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ORIGINAL ARTICLE

Light pollution hampers recolonization of revitalised European Nightjar habitats in the Valais (Swiss Alps)

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Abstract

Increasing light emissions caused by human activities have been recognized as a major threat for nocturnal animals. In Switzerland, the European Nightjar is a rare bird, decreasing in numbers since the 1970s, and is therefore highly threatened. The last breeding population occurs in the canton Valais. Initial expert-based conservation measures on formerly inhabited breeding sites were successful until 2000, however recent additional measures have failed. Nightjars are highly sensitive to light due to their special retina adapted to living in semi-darkness. We hypothesized that food availability, mainly moths, is not a critical limiting factor, but that artificial light emissions prevent successful foraging as well as recolonizing revitalised breeding habitats of the nightjar. To test this hypothesis, we used light trapping data of moths from the last 30 years to evaluate food availability and compared light emission on abandoned versus still-occupied breeding sites. Abundance of larger moths did not change significantly over the last 30 years, and smaller moths even increased in abandoned as well as in still-occupied nightjar habitats. However, light emission was two to five times higher in abandoned compared to still-occupied sites. These results suggest that increasing light emission during recent decades has exceeded tolerable levels for this highly specialized night bird. Authorities of the canton Valais should therefore order a reduction in light emission near nightjar habitats by replacing bulbs currently in use with customized LED or broad-spectrum lamps low in white and blue light, and assign remaining nightjar habitats as areas of complete nocturnal darkness, thereby also protecting other threatened nocturnal animals, including moths.

Keywords *Caprimulgus europaeus* · Conservation measures · Moth availability · Nocturnal adaptation

Zusammenfassung

Lichtverschmutzung erschwert die Wiederbesiedlung renaturierter Habitate des Ziegenmelkers im Wallis (Schweizer Alpen)

Die vom Menschen verursachte, zunehmende Lichtverschmutzung ist ein bekannter Gefährdungsfaktor für nachtaktive Tiere. In der Schweiz ist der seltene Ziegenmelker seit den 1970-iger Jahren in stetigem Rückgang begriffen und stark gefährdet. Die letzte sich fortpflanzende Population befindet sich im Kanton Wallis. Erste von Experten begründete Schutzmaßnahmen in früher besiedelten Brutgebieten waren bis ins Jahr 2000 erfolgreich. Allerdings blieben neuere zusätzliche Maßnahmen wirkungslos. Nachtschwalben sind gegenüber Licht außerordentlich empfindlich, weil ihre spezielle Retina an ein Leben in Dunkelheit adaptiert ist. Wir vermuteten, dass nicht das Angebot an Nahrung, vor allem Nachtfalter, für den Ziegenmelker ein limitierender Faktor ist, sondern dass künstliches Licht erfolgreiches Jagen und eine Wiederbesiedlung von renaturierten Brutplätzen verhindert. Um diese Hypothese zu testen, werteten wir Daten von während der letzten 30 Jahre mit Lichtfallen gefangenen Nachtfaltern aus und verglichen Lichtemissionen in verlassenen und noch immer besiedelten Brutgebieten. Die Häufigkeit größerer Nachtfalter änderte sich über die vergangenen 30 Jahre nicht signifikant. Kleinere Nachtfalter nahmen sogar in verlassenen wie auch in noch immer besiedelten Gebieten zu. Im Gegensatz dazu war die Lichtemission in verlassenen Gebieten zwei-bis fünfmal höher als in besiedelten. Diese Befunde legen nahe, dass die zunehmende Lichtemission während der letzten Jahrzehnte die Toleranzschwelle dieser hochspezialisierten nachtaktiven Vogelart überschritten hat. Die Behörden

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des Kanton Wallis sollten deshalb eine Reduktion der Lichtemission in der Nähe von Ziegenmelkerhabitaten anordnen und gegenwärtig benutzte Leuchtbirnen mit maßgefertigten LED oder Breitspektrumlampen mit einem tiefen Weiß-und Blaulichtanteil ersetzen. Zudem sollten sie in den noch vorhandenen Lebensräumen des Ziegenmelkers totale Dunkelheit anordnen. Damit würden auch andere gefährdete nachtaktive Tiere einschließlich der Nachtfalter geschützt.

Introduction

The most obvious negative effects of artificial light on birds, collisions between migrating birds and lighthouses, were first documented a century ago (Squires and Hanson 1918). However, detrimental effects of artificial light pollution on the environment have only recently received higher attention (Longcore and Rich 2004), and have also been identified as a threat to biodiversity (Hölker et al. 2010; Knop et al. 2017). Furthermore, lethal effects of artificial light on the survival of endemic, pelagic bird populations have been documented (Le Corre et al. 2002; Rodríguez et al. 2017a, c).

As an insectivorous, nocturnal bird, the European Nightjar *Caprimulgus europaeus* (hereafter nightjar) faces increasing artificial light emissions at night. This species is an aerial-hawking bird feeding on airborne insects from dusk to dawn. *Caprimulgids* are known to spend more time for churring activities and courtship during full moon nights (Brigham and Barclay 1992; Mills 1986; Schlegel 1973; Sierro 1991).

The nightjar colonizes xeric deciduous scrubland and scattered pine forests after logging, fire events or avalanches, sometimes not far from human settlements or infrastructures. The species is still widespread in the driest areas of Europe, with its stronghold in Eastern Europe (Hoblyn and Morris 1997). In northern Europe, other semi-open vegetation types can also be suitable habitats. Thus, young commercial pine plantations are preferred nesting and foraging habitats in England, although older forests harbour more prey biomass, suggesting that nightjars prefer habitats where prey is easily accessible (Sharps et al. 2015). Heathlands are used as breeding and roosting sites in Belgium, where nightjars forage in extensively grazed grasslands (Evens et al. 2017a). Low availability of foraging grounds near breeding sites increases foraging distances and physiological stress levels (Evens et al. 2018).

In Switzerland, the nightjar was never common, but has drastically declined since the 1950s. This decrease resulted in 50–70 breeding pairs in 1993–1996, out of which 40–60 lived in the Valais valley (Schmid et al. 1998). At present, the nightjar shows an even more scattered distribution in Switzerland: a number of lower foothills in alpine valleys still colonized during the last breeding bird survey from 1993–1996 (Schmid et al. 1998) are now abandoned, and only a few breeding pairs still survive in remote areas. The current Swiss breeding population consists of fewer than 30 pairs, out of which 25 live in the Valais (Knaus et al. 2018). As a consequence, the European Nightjar is classified as ‘endangered’ in the Red List of breeding birds in Switzerland (Keller et al. 2010).

The most evident reasons for the drastic decline of the nightjar in Switzerland are the destruction of breeding habitats in vineyards and settlements, woodland encroachment on semi-open areas and increasing forest density after abandonment of pastures (Sierro 1991). The decrease of insect biomass should have ceased in vineyard areas after the limitation of pesticide use due to new agricultural practices since 1990 and the implementation of the mating disruption method against grape moths, the most damaging grape pest in Swiss vineyards. At present, more than 90% of the Valais vineyards are protected with this biological control (Favre et al. 2016). The nightjar feeds mainly on moths (81% of prey biomass of adults and 93% of nestlings), uses semi-open oak scrubland (20–50% forest coverage) for foraging and breeding, and occasionally hunts along hedges in the middle of vineyards (Sierro et al. 2001). Knowledge of wintering conditions in Africa is still limited. However, a recent study localized for the first time wintering grounds and pathways of the nightjar for reaching its wintering destinations in Congo. These findings could have implications for the conservation of the nightjar (Evens et al. 2017b).

The first expert-based conservation measures in Switzerland were carried out in two formerly inhabited breeding sites in 1993 (Lens/Véreille) and 1999 (Miège/Planige) following a personal initiative of AS. The management consisted of creating small clearings of 100–500 m^2 in oak or pine woods, sparing a few small trees (<3 m high) and 1–2 dead timbers on the ground. These sites were recolonized by the nightjar immediately in the year following the implemented measures. In contrast, evidence-based revitalisations (Sierro et al. 2001; Sutherland et al. 2004) of formerly inhabited breeding sites implemented from 2001 onwards were not successful for 14 years (Sierro 2016). However, solitary, churring males were temporarily recorded on three different revitalised sites between 2003 and 2013, but did not stay long enough for a nesting attempt (Sierro 2016). These observations suggest that the revitalised habitats were suitable enough to attract males searching for breeding habitats and females, but were still lacking essential ecological features for birds intending to establish breeding sites.

