challenging due to the logistics of deployment and access being prohibitive. This is evident in the majority of studies from these habitats relying on acoustic data (Salvarina 2016, Mas et al. 2021). While acoustic monitoring alone can provide useful data on species assemblages (albeit of non-cryptic species groups) and activity levels over time, they are limited in the breadth of data they can obtain, as behavioural observations (e.g., whether bats are drinking, feeding, or simply commuting) are often inconclusive (Salvarina 2016). Capturing bats affords surveyors to identify cryptic species, gain demographic data (sex, age class, breeding condition) as well as morphometric data, and collect biological samples (e.g., DNA, ectoparasites). However, even studies that focus on mist-netting and capturing bats have their limitations. With the majority of studies into lentic bat activity having taken place on shorelines, there is a noted lack of studies over the ponds themselves, likely due to the difficulty in over-water sampling (Salvarina 2016).

Table 2 - Summary of results of sound analysis of recordings from Kistanje, Croatia in July–August 2021.

Species / Phonic Group	23 July 2021	27 July 2021	30 July 2021	3 August 2021	Total
Eptesicus serotinus[1]	4	1	1	0	**6**
Hypsugo savii[2]	3	3	0	2	**8**
Hypsugo savii/Pipistrellus kuhlii/P. nathusii	153	463	430	189	**1235**
Rhinolophus ferrumequinum	2	2	0	12	**16**
Myotis blythii/myotis	23	7	6	12	**48**
M. capaccinii/daubentonii	1	2	20	1	**24**
M. emarginatus/nattereri	1	6	6	3	**16**
Myotis spp.[3]	7	17	31	18	**73**
Miniopterus schreibersii/P. pygmaeus	1	6	6	31	**44**
Total Bat Activity (Recordings)	195	507	500	268	1470

[1] All calls within the *E. serotinus*/*N. leisleri* group were unambiguous.
[2] Where this species can be reliably separated from the H. savii/P. kuhlii/P. nathusii group.
[3] This group may include calls from *M. bechsteinii*/*M. capaccinii*/*M. mystacinus*/*M. daubentonii*/*M. emarginatus*/*M. nattereri* as they cannot be separated from other *Myotis* spp

This study has found that the deployment of the skynet is a demonstrably effective method to capture bats over open water. Our preliminary (and moderate) survey effort of six net hours (Pereira et al. 2009, Hughes et al. 2020) yielded 22 bats representing five of the eight known species for the study site compared with zero captures from the simultaneously deployed terrestrial mist net. The skynet far exceeded the capture rate and diversity for any nearby terrestrial mist-netting stations monitored by Operation Wallacea in 2021 for the surrounding Krka region (Martin et al. 2021) and those of standard temperate European woodlands (Hughes et al. 2020).

Overall, the assemblage recorded in six net hours of survey effort (including supplementary acoustic monitoring) represents 35% of the known assemblage of Krka National Park. This species richness around a single, small water body indicates the importance of standing water in karst landscapes. Indeed, these small waterbodies may even be more valuable resources than our results suggest, given further species may utilise the Kistanje pond that our methods failed to detect.

Our results highlight the value of trapping over water utilising techniques such as the skynet. Using easily sourced equipment, the skynet allows surveyors to safely and effectively access potential bat trapping sites that would otherwise be inaccessible. The applications for the skynet are not limited to riparian or lentic habitats, or to bat surveys—the design could easily be adapted for capturing birds.

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