



A&W-rapport 1439

ADDITIONAL RESEARCH ON THE IMPACT OF CONVENTIONAL ILLUMINATION OF OFFSHORE PLATFORMS IN THE NORTH SEA ON MIGRATORY BIRD POPULATIONS

Final report

FEBRUARY 2010

Commissioned by

Ministerie van Verkeer en Waterstaat



Rijkswaterstaat

A&W-rapport 1439

**ADDITIONAL RESEARCH ON THE
IMPACT OF CONVENTIONAL
ILLUMINATION OF OFFSHORE
PLATFORMS IN THE NORTH SEA ON
MIGRATORY BIRD POPULATIONS**

Final Report

February 2010

Leo W. Bruinzeel & Jelmer van Belle



Projectnummer	Projectleider	Status
1522OIC	L.W. Bruinzeel	concept
Autorisatie	Paraaf	Datum
Approved	E. Wymenga	February 2010

BRUINZEEL, L.W. & J. VAN BELLE 2010.

Additional research on the impact of conventional illumination of offshore platforms in the North Sea on migratory bird populations.
A&W-rapport 1439 Altenburg & Wymenga, ecologisch onderzoek, Feanwâlden

COMMISSIONED BY

Ministry of Public Works, Rijkswaterstaat, Water dienst

PHOTO FRONT PAGE

An offshore platform at night (photo from a presentation by Marquenie, Poot & Donners).

CONDUCTED BY

Altenburg & Wymenga ecologisch onderzoek bv
PO box 32, 9269 ZR Feanwâlden
Telefoon (0511) 47 47 64, Fax (0511) 47 27 40
e-mail: info@altwym.nl
web: www.altwym.nl

© **ALTENBURG & WYMENGA ECOLOGISCH ONDERZOEK BV**

Use of information from this report is allowed under proper citation. Not that for some figures and photo's the copyright is not with A&W.

CONTENTS

1. CONCLUSIONS AND CONSIDERATIONS	1
2. INTRODUCTION	3
3. NUMBERS OF BIRDS PASSING BY PLATFORMS	5
4. AVIAN NAVIGATION	9
5. DISTANCE OVER WHICH BIRDS ARE ATTRACTED TO LIGHT SOURCES	11
6. ENERGETIC MODELING OF BIRD MOVEMENTS ACROSS THE NORTH SEA	15
7. BIRD MORTALITY: COLLISIONS OR STARVATION?	19
8. LITERATURE REVIEW ON CONVENTIONAL LIGHTS AND BIRD ATTRACTION	21
REFERENCES	25

1. CONCLUSIONS AND CONSIDERATIONS

Conclusions

We conclude:

1. That the numbers and species composition of birds that are attracted by illuminated platforms in Dutch and British part of the North Sea bears a strong resemblance and there is no ground to assume that the study by Bruinzeel *et al.* (2009) might only be applicable to the Dutch situation.
2. That the sphere of influence of 1 km as used by Bruinzeel *et al.* (2009) was well chosen. Under most meteorological conditions this sphere of influence underestimates the range over which the light may cause disorientation.
3. That migratory birds in general can cope with the extra energetic costs associated with circling around illuminated platforms. However, bird casualties on illuminated platforms are not a result of energy stress, the birds die from collisions and are usually carrying large fat loads.
4. That wavelength dependent disorientation in birds is relatively new to science and this phenomenon is well documented in laboratory navigation studies and sufficiently documented in field studies.

Considerations

The conclusions are based on the following considerations:

1. Based on a recent study on bird attractions to platforms in the British part of the North Sea it is concluded that depending on weather conditions, attractions to platforms may involve thousands of nocturnal migrants, at several North Sea installations on the same date.
2. The bird species most commonly attracted to installations in the British part of the North Sea bears strong resemblance with the species composition among attracted birds in Dutch waters. All species that are found to be attracted in high numbers in British waters, face high impacts in the Dutch study (exceeding the 1% mortality threshold by factors between 10x-28x in a worst-case scenario).
3. Birds at night, that cannot navigate on celestial cues, can become disoriented during migration due to interference of light with the magnetic compass. Laboratory tests on four different bird species show proper orientation under short-wavelength light and disorientation under long-wavelength light, with a transmission between orientation and disorientation around wavelengths of 570nm. Disorientation in generally occurs at higher levels of irradiance and at longer wavelengths.