However, we cannot exclude a potential lack of females for the failure of breeding in these revitalized sites, as no data of a potential deviation of the sex ratio from 1:1 are available.

The ongoing decline of the nightjar since 2001 from several suitable, semi-open habitats remained a mystery for the local ornithologists. This decline was particularly frustrating considering thriving populations in Austrian pinewood (Wichmann 2004), in disturbed British oak forests (Lowe et al. 2014), in several semi-open forested areas of France (Issa and Müller 2016), on military training grounds in eastern Germany (Witt et al. 2015) and regarding an increasing population in coastal heathlands of the Netherlands since the 1980s. However, abiotic factors in Swiss breeding habitats have not received adequate attention and thus remained unexplored so far.

True goatsuckers (*Caprimulgidae*) possess a *tapetum lucidum*, a diffuse white reflector in the retina characteristic of darkness-adapted eyes, which causes an extreme light sensitivity (Nicol and Arnott 1974). This adaptation could represent an additional constraint for a nocturnal bird in an artificially lighted environment. We therefore hypothesize that increasing light pollution has negative effects on nightjar populations and could prevent nightjars from settling in potentially suitable breeding and foraging habitats. We also hypothesize that the decline of the nightjar in the Valais is not caused by a reduced food supply of moths.

We tested these hypotheses by assessing food availability across the last decades and by measuring site-specific light conditions in still-occupied versus abandoned breeding sites, thereby providing a potentially new understanding of environmental constraints the nightjar must cope with.

Methods

This study was performed on the last viable Swiss nightjar population in the canton Valais (Knaus et al. 2018). A unique data set on moths spanning three decades allowed us to detect potential differences of food availability between still-inhabited and abandoned regions of the nightjar. The special landform configuration of the Valais and the contrasting development in the Lower and Upper Valais provided a unique opportunity for an investigation of the research goals.

Study area

This research was conducted in the canton Valais (Swiss Alps) from 1986 to 2016. The study area covers 68 km of the Rhône Valley, from Martigny to Visp. Landscape and vegetation of this area are shaped by a continental climate with extreme summer droughts and cold winter periods. These climatic conditions become more pronounced with increasing elevation from the Lower to the Upper Valais (Werner 1988). Thus, the Upper Valais provides more suitable breeding habitats for the nightjar. The canton Valais includes most remote areas of Switzerland; 53.5% of its area are unproductive and 24% are covered with forests (Bender 2016). Consequently, most human activities are concentrated in the plain of the valley (Fig. 1). Where possible, the sunny south-facing slopes up to 800 m above sea level (a.s.l.) are used as vineyards. The main expansion of vineyards occurred between 1950 and 1980, replacing original oak forests, steppes and extensively managed meadows (Sierro 1991).

The population of the Valais has strongly increased during the last three decades, which has led to a significant extension in infrastructure. This development has affected the French-speaking part (lower Valais) in the first place. In addition, a motorway was constructed in the mid-1980s. The three cities (Martigny, Sion and Sierre) have each between 16,000 and 31,000 inhabitants, with many expanding villages in the surrounding areas. In contrast, the German-speaking part (upper Valais) is less densely inhabited. There, agriculture is still practised in more traditional ways. However, a new motorway section was completed in 2016. The single city (Visp) of this area harbours ca. 8000 inhabitants, with some small, until now slowly growing villages nearby (Bender 2016). Therefore, the Upper Valais is still recognized as a biodiversity hot spot in Switzerland (Lachat et al. 2011), particularly for breeding birds (Schmid et al. 1998). Hence, a separation of the Upper and Lower Valais seems appropriate for the current analysis.

The breeding habitats of the nightjar are located on the south-facing slopes of the Rhone Valley, above vineyards, between 550 m and 1600 m a.s.l. In the plain of the valley, only the pine forest (700 ha) of the Nature Park Pfyn-Finges provides actual breeding habitats (Sierro 1991).

A total of 19 abandoned and still-occupied breeding sites were investigated, 8 in the lower Valais (all abandoned) and 11 in the Upper Valais (4 abandoned and 7 still occupied in 2015/2016, Table 1).

Nightjar population data

Nightjars are best surveyed by mapping churring males during the breeding period, spanning from May to August in the Valais. Territories were registered by recording churring males at dusk and dawn. From 1986 to 1998, breeding sites of the Lower Valais were monitored one to two times a year, whereas in the Upper Valais, surveys covered all breeding sites every 3 years (Sierro 1991; A. Sierro pers. obs.). From 1999 to 2014, managed sites in the Lower as well as in the Upper Valais were monitored one to three times a year (Sierro 2016). In addition, the Swiss breeding bird atlas 1972–1976 (Schifferli et al. 1980), 1993–1996 (Schmid et al. 1998) and 2013–2016 (Knaus et al. 2018), completed by a canton-wide survey in 2006

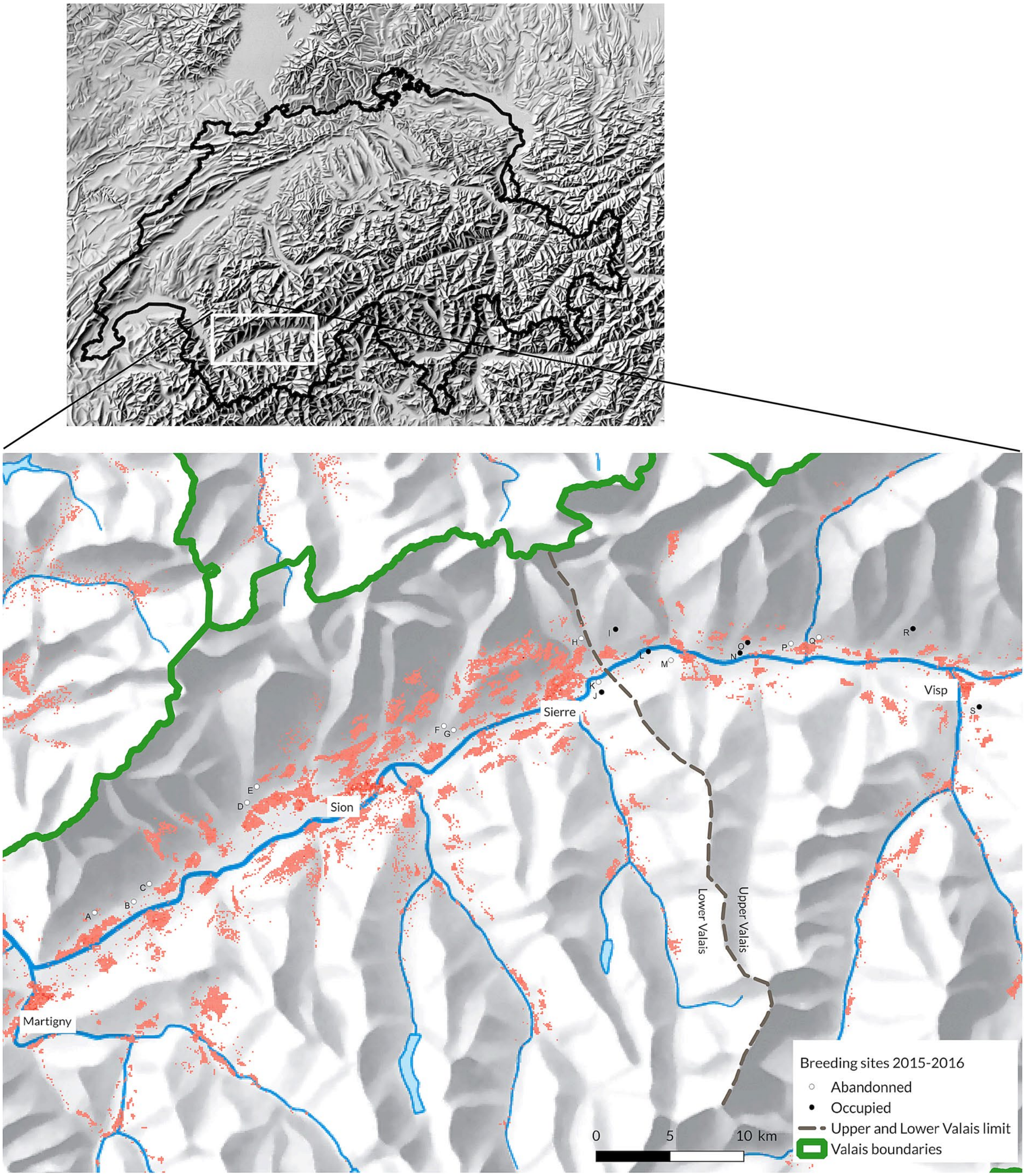

Fig. 1 Study area in Switzerland. Site letters refer to Table 1. The canton Valais is today densely populated. Human population density (2015) is indicated: light (5–20 inhabitants/ha) to dark red (> 80 inhabitants/ha, only in cities and villages) squares. Main cities (8000–31,000 inhabitants) are indicated. Courtesy of Federal Office of Topography

(Sierro and Rey 2007), provided reliable basic data covering almost all abandoned as well as occupied breeding sites of the nightjar. Observations reported by volunteer ornithologists completed the data during the entire study (Swiss Ornithological Institute archives, www.ornitho.ch). Before light emissions were measured in 2015–2016 (see "Light emission measures" section), every site was checked again for nightjar presence.

Table 1 Nineteen study sites (8 in the Lower and 11 in the Upper Valais), their last occupation by the nightjar, number of churring males in 2015–2016, mean and range of light emission measures (LEM) in 2015 and 2016

Site	Locality	Altitude (m)	Last churring male	No. of churring males	Area of revitalised habitat (m^2)	Mean (± range) of LEM (lux) 2015	Mean (± range) of LEM (lux) 2016
	Lower Valais						
A	Fully/Buitonnaz	760	2002	0	5900	0.028 (0.02–0.03)	0.028 (0.02–0.03)
B	Fully/Gru	560	1985	0	7500	0.02 (0.02)	0.02 (0.02)
C	Saillon/Sarvaz	660	1988	0	1800	0.019 (0.01–0.02)	0.018 (0.01–0.02)
D	Ardon/Lizerne	780	1995	0	0	0.064 (0.05–0.09)	0.065 (0.05–0.09)
E	Aven/Lintellière	850	1998	0	0	0.028 (0.02–004)	0.029 (0.02–0.04)
F	St-Léonard/Planisses	900	2002	0	0	0.033 (0.02–0.05)	0.032 (0.02–0.05)
G	Lens/Véreille	850	2001	0	30,000	0.021 (0.02–0.03)	0.021 (0.02–0.03)
H	Miège/Planige	910	2000	0	25,000	0.041 (0.03–0.07)	0.042 (0.03–0.08)
	Upper Valais						
I	Salgesch/Blatte	1000	2016	6–8	0	0.009 (0–0.01)	0.01 (0–0.01)
J	Sierre/St-Antoine	650	2016	1	0	0.04 (0–0.01)	0.04 (0–0.01)
K	Sierre/Collines	590	2006	0	17,500	0.011 (0.01–0.02)	0.011(0.01–0.02)
L	Finges/Rottensand	560	2016	1	39,100	0.001 (0–0.01)	0
M	Leuk/Illbachkegel	650	1990	0	20,500	0.01 (0.01)	0.01 (0.01)
N	Leuk/Getwing	700	2016	3	0	0.005 (0–0.01)	0.009 (0–0.01)
O	Erschmatt/Schnitte	1100	2016	1	0	0.005 (0–0.01)	0.004 (0–0.01)
P	Gampel/Lange Cheer	730	2006	0	0	0.026 (0.01–0.04)	0.025 (0.01–0.04)
Q	Hohtenn/Griebje	950	2006	0	0	0.03 (0.02–0.04)	0.031 (0.02–0.04)
R	Ausserberg/Leiggern	1600	2016	1	0	0.001 (0–0.01)	0
S	Visp/Ribe	1100	2016	2	0	0.003 (0–0.01)	0.002 (0–0.01)

Sites are listed from west to east in the Rhone Valley

Moth data

A reliable, scientific monitoring of moths, as carried out in the UK (Fox et al. 2014), has so far not been realized in Switzerland. The only continuous data set available for the study area was provided by a moth collector, N. von Roten (NvR), who started already in 1977 to collect and identify nocturnal macrolepidoptera with a light trap, a vertically mounted sheet, lighted with a bulb type MBF 125 W. Working intensely on his hobby, NvR carried out weekly trapping sessions from March to November, identified species and recorded species abundance, duration of trapping sessions, weather conditions and geographic coordinates. He also built up a reference collection, now deposited at the Musée de la nature in Sion. NvR carried out his trapping sessions in the Valais during still, mild and dark nights, from the lowlands to the alpine level. Favourite trapping sites were forest clearings, forest edges, vineyard margins and steppes interspersed with oak scrubland secluded from human settlements. Since 1998, AS joined NvR and has run a digital database of the trapping sessions (34,000 single moth recordings and 1473 trapping sessions from 1980 to 2016). Since 2001, two bulb types (MBF 125 W and MBTF 125 W, Osram™) have been used for every trapping session.

This unique data set was originally used to detect a potential difference in moth populations between the Upper and Lower Valais, but not for measuring site-specific differences. Due to the fact that naturalists improve their knowledge during the first year of activity, we only considered data from 1983 to 2012 to minimize learning effects. 2013 and 2014 were characterized by extremely harsh spring weather conditions, possibly caused by climate change (Frei et al. 1998), and were therefore not used in the current analysis. Furthermore, we selected only the trapping sessions from May to August, the breeding period of the nightjar in the Valais. According to the known breeding range in the Valais (Sierro 1991) and the feeding habits of the nightjar (Alexander and Cresswell 1990; Sierro 1991), only trapping sessions carried out at elevations from 450 to 1700 m a.s.l. were used in the analyses of the present study. Trapping results of the two main regions, Lower and Upper Valais, were separated. Most trapping sessions lasted between 2 and 2.5 h. For all trapping sessions not equal to 2.5 h, moth numbers were standardized to a trapping time of 2.5 h. Overall, 65% of trapping sessions in the Upper and 70% in the Lower Valais were adjusted in order to obtain a homogenous, comparable data set. Overall, 317 trapping sessions were considered, 161 in the Upper and 156 in the Lower Valais.

Based on food samples from neck-collared birds (Auclair 1988; Sierro et al. 1995), we set a limit of a 25-mm abdomen length to separate "bigger moths" (abdomen length ≥ 25 mm) from "smaller moths" (abdomen length < 25 mm).

Light emission measures

Light emission was measured on all study sites in 2015 and 2016 with a high-precision luxmeter (Malvolux™ 5032 B USB, Gossen Metrawatt, Germany, resolution of 0.01 lx, adapted to outdoor measurements). Measurements were taken at 2 m above ground in a semi-circular movement. The highest light emission measure (LEM), usually situated in the centre of the semi-circle around the observer's front, was recorded, avoiding darkening side effects. LEM were always taken in total darkness, approximately 1 h after dusk to midnight, from May to August. Measurements were taken during moonless, dark and clear nights, only with star light, avoiding trees shading the surrounding area. LEM were only taken in dark nights, as hunting activity of the nightjar is highest in dark nights (Brigham and Barclay 1992; Mills 1986; Schlegel 1973; Sierro 1991).

LEM were taken along forest edges, in clearings and semi-open habitat, the preferred hunting habitats of the nightjar in the Valais (Sierro et al. 2001). Dense woodlands, inaccessible rocky outcrops and shaded places were not considered for the LEM. When sites harboured more than one churring male (three sites), LEM were taken on the site most exposed to light emission (lower altitude, in line with the nearest artificial light source). All measurements were replicated in 2016 with the same protocol. Only the dates of LEM were adapted (± 12 days) due to the lunar cycle shift between 2015 and 2016 and unpredictable weather conditions.

As the mean home range of three radio-tracked breeding nightjar males was estimated to 11.5 ha (range 9.4–13 ha) in the Valais (Sierro et al. 1995), 10 LEM per site were spread over a 13-ha area around current (2015–2016) and formerly churring males (Fig. 2). The LEM points were recorded in the field with a GPS (precision 5–6 m), and registered on a QGIS map (Essen 2.14.) in order to allow precise future replication measurements.