4. Disorientation in laboratory trials was observed at irradiance levels between 2.10^{11} and 50.10^{11} photons. $s^{-1}.cm^{-2}$ and was wavelength dependent. However, the lowest level at which disorientation was observed, was also the lowest light intensity that birds were subjected to (e.g there are no data available for irradiance levels below 2.10^{11} photons. $s^{-1}.cm^{-2}$). In the remaining analysis we adhere to a conservative irradiance levels of 5.10^{11} photons. $s^{-1}.cm^{-2}$ as the threshold above which disorientation may occur.
5. We calculated that for a platform with 30kW of lights, the threshold for disorientation ranges up to a distance of 200m (for dense fog), up to 1000m (fog), up to 1250 m (mist), up to 1400m (light rain) and up to 1650m for heavy rain. The 1000m sphere of influence arbitrarily used by Bruinzeel *et al.* (2009) therefore overestimates the impact in dense fog, but underestimates the impact for all other meteorological conditions, and is therefore on average a proper, but conservative estimate.
6. A potentially dangerous situation arises when visibility is perfect at sea level in a horizontal plain, but without available celestial cues due to clouds. Theoretically this may create a situation where disorientation can occur up to 4500m from a platform. This situation exceeds the theoretical scenario with the largest impact used by Bruinzeel *et al.* (2009). Although we have no information on the probability of occurrence of this meteorological state, this suggests that the 1000m contour as used by Bruinzeel *et al.* (2009) is a conservative estimate.
7. Energetic modeling shows that Willow warbler *Phylloscopus trochilus*, Robin *Erythacus rubecula* and Red Knot *Calidris canutus* can overcome the direct costs of circling one night around a platform. Redwings *Turdus iliacus* with a fuel supply of less than 10% fat can face critical energy depletion upon encountering an illuminated platform. Most migratory birds travel (on average) with sufficient energy stores to cover the additional costs associated with circling an entire night around an illuminated platform. However it is not known to what extent extra costs are involved such as costs associated with additional re-fueling, cost of arriving lean and the costs associated with diurnal instead of nocturnal migration (predation).
8. Birds that were found dead on an illuminated research platform in Germany and at a lighthouse in Wales were nearly all carrying normal amounts of fat. The birds in Germany were meticulously screened for wounds and nearly all birds had died as a direct result from trauma's and not from depletion of energy stores.
9. Research on wavelength dependent disorientation in the field is very new, all key publications on this topic date from the last 4 years. There is (circumstantial) evidence from lighthouses that a change of spectrum resulted in a decrease in victims. There are three field studies available that (through direct observation) support the evidence from laboratory work that light consisting of long-wavelengths cause disorientation. There is one study, using an indirect method, that does not support this.

2. INTRODUCTION

Framework

OSPAR is the mechanism by which fifteen governments of the western coasts and catchments of Europe, together with the European Community, cooperate to protect the marine environment of the North-East Atlantic. At the recent MASH-OSPAR meeting The Netherlands presented results of a research study on the impact of conventional illumination of offshore platforms in the North Sea on migratory bird populations (MASH 09/4/5 Rev.1/Bruinzeel *et al.* 2009). MASH noted that also EIHA 2009 had considered this issue and invited The Netherlands to work together with the UK and, as appropriate, other Contracting Parties, to explore how remaining scientific uncertainties could be solved.

Services requested

Recognizing that there are reasonable grounds for concern that conventional lighting of offshore platforms could affect migratory birds at a population level, MASH noted that:

- a. according to the precautionary principle a lack of full scientific evidence should not postpone the consideration of possible measures for preventing harmful effects on migratory birds at a population level;
- b. there is a need to further strengthen the evidence base by The Netherlands, in particular with regard to:
 1. further collection of (published) field data, to provide more accurate estimates of the number of birds passing by platforms;
 2. a better understanding of the distance over which birds are attracted to light sources on the basis of published scientific studies;
 3. an energetic (modeling) approach based on the estimated flight costs;
 4. evidence in peer reviewed literature on conventional illumination and the different light spectra attracting birds;
- c. there were safety concerns as green light is used as landing light for helicopters offshore

Following discussion, MASH invited The Netherlands to update the research study taking into account the comments made during the meeting and to report back to OIC 2010. This report contains the requested evidence base as requested by MASH.

Line-out

This report deals with the above mentioned topics. In chapter 3 we present information collected by ornithologists in the British part of the North Sea. This chapter is exclusively based on a recent study performed by Cork Ecology (Barton & Pollock 2009). The following chapter (4) is an essential side step and deals with avian navigation. Here we explain shortly how disorientation of birds occurs and synthesize results from avian navigation studies performed under laboratory conditions. These laboratory findings are used in chapter 5 to estimate at what distance from a platform birds might experience conditions that can give

rise to disorientation. We calculate the sphere of influence for a range of visibilities and associated meteorological conditions. These results are then compared to the spheres used by Bruinzeel *et al.* (2009) that were arbitrarily chosen. In chapter 6 we calculate flight costs for birds migrating across the North Sea and investigate whether migratory birds carry sufficient energy stores to cover the additional energetic costs of circling for prolonged periods of times around a platform. In chapter 7 we give a brief (non exhaustive) summary of the mortality factors and energy stores of birds that were found dead on an illuminated platform and a lighthouse. We explicitly investigate these cases with respect to the occurrence of fuel depletion as a main cause for mortality. In chapter 8 we give a review on the existing evidence regarding conventional lights and bird attraction.

3. NUMBERS OF BIRDS PASSING BY PLATFORMS

Impact of UK offshore installations on migratory birds

A recent study by Cork Ecology (Barton & Pollock 2009) investigated the significance of impact of UK offshore installations on migratory birds. This analysis was based on observations collected by the North Sea Bird Club between 2000 and 2005. The methodology followed by Barton & Pollock (2009) consisted of a thorough review of all observations collected on platforms by the North Sea Bird Club (see references in Barton & Pollock 2009). In summary, Barton & Pollock (2009) concluded that depending on weather conditions, attractions to platforms may involve thousands of nocturnal migrants, at several North Sea installations on the same date. The largest attractions would be associated with poor weather conditions involving fog, mist or drizzle and south-easterly winds. The study by Cork Ecology describes observations on species that are observed to circle around platforms and gives rough indications of their numbers. Bruinzeel *et al.* (2009) used observations carried out by one skilled observer (F van der Laar), on different platforms, over various years and over various seasons. In table 1 the main results are given from the British study. For each year (over the years 2000-2005) the peak magnitude of migration is given per species. The numbers refer to estimates at any one offshore installation at any one date. The median number is the median over the years 2000-2005. Seven species are most likely to occur in large numbers at North Sea installations during spring and autumn migration (these are highlighted in bold). Many of the species peak estimates occurred on the same dates.