In order to record light emission variation during the year, LEM were taken on five moonless, dark nights at two different sites between 22h00 and midnight in 2016 (May to September). One site was located in a semi-open area near Leuk (low artificial light emission) at 1000 m a.s.l., and the other in vineyards in Venthône just above the town of Sierre (high artificial light emission) at 700 m a.s.l.

As an expansion of light pollution was already noticed as a by-product of urbanization, correlated with population growth in occidental societies (Falchi et al. 2016), we considered population growth of the inhabitants of the Valais as an additional indirect measure of artificial light emissions.

Fig. 2 Example of the LEM distribution around the last churring male on the study site (a)

Results

Development of nightjar populations in the Valais

The development of nightjar populations during the last four decades showed a strong decline in the Upper and Lower Valais. A clear negative relationship exists between nightjar breeding populations and the growing human population in the Upper ($r^2 = 0.961$, $n = 5$, $p = 0.001$) and Lower ($r^2 = 0.867$, $n = 5$, $p = 0.010$) Valais (Fig. 3). In the Lower Valais, the nightjar sub-population disappeared in 2002, whereas in the Upper Valais, the regularly breeding sub-population still survived.

Moth availability

The mean number of trapping sessions per year (May to August) from 1983 to 2012 was 5.366 (± 1.958, range: 3–9) in the Upper and 5.2 (± 1.922, range: 2–9) in the

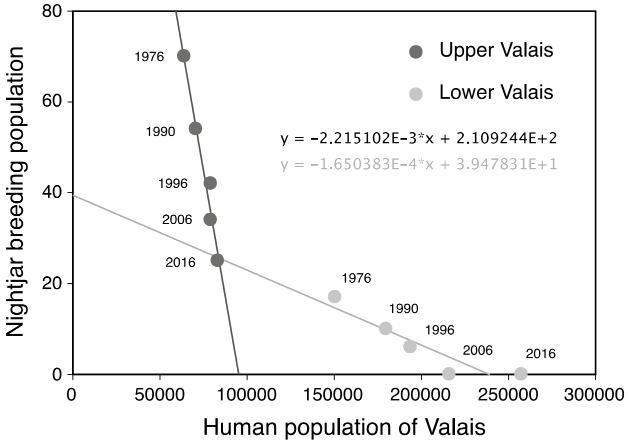

Fig. 3 Relationship between nightjar breeding population (churring males) and human population growth in Upper (black symbols) and Lower (grey symbols) Valais from 1976 to 2015. Both regression lines are statistically significant (Upper Valais, $p = 0.001$; Lower Valais $p = 0.010$)

Lower Valais. Trapping effort did not differ between Upper and Lower Valais during the three investigated decades (1983–1992: Wilcoxon test = 97, $df = 9$, $p > 0.05$; 1993–2002: Wilcoxon test = 102, $df = 9$, $p > 0.05$; 2003–2012: Wilcoxon test = 126, $df = 9$, $p > 0.05$). Likewise, trapping effort between the three decades did not differ in the Upper (Friedman test = 1.4; $df = 2$; $p = 0.496$) or Lower Valais (Friedman test = 3.2; $df = 2$; $p = 0.201$).

Interestingly, the abundance of smaller moths increased significantly from 1983 to 2012 in the Lower Valais (Mann–Kendall test, $S = 143$, $n = 30$, $p = 0.011$), and also tended to increase in the Upper Valais (Mann–Kendall test, $S = 103$, $n = 29$, $p = 0.056$). The abundance of bigger moths did not show any significant trend, neither in the Upper (Mann–Kendall test, $S = 26$, $n = 30$, $p = 0.639$) nor in the Lower Valais (Mann–Kendall test, $S = 56$, $n = 30$, $p = 0.326$, Fig. 4).

Light emission measures (LEM)

Mean light emission was two to five times higher in abandoned compared to still-occupied sites (Fig. 5). Light emissions originated mainly from settlements in the Rhône plain and from villages on the south-facing valley slope. The first artificial lighting was 1400 m away from the closest inhabited site (site 14, Fig. 1). Mean LEM reached 0.027 lx (range: 0.01–0.09 lx) in abandoned and 0.005 lx (range: 0.00–0.01 lx) in occupied sites in 2015 and 2016. An extreme value (0.09 lx) was recorded at Ardon/Lizerne (site 4), where light emissions were caused by growing suburbs. The difference in LEM between abandoned and occupied sites was highly significant in 2015 (Mann–Whitney U test = 322; $p < 0.0001$) as well as in 2016 (Mann–Whitney U test = 362.5; $p < 0.0001$). However, LEM did not differ between 2015 and 2016 in abandoned (Wilcoxon matched pairs test = 0.376; $n = 120$; $p = 0.646$) and occupied (Wilcoxon matched pairs test = 0.2998; $n = 70$; $p = 0.617$) sites (Fig. 5). Values of LEM were conservative, remaining often constant for an area of 1000 m^2.

Variation of LEM on moonless nights at the same location during the breeding season did not exceed 10% in a strongly (Venthône) and a weakly (Leuk) artificially lighted location (Fig. 6). At the end of the summer and the end of the breeding season, humidity slightly influenced LEM (data not shown).

Discussion

Prior studies reported negative effects of artificial light emissions only on terrestrial nesting seabirds (Le Corre et al. 2002; Rodríguez et al. 2017b), songbirds (de Jong et al. 2015; Raap et al. 2015, 2016; Da Silva et al. 2015) or commuting bats, but there are, to our knowledge, so far no studies documenting detrimental effects of light pollution on a threatened, highly specialized, insectivorous nocturnal bird such as the nightjar. However, studies have shown drastic declines of moths (Conrad et al. 2006; Fox et al. 2013; Macgregor et al. 2016), profound changes in invertebrate communities (Davies et al. 2012) or life history change in a common moth (van Geffen et al. 2014) caused by artificial lighting due to ongoing urbanization. In addition, a recent study has documented declines of insect biomass of 75% in German nature reserves (Hallmann et al. 2017). However, this study was also criticised for its methodological procedure (Leather 2018).

Decline of the nightjar

The nightjar has continuously declined in the Valais. This decline is obviously related to human population growth and its detrimental collateral effects. The decline in the Upper Valais is even more pronounced than in the Lower Valais, but starts from a higher level (Fig. 3). This finding is most concerning, as urbanization, the likely cause for the decline, is progressing also in the Upper Valais.

It has also been argued that unfavourable ecological conditions in wintering grounds, i.e., increasing droughts in the Sahel desert, could play a key role for the decline of the European breeding population of the nightjar (Evens et al. 2017b; Knaus et al. 2018). This argument had also been put forward for the decline of the insectivorous Common Redstart *Phoenicurus phoenicurus* (Bruderer and Hirschi 1984; Schifferli et al. 1980). However, a strong increase of breeding pairs of this bird in a burnt wood area in the Valais, which provided the necessary bare ground for successful