Comparing the Dutch and British part of the North Sea

The species most commonly observed in the British study are compared with the estimated most common species attracted in Dutch waters (table 2). The species composition in the two studies bears a strong resemblance. Exceptions are Bramblings and Chaffinches that pass in relatively low numbers across Dutch platforms (they mainly follow the coastline in The Netherlands), while there is a strong flux passing over the central North Sea, from Norway to Scotland, that explains the high abundance in the study by Barton & Pollock (2009). Two other species are numerous in the Dutch study and less common in British waters. For the Robin this is explained by the long time window over which migration occurs and the different methods used (daily maxima versus total for a whole season). Therefore total numbers for a whole season are high (Dutch study) while daily maxima are low (British study), while in fact the total volume of birds passing across these areas might be comparable. Skylarks follow scenario C (see Bruinzeel *et al.* 2009), and pass through the central North Sea and are probably not recorded on platforms in the Northern North Sea and therefore relatively more numerous in Dutch waters. In addition the same explanation related to the methodology as for the Robin might apply.

Table 1. Peak magnitude of occurrence of commoner species recorded at North Sea installations (based on NSBC data), compiled by Barton & Pollock (2009). Species written in bold are most numerous.

Species:	year						median number
	2000	2001	2002	2003	2004	2005	
Oystercatcher	100-1,000	10-100	10-100	1-10	10-100	10-100	10-100
Golden plover	1-10	10-100	1-10	1-10	10-100	1-10	1-10
Lapwing	100-1,000	100-1,000	10-100	10-100	10-100	10-100	10-100
Dunlin	10-100	1-10	1-10	10-100	10-100	1-10	1-100
Snipe	1-10	10-100	1-10	1-10	1-10	1-10	1-10
Woodcock	1-10	10-100	1-10	10-100	1-10	1-10	1-10
Curlew	10-100	10-100	10-100	1-10	1-10	10-100	10-100
Redshank	1-10	10-100	1-10	1-10	1-10	1-10	1-10
Wood pigeon	1-10	100-1,000	1-10	10-100	1-10	1-10	1-10
Collared dove	1-10	1-10	1-10	1-10	1-10	1-10	1-10
Skylark	10-100	100-1,000	10-100	10-100	10-100	10-100	10-100
Meadow pipit	100-1,000	100-1,000	10-100	10-100	10-100	10-100	10-100
Pied wagtail	1-10	10-100	10-100	1-10	1-10	1-10	1-10
Wren	1-10	10-100	10-100	1-10	1-10	1-10	1-10
Robin	10-100	10-100	10-100	10-100	10-100	1-10	10-100
Redstart	1-10	1-10	1-10	1-10	1-10	1-10	1-10
Wheatear	10-100	1-10	1-10	1-10	1-10	1-10	1-10
Blackbird	1,000-10,000	100-1,000	100-1,000	10-100	1,000-10,000	100-1,000	100-1,000
Fieldfare	1,000-10,000	1,000-10,000	1,000-10,000	100-1,000	1,000-10,000	100-1,000	1,000-10,000
Song thrush	1,000-10,000	1,000-10,000	10-100	10-100	10-100	100-1,000	10-1000
Redwing	1,000-10,000	1,000-10,000	1,000-10,000	10,000-100,000	1,000-10,000	100,000-1,000,000	1,000-10,000
Garden warbler	1-10	1-10	10-100	1-10	1-10	1-10	1-10
Blackcap	100-1,000	10-100	1-10	1-10	10-100	10-100	10-100
Chiffchaff	1-10	1-10	10-100	1-10	1-10	1-10	1-10
Willow warbler	10-100	10-100	10-100	1-10	1-10	1-10	1-100
Goldcrest	100-1,000	10-100	10-100	100-1,000	10-100	10-100	10-100
Starling	1,000-10,000	1,000-10,000	1,000-10,000	100-1,000	1,000-10,000	1,000-10,000	1,000-10,000
Chaffinch	1,000-10,000	100-1,000	10-100	10-100	100-1,000	100-1,000	100-1,000
Brambling	1,000-10,000	100-1,000	10-100	10-100	100-1,000	1,000-10,000	100-1,000
Greenfinch	1-10	10-100	1-10	1-10	10-100	10-100	1-100
Siskin	1-10	1-10	1-10	10-100	10-100	10-100	1-100
Crossbill	0	10-100	10-100	1-10	1-10	1-10	1-10
Snow bunting	1-10	1-10	10-100	1-10	1-10	1-10	1-10

Table 2. Species most commonly attracted to platforms in the British part of the North sea (from Barton & Pollock 2009) compared to the estimated number for one platform for one autumn and the times the threshold is exceeded in Dutch waters from Bruinzeel *et al.* (2009).

Species	Median numbers in British waters (any one day, any one platform, 2000-2005, table 1)	Estimated number in Dutch waters (one place, whole autumn)	Times Exceeding threshold (1 km worst case scenario, see Bruinzeel <i>et al.</i> 2009)
Blackbird	100-1,000	150,000	18
Fieldfare	1,000-10,000	100,000	12
Song thrush	100-1,000	150,000	10
Redwing	1,000-10,000	250,000	14
Starling	1,000-10,000	25,000	14
Chaffinch	100-1,000	3,000	28
Brambling	100-1,000	2,500	21
Robin	10-100	90,000	9
Skylark	10-100	50,000	23

summary

The list of bird species most commonly attracted to installations in the British part of the North Sea bears strong resemblance with the species composition among attracted birds in Dutch waters. All species that are found to be attracted in high numbers in British waters, face high impacts in the Dutch study (exceeding the 1% mortality threshold by a factors between 10x-28x in a worst-case scenario). Species composition, number per species observed and associated risk factors in Dutch waters are in general applicable for the whole North Sea region, however small differences might exist between sub regions in the North Sea, but these can be explained in differences in migration routes taken by the different species, accounted for in the model by Bruinzeel *et al.* (2009).

In general there is no ground to assume that the study by Bruinzeel *et al.* (2009) might only be applicable to the Dutch situation.

Box**Seabirds and attraction to lights**

In the North Sea, seabirds are not documented as falling regularly victim to illuminated platforms on a large scale (Bruinzeel *et al.* 2009, Barton & Pollock 2009, Wiese *et al.* 2001). However in the Atlantic, Storm Petrels *Oceanodroma spp* and Little Auks *Alle alle* and shearwaters *Puffinus spp* regularly fall victim to these objects, sometimes involving large numbers (for review see Wiese *et al.* 2001, Rodriguez & Rodriguez 2009). For instance in the Pacific this type of mortality contributes significantly to the decline of endangered Hawaiian seabirds (Reed *et al.* 1985).



An offshore worker with a stranded Little Auk Alle alle, a species that is not frequently attracted in the North Sea in contrast to the Atlantic. Probably they only use magneto reception on the high seas, and not in the North Sea. Photo: Wim Maatje

4. AVIAN NAVIGATION

The avian compass

As Wiltschko & Wiltschko (2009) pointed out in their extensive review: ‘the navigation system of birds centres around two questions: how do birds set the course to a goal and what type of compass mechanisms do they use?’ A compass is a mechanism that indicates where directions like north and east lie, independent of the location on the globe where it is used. There are only two types of natural cues that can provide this information: (1) the geomagnetic field and (2) celestial cues. Both are used by birds for directional orientation (Wiltschko & Wiltschko 2009). The magnetic field is always available, but the mechanism based on celestial cues differs between day and night and is not always available at night due to cloud formations and other meteorological factors. Researchers have analyzed how the avian magnetic compass works and it was found to differ from a technical compass in three ways (see Wiltschko and Wiltschko 2007): it is an inclination compass (inclination is what differs between the magnetic field lines on the northern and the southern hemisphere), it operates only within a limited functional window and it is light (wavelength) dependent. This wavelength dependency is a relatively new scientific finding and is crucial in understanding the aggregation of birds around illuminated objects at night.

Wavelength dependence.

Tests with migratory birds under monochromatic light of different wavelengths indicate that the avian magnetic compass requires short-wavelength light from 360 nm (ultraviolet) up to ca. 565 nm (green). Under longer wavelengths, such as yellow-orange light (590 nm) and red light (630 nm) birds become disoriented (Rappl *et al.* 2000, Muheim *et al.* 2002, Wiltschko and Wiltschko 2007 and figure 1). Tests on four different bird species (European Robins, Australian Silvereyes, Garden Warblers and Homing Pigeons) showed proper orientation under monochromatic short-wavelength light, but disorientation under long-wavelength light, with a transition between orientation and disorientation around 570nm (see references in Johnson *et al.* 2007). This means that the same wavelength dependency of magnetoreception is found in birds of different orders and among passerines of different families (*Zosteropidae*, *Turdidae* and *Sylvidae*) and for different behaviours (homing in pigeons and migration orientation in passerines, Rappl *et al.* 2000). In general light intensity (quantal irradiance) for oriented (correct) behavior is generally less than for disoriented behaviour, though overlap occurs (Johnsen *et al.* 2007, figure 1). Correct orientation behaviour can only occur at artificial spectra below 600nm (Johnson *et al.* 2007). Disorientation in generally occurs at higher levels of irradiance and at longer wavelengths (figure 1). The lowest level at which disorientation was observed, was also the lowest light intensity that birds were subjected to in the laboratory trails. There is no data available for irradiance levels below 2.10^{11} photons. s^{-1} . cm^{-2}).