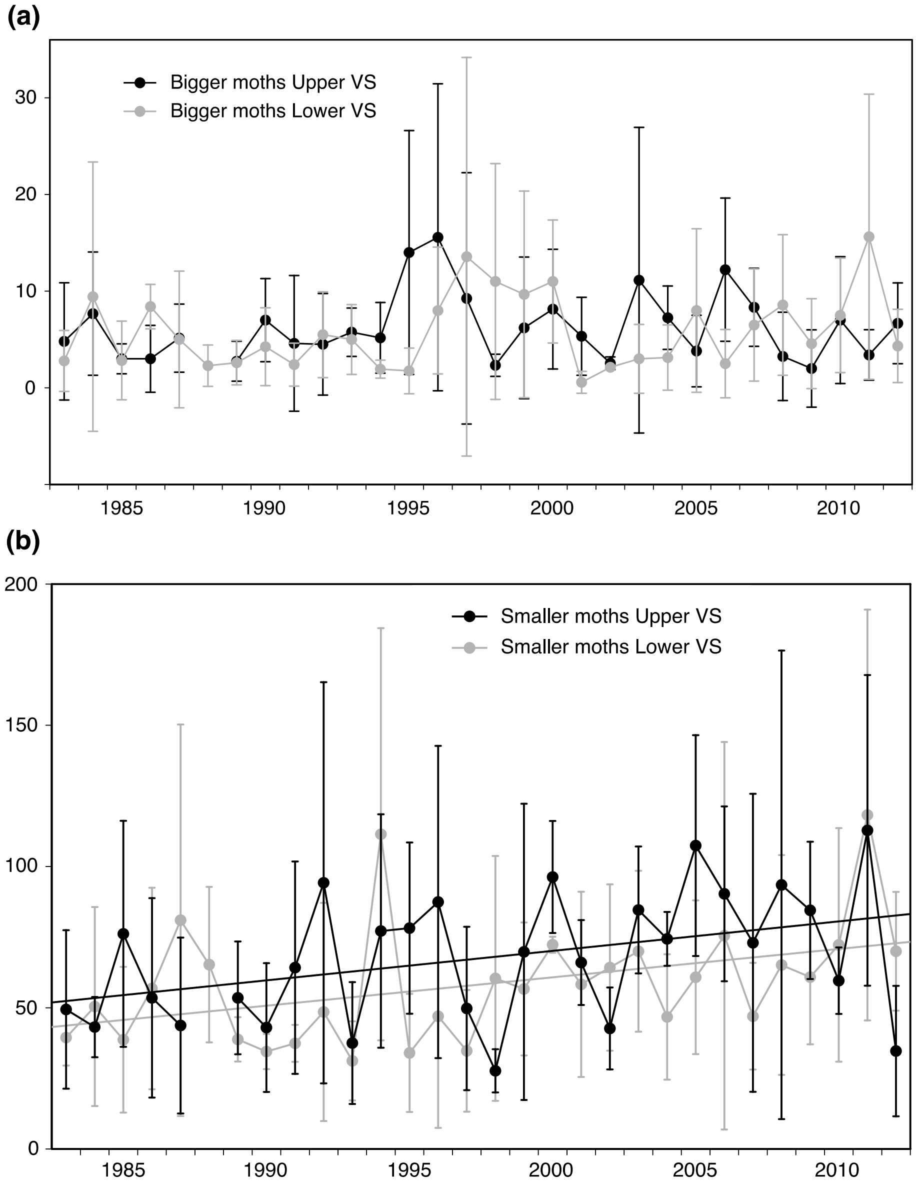

Fig. 4 Mean (± sem) of moth abundance from light traps (May to August), separated in bigger **a** and smaller **b** moths, in Upper (black symbols and lines) and Lower (grey symbols and lines) Valais from 1983 to 2012. No light trappings in Upper Valais in 1988. Mann–Kendall test: bigger moths (both values $p > 0.05$); smaller moths, Upper Valais $p = 0.056$, Lower Valais $p = 0.011$

breeding, proved that the former lack of suitable breeding conditions was the key factor for the decline of the Common Redstart (Schaub et al. 2010, Wohlgemuth et al. 2010). Similarly, the nightjar may mainly suffer from a lack of suitable breeding grounds in the Valais. Meanwhile, the Sahel drought has not decreased and has even become tougher locally (Epule et al. 2014).

Moth availability

Moth data of a citizen science activity (data of NvR) show that during the last three decades, the biomass of smaller moths has significantly increased in the Lower Valais and marginally in the Upper Valais. Bigger moths did not show a corresponding increase in biomass over the same time period, possibly because they were generally less abundant. However, the finding that moth biomass did not decrease as in other European areas (e.g., Conrad et al. 2006), but actually increased, is encouraging and might be interpreted as a sign of recovery after the prohibition of DDT use in Switzerland in 1972 (www.bafu.admin.ch), and the promotion of biological pest control in the Valais since the beginning of the 1990s (SCA 2017). Interestingly, the observed increase in moth biomass is consistent with an increase in the abundance of another night-active, insectivorous bird species in the Valais, the Scops Owl *Otus scops*. Relying on acoustic rather than optic signals of their prey animals (moths, terrestrial bush crickets, Heller and Arlettaz 1994), Scops Owls are obviously not disturbed by light pollution. However, global warming might also have favoured this bird species independently from prey availability (Huntley et al. 2007; Knaus et al. 2018). In contrast to the positive response of

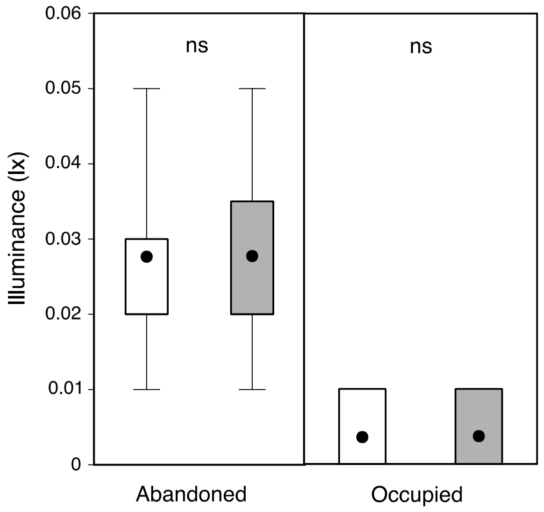

Fig. 5 Light emission measures (LEM) on abandoned and still-occupied breeding sites in 2015 (white boxes) and 2016 (grey boxes). Extreme values are not shown on the box plot. Q1 and median values are superposed for the two categories on the graph. LEM 'Abandoned' versus 'Occupied': $p < 0.0001$, Mann–Whitney *U* test

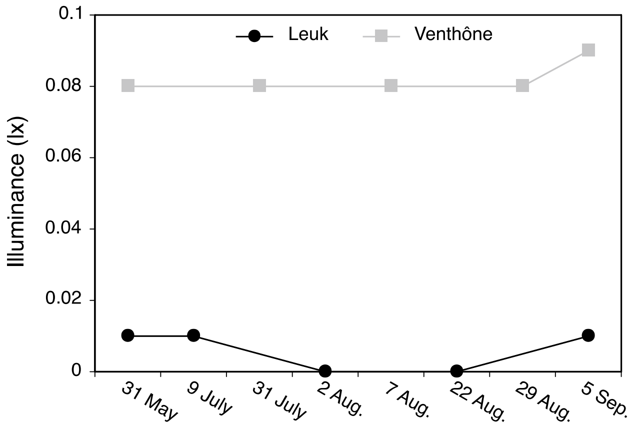

Fig. 6 Variability of light emission measures (LEM) on moonless nights in a strongly (Venthône) and weakly (Leuk) artificially lighted location in the central Valais, from May to September 2016. The sky was clouded on May 31 and on September 5

the Scops Owl to the observed increase of prey availability, we could not observe a corresponding response of nightjars. In fact, the flexibility of nightjars to reach distant foraging grounds for feeding (Alexander and Cresswell 1990) should have allowed them to hunt successfully in moth-rich habitats in the Lower as well as in the Upper Valais. Thus, in spite of a study showing that sites still occupied in the Upper Valais harboured a higher general insect biomass than deserted sites in the Lower Valais in 2013 (Winiger et al. 2018), our results clearly contradict the hypothesis that the actual lack of breeding nightjars in the Lower Valais is caused by a decline of prey biomass.

As most nocturnal insects, and moths in particular, are lunarphobic (Macgregor et al. 2016; van Geffen et al. 2014, 2015a, b; van Langevelde et al. 2017, 2018, but see Eisenbeis 2006), artificial light in natural habitats obviously disrupts their activity, especially also their mating behaviour, and therefore contributes to a decline of the available moth biomass, potentially resulting in a cascading effect (Conrad et al. 2006; Fox 2013; Knop et al. 2017; Macgregor et al. 2016). However, moth species living in light-polluted urban areas are less attracted to light over the years and seem capable of adapting to light pollution (Altermatt and Ebert 2016). Nevertheless, larger moths are more strongly attracted by artificial light than smaller moths. Consequently, artificial lighting could not only affect the nightjar and its prey, but the total food web depending on nocturnal insects in dramatic ways (Knop et al. 2017; van Langevelde et al. 2011).

Night vision of the nightjar

It has long been recognized that *Caprimulgids* are anatomically well-adapted to see under crepuscular light conditions (Nicol and Arnott 1974), and that they have developed a high ability to discriminate prey in semi-darkness (Brigham and Barclay 1995). Nevertheless, nightjars obviously show some tolerance to stronger light conditions. Thus, nightjars have been observed to hunt under moonlight in the tropics, where light levels at night are too low for efficient hunting (Jetz et al. 2003). Furthermore, tropical (*Caprimulgus cayennensis*) and temperate (*Caprimulgus ruficollis*) nightjars have been observed hunting moths at street lights (Debrot 2014; Gragera 2015). Nightjars can also be flushed during daytime and then fly for short distances to find a new hiding place. However, in all these cases, nightjars are not exposed to constant, long-lasting higher light levels as they are now prevailing in abandoned sites.