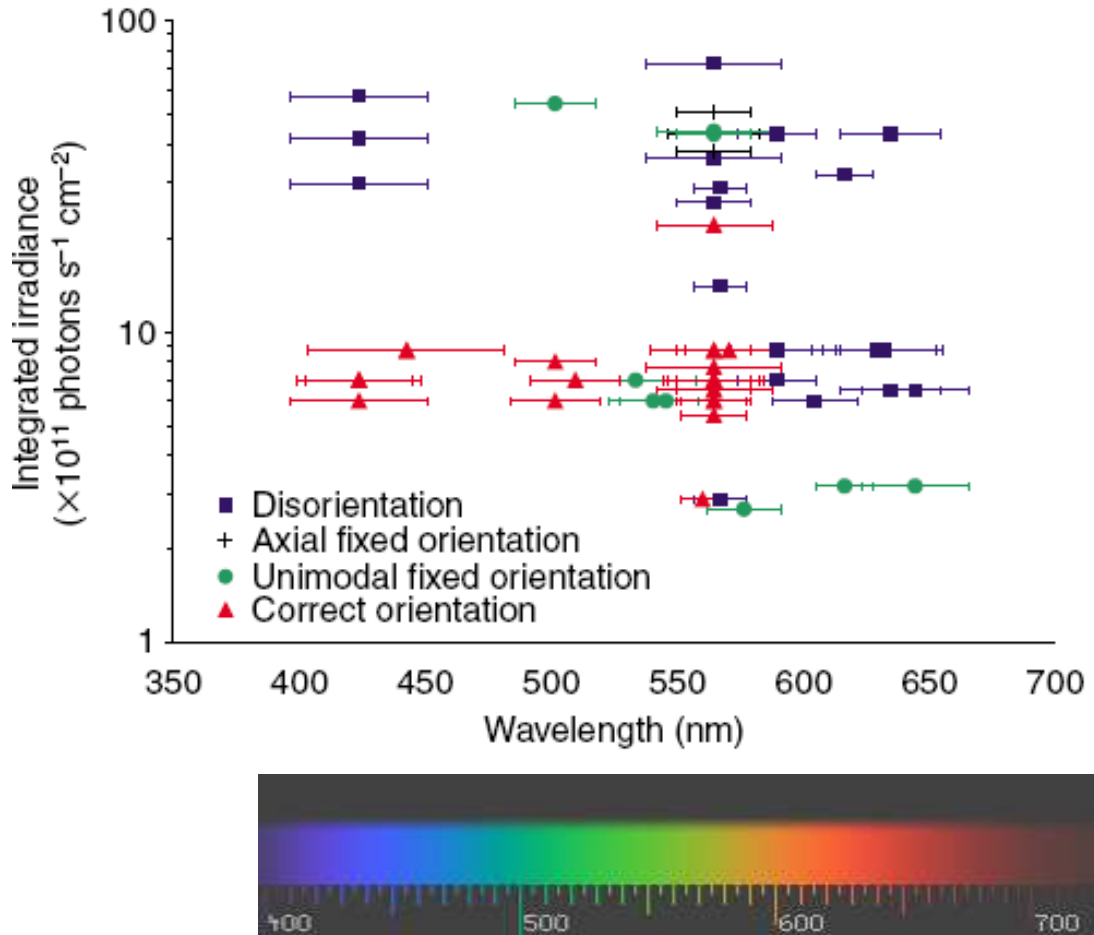


Figure 1 Scatterplot for the various behaviours measured in laboratory navigation trails as a function of the light intensity (measured in integrated irradiance) and wavelength (from Johnson et al. 2007). For comparison the wavelength of light of various colours is plotted on the same scale. ©Journal of experimental biology.

5. DISTANCE OVER WHICH BIRDS ARE ATTRACTED TO LIGHT SOURCES

Applying laboratory findings to the field situation

The lower threshold for light levels necessary for magneto reception in birds in the field are unknown (Evans *et al.* 2007) and the only evidence is from controlled laboratory trails. In the analysis by Johnson *et al.* (2007) disorientation was observed at irradiance levels between 2.10^{11} and 50.10^{11} photons. $s^{-1}.cm^{-2}$ and was wavelength dependent (Figure 1). The lowest light intensity where disorientation was observed (at 2.10^{11} photons. $s^{-1}.cm^{-2}$) lies a bit isolated from the other data points in figure 1 and might be regarded as an outlier. Therefore we adhere to a light intensity of 5.10^{11} photons. $s^{-1}.cm^{-2}$ as the lowest intensity where disorientation can occur. This is a conservative estimate for two reasons :1) the lack of available laboratory data for low light intensities (see chapter 4) and 2) since we regard the lowest level in Figure 1 as an outlier. We can calculate at which distance from the platform light intensity is comparable to the level where Johnson *et al.* (2007) witnessed disorientation. This will be compared with the arbitrarily chosen spheres of influence as used by Bruinzeel *et al.* (2009).

Light intensity in Figure 1 is measured in units for integrated irradiance, to convert these 'integrated irradiance' in to units that are applicable to the field situations ('integrated power') we used the following equation and the results are given in Table 3.:

$$E = h \cdot c \cdot \lambda^{-1}$$

According to Planck, the energy content of photons is linearly related to the frequency, and therefore the wavelength (i.e. colour) of the light source:

$$E = h \cdot c \cdot \lambda^{-1} \text{ (J)}$$

where :

h =	Planck constant	$6.63 \cdot 10^{-34}$	(J.s)
c =	speed of light	$3.0 \cdot 10^8$	(m.s ⁻¹)
λ =	wavelength		(m)

Table 3. Integrated power is a function of wavelength and integrated irradiance. Integrated irradiance levels are from Figure 1.