Illuminance on nightjar breeding sites

Population growth and urbanization have not only increased light pollution, but also other levels of disturbance, including habitat deterioration and habitat loss. However, the latter can be excluded as a reason for the decline of nightjars in the Valais, as most of habitat destruction, particularly the installation of vineyards, had been terminated already by ca. 1980. Critical habitat such as oak bushes and open forests has not decreased during the last decades, but has even increased by specific conservation efforts. Landscape connectivity between breeding and foraging sites, a further potential stress factor for nightjars (Evens et al. 2017a, 2018), does also not seem to be a decisive driver at least in the seven still-occupied breeding sites in the Valais, as suitable breeding and foraging habitats are mixed and situated close to each other in these sites (A. Sierro pers. obs.). Thus, the high quantity of light emission measured in abandoned breeding sites supports our hypothesis that nightjar populations suffer from too high light emissions in the Valais and possibly also elsewhere.

Most of the actual bulb types for street lighting in the Valais are metal-halide and mercury vapour lamps (pers. comm. P.-M. Barras), which are both rich in UV and affecting moth as well as nightjar vision. The amount of artificial light dispersed from settlements to hunting habitats and its related sky glow disrupt ecosystem functioning at different levels (Kyba et al. 2015). Despite the above-mentioned tolerance, high artificial light emissions could blind nightjars and reduce the contrast between prey and background. Considering that the observer (AS) could easily distinguish a non-lighted (0.00 lx) from a weakly lighted environment (≥ 0.02 lx), it is easy to imagine a blinding effect experienced by the nightjar when an increased amount of artificial light reaches its hypersensitive retina. Thus, light pollution may have progressively diminished the foraging success of nightjars in the Valais, and may over the years brought the species to the brink of extinction. This subtle process may have begun in the 1970s in the Lower Valais. In the Upper Valais, the optimal site (I) above the village of Salgesch belonging to the Pfyn-Finges Nature Park is now also increasingly threatened. The growing village of Salgesch and its associated light emission are the likely cause for a reduction of the nightjar population from 17 churring males in 1998 (A. Sierro in Revaz 1999) to 9 churring males in 2010 (Sierro 2016), since the habitat structure in this location with still semi-open, dry oak scrubland has remained unchanged.

Two further examples in the Upper Valais document detrimental effects of artificial light on the nightjar: (1) 310 ha of pinewood and larch forest above Leuk were destroyed by a fire in 2003 (Wohlgemuth et al. 2010). In 2009, eight churring males colonized the east-facing slope of this area. However, the south-facing slope above the town of Leuk, remained uncolonized by breeding pairs during 2009 to 2016, but was only temporarily used by churring males (Sierro 2016). The mean of ten LEM on this south-facing slope reached 0.025 lx (0.02 to 0.03 lx) in suitable semi-open habitats, whereas corresponding LEM on the colonized east-facing slope amounted to only 0.005 lx (0.00 to 0.01 lx). (2) Site (M) is an optimally revitalised habitat, and LEM on a dark evening showed a mean of 0.01 lx. However, this site is situated directly in line with eight powerful projectors from a football playground, used three times a week from March to November for football trainings until 23h00 and producing an artificial light flow of 0.01–1 lx onto the revitalised habitat. It is therefore not surprising that the nightjar has not colonized this area so far. Most likely, these frequent and high light emissions during twilight are not tolerable by the nightjar and have prevented a recolonization.

It could be argued that a range of civilization-related factors other than increasing levels of light emission is operating and interacting over the entire annual cycle of the nightjar. Such a comprehensive analysis is clearly beyond the scope of this paper (and would be highly demanding to accomplish). However, disturbance associated with human activities has caused altering settlement patterns in the nightjar in Nottinghamshire, England (Lowe et al. 2014), diminished the density of breeding nightjars in Dorset, England (Liley and Clarke 2003) and flushed breeding birds, leading to nesting failure on the Dorset heaths (Langston et al. 2007). In our study region, human-associated disturbance other than light pollution cannot fully be ruled out as an additional factor further harming nightjar populations. Walkers and dogs may disturb nightjars and may flush resting birds. However, most of the former (and still existing) breeding sites are located on dry, south-facing slopes, where walking trails are scarce or completely lacking due to the unsuitable topography and rough, xeric deciduous scrubland. Hence, human disturbance in these sites appears to be low. Thus, our findings still suggest that high levels of light pollution are an important, if not the main, cause for the recent decline and the failure of recolonizing otherwise suitable habitat of the nightjar in the Valais. Nevertheless, further research is needed to better understand mechanisms governing food detection and tolerated light emission levels of this fascinating, but highly threatened, bird.

Novel conservation measures

The results of this study strongly suggest that besides traditional conservation measures regarding forest structure (Sierro et al. 2001), artificial light emissions should be considered in future conservation plans. In the vicinity (< 1500 m) of formerly and still-inhabited breeding habitats of the nightjar on the outskirts of villages, artificial lighting should be reduced by 80% from dusk to dawn during May to August. A substantial reduction of light emission in public areas seems to be quite feasible, as people in the town Sierre in the Lower Valais do not notice a current light reduction of 50% at night (P.-M. Barras, pers. comm.). The tolerated illuminance in breeding sites of the nightjar should not exceed a mean of 0.005 lx. Furthermore, bulb types of customized LED (Longcore et al. 2015) or broad-spectrum lamps (Plummer et al. 2016; van Langevelde et al. 2011), poor in blue and white light, should be used, as they are less harmful to moth populations and reduce blinding effects on the nightjar. Finally, the canton of Valais should set aside areas protected from human light emissions, in which nocturnal, red-listed species among birds, bats and moths still thrive. For this purpose, the Pfyn-Finges Nature Park, harbouring half of the current Swiss nightjar population, is a prime area.

Conclusion

The booming light emission during the last decades seems to be a major factor for the concerning decline of the nightjar in the fast-developing Lower Valais. At present, the species only survives in light-protected areas in the Upper Valais. Our study suggests that this nocturnal species cannot cope with the growing, human-induced light emission. Current light emission seems to have brought the nightjar to the brink of extinction in Switzerland, as it exceeds tolerable levels for this highly specialized nocturnal bird species. Implementation of conservation measures such as a change in bulbs of lamps in surroundings of, and a prohibition of light emission within, remaining habitats as well as in restored but so far not colonized sites is needed to safeguard this umbrella species.

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References

Alexander I, Cresswell B (1990) Foraging by Nightjars *Caprimulgus europaeus* away from their nesting areas. Ibis (Lond 1859) 132:568–574. https://doi.org/10.1111/j.1474-919X.1990.tb00280.x

Altermatt F, Ebert D (2016) Reduced flight-to-light behaviour of moth populations exposed to long-term urban light pollution. Biol Lett 12:1–4. https://doi.org/10.1098/rsbl.2016.0111

Auclair R (1988) Synthèse d'une étude sur l'engoulevent d'Europe Caprimulgus europaeus en Allier. Le Grand-Duc 32:1–34

Bender R (2016) Le Valais en chiffre. Rapport 2015. Office cantonal de la statistique

Brigham RM, Barclay MR (1992) Lunar influence on foraging and nesting activity of common poorwills (*Phalaenoptilus nuttallii*). Auk 109:315–320

Brigham RM, Barclay RMR (1995) Prey detection by common nighthawks—does vision impose a constraint. Ecosci 2:276–279

Bruderer B, Hirschi W (1984) Langfristige Bestandsentwicklung von Gartenrötel *Phoenicurus phoenicurus* und Trauerschnäpper *Ficedula hypoleuca*. Ornithol Beobachter 81:285–302

Conrad K, Warren M, Fox R, Parsons M, Woiwod I (2006) Rapid declines of common, widespread British moths provide evidence of an insect biodiversity crisis. Biol Conserv 132:279–291. https://doi.org/10.1016/j.biocon.2006.04.020