colour	Wavelength (nm)	Integrated power (W.m ⁻²) for different irradiances	
		Irradiance: 5.10^{11} photons. $s^{-1}.cm^{-2}$	Irradiance: 50.10^{11} photons. $s^{-1}.cm^{-2}$
Blue	400	$2.48 \cdot 10^{-3}$	$2.48 \cdot 10^{-2}$
Green	555	$1.79 \cdot 10^{-3}$	$1.79 \cdot 10^{-2}$
Red	650	$1.53 \cdot 10^{-3}$	$1.53 \cdot 10^{-2}$

Therefore, monochromatic green light, with a wavelength $\lambda = 555$ nm has an energy content of $3.58 \cdot 10^{-19}$ J per photon, leading to an integrated power of $1.79 \cdot 10^{-3}$ W. m⁻² at an integrated irradiance of $5 \cdot 10^{11}$ photons s⁻¹. cm⁻². Since normal working lights have a broad spectrum, we use from Table 3 the lowest value ($1.53 \cdot 10^{-3}$ W.m⁻²) as boundary values for the field situation. So disorientation of birds generally occurs at integrated powers above this value.

Light intensity as a function of visibility and distance

An illuminated platform at sea roughly produces 30kW of light (Poot *et al.* 2008) of which the helicopter deck and other upright located lights only form a minority (<10%) of all light produced (from data in Poot *et al.* 2008). We assume that one platform acts as a point light source and is emitting light with a power of 30kW/m². Under perfect conditions light intensity drops with the squared distance to the source (Figure 2). However situations are never perfect and we know that attraction of birds mainly occurs during periods of bad weather. In meteorology visibility is expressed in meters, and a visibility of 1000m implies that the light intensity at 1000m from the source is reduced by 95% (www.knmi.nl) and similar for other visibilities. In Figure 2 we plotted light intensity (w.m⁻²) of a platform (of 30kW) as a function of the distance (in meters) for visibilities of respectively 200m, 500m, 1000m, 1500m and 2000m. We also plotted the light intensity curve for the perfect situation where visibility is larger than 10,000m.

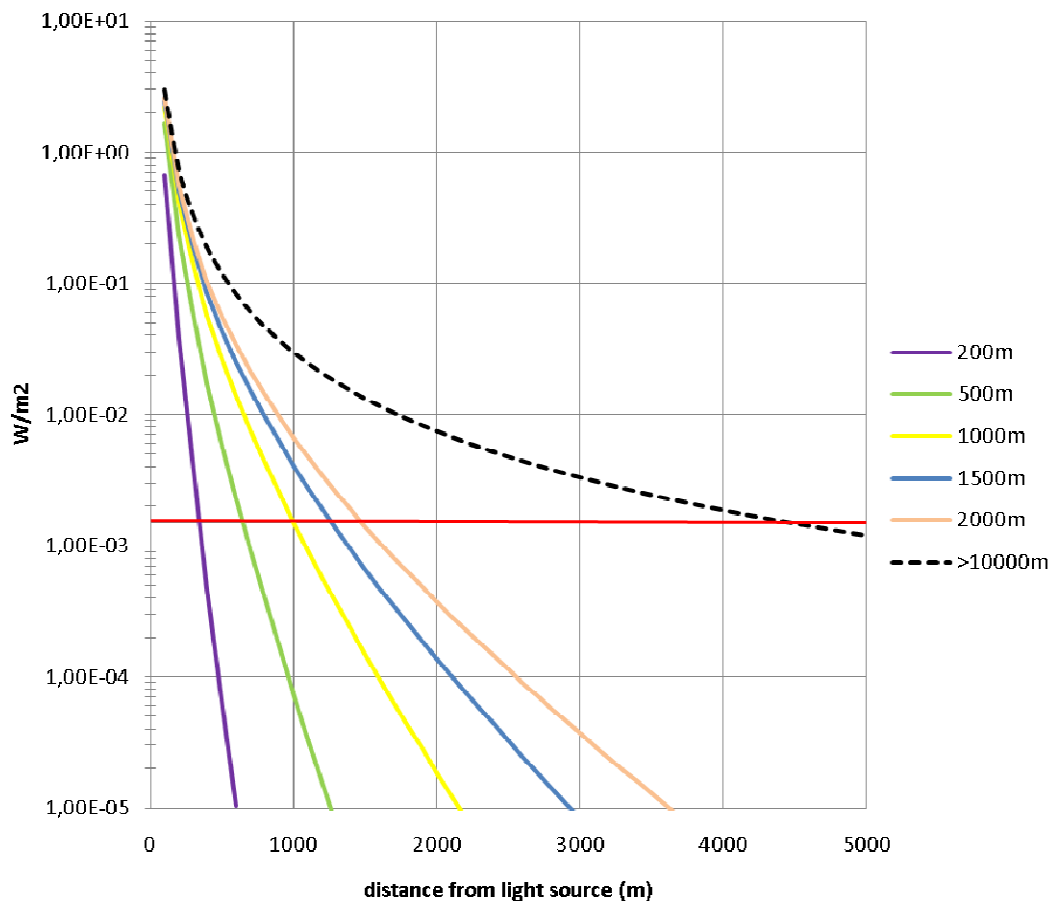


Figure 2. Light intensity as a function of the distance from a 30kW emitting platform for different visibility conditions (for a link between visibility and meteorological conditions see table 4). The red horizontal line represents an integrated power of $1.53 \cdot 10^{-3}$ W.m⁻²

Relation between visibility and meteorological state

In Table 4 we summarize the relation between visibility and the distance from a platform up to where the light intensity exceeds the value at which disorientation may occur. For a platform with 30kW of lights, the threshold for disorientation ranges up to a distance of 200m (for dense fog), 1000m (fog), 1250 m (mist), 1400m (light rain) and 1650m for heavy rain (Table 4). The 1000m sphere of influence arbitrarily used by Bruinzeel *et al.* (2009) therefore overestimates the impact in dense fog, but underestimates the impact for all other meteorological states and is therefore on average a conservative estimate.