Da Silva A, Valcu M, Kempenaers B (2015) Light pollution alters the phenology of dawn and dusk singing in common European songbirds. Phil Trans B R Soc 370:20140126. https://doi.org/10.1098/rstb.2014.0126

Davies TW, Bennie J, Gaston KJ (2012) Street lighting changes the composition of invertebrate communities. Biol Lett 8:764–767. https://doi.org/10.1098/rsbl.2012.0216

de Jong M, Ouyang JQ, Da Silva A, van Grunsven RHA, Kempenaers B, Visser M, Spoelstra K (2015) Effects of nocturnal illumination on life-history decisions and fitness in two wild songbird species. Philos Trans B 370:20140128. https://doi.org/10.1098/rstb.2014.0128

Debrot AO (2014) Nocturnal foraging by artificial light in three Caribbean bird species. J Caribb Ornithol 27:40–41

Eisenbeis G (2006) Artificial night lighting and insects: attraction of insects to streetlamps in a rural setting in Germany. In: Rich C, Longcore T (eds) Ecological consequences of artificial night lighting. Washington, p 281–304

Epule ET, Peng C, Lepage L, Chen Z (2014) The causes, effects and challenges of Sahelian droughts: a critical review. Reg Environ Chang 14:145–156. https://doi.org/10.1007/s10113-013-0473-z

Evens R, Beenaerts N, Witters N, Artois T (2017a) Study on the foraging behaviour of the European Nightjar *Caprimulgus europaeus* reveals the need for a change in conservation strategy in Belgium. J Avian Biol 48:1238–1245. https://doi.org/10.1111/jav.00996

Evens R, Conway GJ, Henderson IG, Cresswell B, Jiguet F, Moussy C, Sénécal D, Witters N, Beenaerts N, Artois T (2017b) Migratory pathways, stopover zones and wintering destinations of western European Nightjars *Caprimulgus europaeus*. Ibis (Lond 1859) 159:680–686. https://doi.org/10.1111/ibi.12469

Evens R, Beenaerts N, Neyens T, Witters N, Smeets K, Artois T (2018) Proximity of breeding and foraging areas affects foraging effort of a crepuscular, insectivorous bird. Sci Rep 8:1–11. https://doi.org/10.1038/s41598-018-21321-0

Falchi F, Duriscoe DM, Kyba CCM, Falchi F, Cinzano P, Duriscoe D, Kyba CCM, Elvidge CD, Baugh K, Portnov BA, Rybnikova NA, Furgoni R (2016) The new world atlas of artificial night sky brightness. Sci Adv 2:e1600377. https://doi.org/10.1126/sciadv.1600377

Favre M, Clavien C, Richoz P, Favre G, Emery S, Coupy G, Carré D, Balleys PD, Buchard J-B, Roduit P-A (2016) Année vitivinicole 2015 Rapport annuel. Office cantonal de la viticulture. Sion

Fox R (2013) The decline of moths in Great Britain: a review of possible causes. Insect Conserv Divers 6:5–19. https://doi.org/10.1111/j.1752-4598.2012.00186.x

Fox R, Parsons MS, Chapman JW, Woiwod IP, Warren MS, Brooks DR (2013) The state of Britain's larger moths 2013. Butterfly conservation. Rothamsted Research. Manor Yard, East Lulworth, Wareham, Dorset

Fox R, Oliver TH, Harrower C, Parsons MS, Thomas CD, Roy DB (2014) Long-term changes to the frequency of occurrence of British moths are consistent with opposing and synergistic effects of climate and land-use changes. J Appl Ecol 51:949–957. https://doi.org/10.1111/1365-2664.12256

Frei C, Schär C, Lüthi C, Davies Huw C (1998) Heavy precipitation process in a warmer climate. Geophys Res Lett 25:1431–1434

Gragera FD (2015) Tacticas de caza del chotacabras cuellirrojo en la costa malaguena. Quercus 355:33–35

Hallmann CA, Sorg M, Jongejans E, Siepel H, Hofland N, Schwan H, Stenmans W, Müller A, Sumser H, Hörren T, Goulson D, de Kroon H (2017) More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PLoS One 12:e0185809. https://doi.org/10.1371/journal.pone.0185809

Heller K, Arlettaz R (1994) Is there a sex ratio bias in the bushcricket prey of the scops owl due to predation on calling males? J Orthoptera Res 2:41–42

Hoblyn R, Morris T (1997) Nightjar. In: Hagemeijer WJM, Blair MJ (eds) The EBCC Atlas of European breeding birds. Their distribution and abundance. Poyser, London, pp 422–423

Hölker F, Wolter C, Perkin EK, Tockner K (2010) Light pollution as a biodiversity threat. Trends Ecol Evol 25:681–682. https://doi.org/10.1016/j.tree.2010.09.007

Huntley B, Green RE, Collingham YC, Willis SG (2007) A climatic Atlas of European breeding birds. Durham University, RSPB, Lynx Edicion

Issa N, Müller Y (2016) Atlas des oiseaux nicheurs de France métropolitaine. Delachaux & Niestlé, Paris

Jetz W, Steffen J, Linsenmair KE (2003) Effects of light and prey availability on nocturnal, lunar and seasonal activity of tropical nightjars. Oikos 103:627–639

Keller V, Gerber A, Schmid H, Volet B, Zbinden N (2010) Liste rouge oiseaux nicheurs. Espèces menacées en Suisse, état 2010. Office fédéral de l'environnement, Berne et Station ornithologique suisse, Sempach

Knaus P, Antoniazza S, Wechsler S, Guélat J, Kéry M, Strebel N, Sattler T (2018) Atlas des oiseaux nicheurs de Suisse. Distribution des oiseaux nicheurs en Suisse 2013–2016. Distribution et évolution des effectifs des oiseaux en Suisse et au Lichtenstein. Station orntihologique suisse, Sempach

Knop E, Zoller L, Ryser R, Gerpe C, Hörler M, Fontaine C (2017) Artificial light at night as a new threat to pollination. Nat 548:206–209. https://doi.org/10.1038/nature23288

Kyba CCM, Tong KP, Bennie J, Birriel I, Birriel JJ, Cool A, Danielsen A, Davies TW, Outer PN Den, Edwards W, Ehlert R, Falchi F (2015) Worldwide variations in artificial skyglow. Sci. Rep. 5:1–6. https://doi.org/10.1038/srep08409

Lachat T, Pauli D, Gonseth Y, Klaus G, Scheidegger C, Vittoz P, Walter T (2011) Evolution de la biodiversité en Suisse depuis 1900. Avons-nous touché le fond? Zürich, Bristol-Stiftung. Haupt Verlag, Bern

Langston RHW, Liley D, Murison G, Woodfield E, Clarke RT (2007) What effects do walkers and dogs have on the distribution and productivity of breeding European Nightjar *Caprimulgus europaeus*? Ibis (Lond 1859). 149:27–36. https://doi.org/10.1111/j.1474-919X.2007.00643.x

Le Corre M, Ollivier A, Ribes S, Jouventin P (2002) Light-induced mortality of petrels: a 4-year study from Reunion Island (Indian Ocean). Biol Conserv 105:93–102. https://doi.org/10.1016/S0006-3207(01)00207-5

Leather SR (2018) "Ecological Armageddon"—more evidence for the drastic decline in insect numbers. Ann. Appl. Biol. 172:1–3. https://doi.org/10.1111/aab.12410

Liley D, Clarke RT (2003) The impact of urban development and human disturbance on the numbers of nightjar *Caprimulgus europaeus* on heathlands in Dorset. England. Biol. Conserv. 114:219–230. https://doi.org/10.1016/S0006-3207(03)00042-9

Longcore T, Aldern HL, Eggers JF, Flores S, Franco L, Hirshfield-Yamanishi E, Petrinec LN, Yan WA, Yamanishi E, Ln P, Wa Y, Am B, Longcore T (2015) Tuning the white light spectrum of light emitting diode lamps to reduce attraction of nocturnal arthropods. Philos Trans B R Soc 370:20140125. https://doi.org/10.1098/rstb.2014.0125

Longcore T, Rich C (2004) Ecological light pollution. Front Ecol Environ 2:191–198. https://doi.org/10.2307/3868314