Table 4. Relations between visibility at ground level (m) and associated meteorological states and the distance up to where disorientation may occur.

Meteorological condition	Visibility (m)	Distance (m) from a platform up to where the light intensity exceeds the value at which disorientation may occur.
Dense Fog	200m	350m
--	500m	650m
Fog	1,000m	1,000m
Mist	1,500m	1,300m
Heavy Rain (10mm.hr ⁻¹)	1,700m	1,400m
--	2,000m	1,500m
Light Rain (5 mm.hr ⁻¹)	2,500m	1,650m
Perfect ground visibility	>10,000m	4,500m

A potentially dangerous situation where visibility is perfect around sea level in a horizontal plain, but without celestial cues due to clouds, may create a situation where disorientation can occur up to 4500m from a platform. This scenario surpasses the most dramatic theoretical scenario of Bruinzeel *et al.* (2009). Although we have no information on the occurrence of such meteorological conditions, this finding also suggests that the 1000m contour as used by Bruinzeel *et al.* (2009) is a conservative estimate. The sphere of influence of 1 km as used by Bruinzeel *et al.* (2009) fits within the above presented analysis. Under most meteorological conditions (associated with mass attraction) a sphere of influence of 1 km underestimates the impact and is therefore a conservative estimate.

6. ENERGETIC MODELING OF BIRD MOVEMENTS ACROSS THE NORTH SEA

Apart from collisions, the most obvious costs of circling around oil rigs lies in the additional energy expenditure of a prolonged flight. Many migrants fly relatively short distances per night, approximately 100-300 km (Schaub & Jenni 2002), but crossing the North Sea between Norway, the UK or the Netherlands requires an uninterrupted flight of 450-500 km, without landing possibilities. Birds generally fly with more fuel stores than is a strictly necessary (Metcalf & Ure 1995, Kvist *et al.* 2001) but the question arises whether this is enough to sustain prolonged flight after a night of circling around an oil rig. This is especially important in autumn, when birds migrate slower and generally accumulate less fat than in spring (Berthold 1996). Therefore we calculated the estimated potential and required flight for autumn migrating birds trapped near an oil rig while crossing the North Sea between Norway, the UK and the Netherlands.

Energetic costs

Energetic costs of flying were calculated using the *Flight* program by Pennycuik (v1.22, 2009) and references therein. This program calculates the optimal speed and costs of flying based on aerodynamic theory, biometry and the energy content of fat and proteins (Pennycuik 2008, 1997, 1978). The sub-program *Migrate* estimates the costs of prolonged flight, incorporating the effects of the change in body mass, body contour and tissue composition during flight. The basic measure of migration potential in the *Flight* program is the 'energy height' (in km), a concept that is similar to 'potential energy' in physics and incorporates energy content of both fat and proteins (muscles) as they are 'used up' as fuel during flight. For this study however, we will focus on the potential flight hours connected to the fuel load.

The aerodynamical flight range equations require input on the type of bird (passerine or non-passerine), type of flight (continuously flapping or bounding flight), wing morphology (wing length and surface area), lean body mass and initial fat content of the birds (wet weights). For the wing morphology we relied on the wing database that is provided with the *Flight* program and fat fractions and body masses were obtained from the literature. In avian aerodynamical flight theory, the flight distance is mainly determined by the fat fraction in relation to the lean body mass (LBM), and this is also the fat fraction that is used in this study. If standard errors of fat fractions and/or body masses were found, we calculated the flight potential (in flight hours) for the average fat fraction of birds departing from a stopover site, and average fat fraction minus 2 standard deviations (i.e. the lowest 2.5%, assuming a normal distribution of fat fractions). For the required chemical power, the wing beat frequency was calculated using allometrical calculations in the *Flight* program.

Flight hours affected by milling

In our calculations, birds take off from the coast at astronomical dusk (sun > 12 degrees below the horizon) and fly in a straight line to their target coast. If a bird is attracted by a light source, it starts circling around the light up to astronomical dawn. At astronomical dawn (sun < 18 degrees below the horizon), the skies start to become lighter and other cues

can support the bird's orientation system and it resumes its flight in the desired direction to the target coast. We have not included wind effects in our calculations. Migration departure, especially near ecological barriers, is generally triggered by supporting winds (Åkesson *et al* 1996) and migrating birds tend to select flight altitudes with the most preferable winds (Liechti & Bruderer 1998), but situations with changing wind conditions over the North Sea are not uncommon and are suggested to affect flight routes over the North Sea (Buurma 1987).

Four bird species as model

For each bird type we have chosen specific species based on the availability of reliable data. We have specifically looked at reliable estimates for the lower part of the data distribution.