Lowe A, Rogers AC, Durrant KL (2014) Effect of human disturbance on long-term habitat use and breeding success of the European Nightjar *Caprimulgus europaeus*. Avian Conserv. Ecol. 9:6. https://doi.org/10.5751/ACE-00690-090206

Macgregor CJ, Evans DM, Fox R, Pocock MJO (2016) The dark side of street lighting: impacts on moths and evidence for the disruption of nocturnal pollen transport. Glob. Chang. Biol. 23:697–707. https://doi.org/10.1111/gcb.13371

Mills AM (1986) The influence of moonlight on the behavior of goatsuckers (*Caprimulgidae*). Auk 103:370–378. https://doi.org/10.2307/4087090

Nicol JAC, Arnott HJ (1974) Tapeta Lucida in the eyes of goatsuckers *Caprimulgidae*. Proc. R. Soc. B 187:349–352

Plummer KE, Hale JD, Callaghan MJO, Sadler JP, Siriwardena GM (2016) Investigating the impact of street lighting changes on garden moth communities. J. Urban Ecol. https://doi.org/10.1093/jue/juw004

Raap T, Pinxten R, Eens M (2015) Light pollution disrupts sleep in free-living animals. Sci. Rep. https://doi.org/10.1038/srep13557

Raap T, Pinxten R, Eens M (2016) Artificial light at night disrupts sleep in female great tits (Parus major) during the nestling period, and is followed by a sleep rebound. Environ Pollut 215:125–134. https://doi.org/10.1016/j.envpol.2016.04.100

Revaz E (1999) Chronique ornithologique valaisanne: de l'hiver 1997–1998 à l'automne 1998. Bull. Murithienne 117:73–87

Rodríguez A, Dann P, Chiaradia A (2017a) Reducing light-induced mortality of seabirds: high pressure sodium lights decrease the fatal attraction of shearwaters. J Nat Conserv 39:68–72. https://doi.org/10.1016/j.jnc.2017.07.001

Rodríguez A, Holmes ND, Ryan PG, Wilson KJ, Faulquier L, Murillo Y, Raine AF, Penniman JF, Neves V, Rodríguez B, Negro JJ, Chiaradia A, Dann P, Anderson T, Metzger B, Shirai M, Deppe L, Wheeler J, Hodum P, Gouveia C, Carmo V, Carreira GP, Delgado-Alburqueque L, Guerra-Correa C, Couzi FX, Travers M, Corre M Le (2017b) Seabird mortality induced by land-based artificial lights. Conserv Biol. https://doi.org/10.1111/cobi.12900

Rodríguez A, Moffett J, Revoltós A, Wasiak P, McIntosh RR, Sutherland DR, Renwick L, Dann P, Chiaradia A (2017c) Light pollution and seabird fledglings: targeting efforts in rescue programs. J Wildl Manag 81:734–741. https://doi.org/10.1002/jwmg.21237

SCA (2017) Etat de situation de l'agriculture valaisanne. Rapport statistique 2016. Châteauneuf-Sion

Schaub M, Martinez NM, Tagmann-Ioset A, Weisshaupt N, Maurer M, Reichlin TS, Abadi F, Zbinden N, Jenni L, Arlettaz R (2010) Patches of bare ground as a staple commodity for declining ground-foraging insectivorous farmland birds. PLoS ONE 5(10):e13115. https://doi.org/10.1371/journal.pone.0013115

Schifferli L, Géroudet P, Winkler R, Jacquat B, Jean-Claude P (1980) Atlas des oiseaux nicheurs de Suisse (1972–1976). Station orntihologique suisse, Sempach

Schlegel R (1973) Der Ziegenmelker. Neue Brehm Bücherei

Schmid H, Luder R, Naef-Daenzer B, Graf R, Zbinden N (1998) Atlas des oiseaux nicheurs de Suisse. Distribution des oiseaux nicheurs en Suisse et au Lichtenstein en 1993–1996. Station ornithologique suisse, Sempach

Sharps K, Henderson IAN, Conway G, Armour- N, Dolman PM (2015) Home-range size and habitat use of European Nightjars. Ibis (Lond 1859). https://doi.org/10.1111/ibi.12251

Sierro A (1991) Ecologie de l'Engoulevent, *Caprimulgus europaeus*, en Valais (Alpes suisses): biotopes, répartition spatiale et protection. Nos Oiseaux 41:209–235

Sierro A (2016) Interventions forestières en faveur de l' Engoulevent en Valais (Alpes suisses). Bilan de 22 ans d'expérience (1993-2014). Station ornithologique, Sempach

Sierro A, Rey E (2007) Mesures de conservation et suivi de l'Engoulevent *Caprimulgus europaeus* en Valais: bilan 2007. Mesures de conservation, suivi de populations témoins et prospections élargies. Rapport interne. Station ornithologique suisse

Sierro A, Strebel S, Naef-Daenzer B (1995) Ecologie de l'engoulevent *Carpimulgus europaeus* en Valais. Rapport interne. Station ornithologique suisse, Sempach

Sierro A, Arlettaz R, Naef-Daenzer B, Strebel S, Zbinden N (2001) Habitat use and foraging ecology of the nightjar in the Swiss Alps: towards a conservation scheme. Biol Conserv 98:325–331. https://doi.org/10.1016/S0006-3207(00)00175-0

Squires WA, Hanson HE (1918) The destruction of birds at the lighthouses on the coast of California. Condor 20:6. https://doi.org/10.2307/1362354

Sutherland WJ, Pullin AS, Dolman PM, Knight TM (2004) The need for evidence-based conservation. Trends Ecol Evol 19:305–308. https://doi.org/10.1016/j.tree.2004.03.018

van Geffen KG, Van Grunsven RHA, Van Ruijven J, Berendse F, Veenendaal EM (2014) Artificial light at night causes diapause inhibition and sex-specific life history changes in a moth. Evol, Ecol. https://doi.org/10.1002/ece3.1090

van Geffen KG, Groot AT, van Grunsven RHA, Donners M, Berendse F, Veenendaal EM (2015a) Artificial night lighting disrupts sex pheromone in a noctuid moth. Ecol Entomol 1:1. https://doi.org/10.1111/een.12202

van Geffen KG, van Eck E, de Boer RA, van Grunsven RHA, Salis L, Berendse F, Veenendaal EM (2015b) Artificial light at night inhibits mating in a Geometrid moth. Insect Conserv Divers. https://doi.org/10.1111/icad.12116

van Langevelde F, Ettema JA, Donners M, WallisDeVries MF, Groenendijk D (2011) Effect of spectral composition of artificial light on the attraction of moths. Biol Conserv 144:2274–2281. https://doi.org/10.1016/j.biocon.2011.06.004

van Langevelde F, van Grunsven RHA, Veenendaal EM, Fijen TPM (2017) Artificial night lighting inhibits feeding in moths. Biol Lett. https://doi.org/10.1098/rsbl.2016.0874

van Langevelde F, Braamburg-Annegarn M, Huigens ME, Groendijk R, Poitevin O, van Deijk JR, Ellis WN, van Grunsven RHA, de Vos R, Vos RA, Franzén M, WallisDeVries MF (2018) Declines in moth populations stress the need for conserving dark nights Glob Change Biol 24:925–932. https://doi.org/10.1111/gcb.14008

Werner P (1988) La flore du Valais. Editions Pillet, Martigny

Wichmann G (2004) Habitat use of nightjar (*Caprimulgus europaeus*) in an Austrian pine forest. J Ornithol 145:69–73. https://doi.org/10.1007/s10336-003-0013-6

Winiger N, Korner P, Arlettaz R, Jacot A (2018) Vegetation structure and decreased moth abundance limit the recolonisation of restored habitat by the European Nightjar. Rethink Ecol 3:25–39. https://doi.org/10.3897/rethinkingecology.3.29338

Witt K, Völker F, Steffens R, Sudmann SR, Stübing S (2015) Atlas Deutscher Brutvogelarten. Dachverband Deutscher Avifaunisten und Stiftung Vogelwelt Deutschland, Münster

Wohlgemuth T, Brigger A, Gerold P, Laranjeiro L, Moretti M, Moser B, Rebetez M, Schmatz D, Schneiter G, Sciacca S, Sierro A, Weibel P, Zumbrunnen T (2010) Merkblatt für die Praxis Leben mit Waldbrand. Eidgenössische Forschungsanstalt WSL, Birmensdorf

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