Willow Warblers *Phylloscopus trochilus* are long distance migrants. Willow Warblers from western Norway and western Europe winter in western Africa and southern Europe (Hedenström & Petterson 1987) and birds from southern Norway presumably cross the North Sea between Norway and the Netherlands, a distance of 500 km. Schaub & Jenni (2000) and Salewski *et al* (2009) refer to 'light' birds at autumn stopover sites with a fat fraction smaller than 15% of the lean body mass (LBM) and heavy birds with a fat fraction larger than 35% of the LBM. Using the mass estimates from these studies and the wing morphology in the wings database of the *Flight* program, we ran Flight calculations for an average bird with lean body mass 9.7(g) and fat fractions of 15%, 25% and 35% of LBM. For the birds with the smallest fat fraction, the estimated flight duration based on fuel stores was 26.3 hours. With an average flight speed of 11 m/s, 500 km can be crossed in 12.6 hours. In other words, birds with low departure fuel stores, that would get trapped around illuminated platforms just at the Norwegian coast and circle for the remainder of the night (6 hours at September 15), would have two hours of flight left after arrival on the Dutch coast. For birds with average departure fuel stores (fat fraction 25%) the potential flight time is 45 hours, leaving 20 hours after one night 'milling' and subsequent arrival at the Dutch coast in the scenario above.

Robins *Erithacus rubecula* are small short-distance partial migrants: Scandinavian birds winter in southern Europe, and Norwegian birds pass the Netherlands and the UK on their route during autumn migration in September and October. Karlsson *et al* (1988) showed clear differences in fat fractions between birds caught at two sites in Sweden: Ottenby *vs* Falsterbo and the higher fat fraction of Ottenby birds was attributed to the larger sea-passage ahead. In September, fat fractions were lower than in October. The mean fat fraction in September at Falsterbö was 9% of LBM, the lower value in the study, while the mean fat fraction in October at Ottenby was 32%, the higher value. The fat fraction in September at Ottenby was 18%. For the lowest fat fraction of 9%, the potential flight time was 15 hours, and flight duration would be 12 hours for 500 km (from Norway to the Netherlands), leaving only three hours 'spare time'. However, the appropriate low value is probably closer to value for Ottenby in September, when fat fraction was 18%. This leads to a potential flight time of 31 hours, ample time to get trapped for the duration of a night (10 hrs at October 15) and proceed flight tot the Dutch or UK coast.

The Redwing *Turdus iliacus* is a short-to medium distance migrant: Norwegian birds migrate in October and early November to the UK and Ireland, either directly through Scotland, or via the Netherlands (Meyers 1978, Buurma 1986). Redfern *et al.* (2000) provide data on fat fractions of birds that were found dead below a light house on the Welsh coast, right before

autumn departure towards Ireland. These birds carried 3-6 g fat, i.e. fat fractions of 5-10% relating to LBM's of 59 g, which is very low, especially in the vicinity of a barrier, and are strikingly low compared to fat fractions of other short-distance migrants such as the Robin, which had fat fractions of 15-30% before autumn departure near an ecological barrier (Karlsson et al 1988). With the given fat fractions, average birds with 7.5% fat can fly for 11.3 hours. At a speed of 16 m/s, birds leaving the western Norwegian coast will reach Scotland, UK (450 km) in 8.3 hours, leaving only 3 hours to spend on milling around an oil rig. Night duration at the latitude of Bergen is 9 hours at 15 October and birds getting trapped in the light of a platform up to 150km from the UK coast (relatively close to the target) or further from the UK coast, will not make it. Light birds with 5% fat can fly for only 7.5 hours and would not reach the UK coast at all. Therefore, for Redwings with fat fractions below 10%, fuel supplies will limit survival of birds that get trapped in the light of a platform.

The Red Knot *Canutus canutus* is a long-distance migrant that breeds in the subarctic regions of Siberia (ssp *canutus*) or Canada (ssp *islandica*). Helseth *et al.* (2005) estimated fat fractions at Ottenby (eastern Sweden) at 13.4% of LBM, and LBM at 100-110g. These LBM's and fat fractions are lower than generally found for spring migration. Assuming that standard deviations of body mass ($\pm 9.5\%$) scale equally to fat deposition, we set the standard deviation for fat fraction at 1.3%. The flight potential for the average fat fraction, 13% of LBM, was 37 hours and for the lowest 2.5% (-2sd) 29.5 hours. In other words, Red Knots departing with low fuel stores that get trapped in the light of a platform just at the Norwegian coast and circle for the remainder of the night (6 hours at September 15), would have 2 hours of flight left after arrival on the Dutch coast. For birds with average departure fuels stores (fat fraction 25%) the potential flight time is 45 hours, leaving 20 hours after one night 'milling and subsequent arrival at the Dutch coast in the scenario above.

Discussion and conclusions

Based on these flight simulations a lack of fuel reserves may be an important cause of mortality only for the Redwing. For the other species (Willow warbler, Robin and Red Knot) lack of fuel reserves is not likely to cause direct mortality. This is supported by several light house studies, which commonly show that birds found dead near lighthouses carry large fuel stores (see chapter 7). However, fuel stores are not only necessary for one night of flight, but are often the basis for build-up of fuel stores during migration, for instance to cross the Mediterranean Sea and the Sahara in a later stage of migration (Schaub & Jenni 2000). One night of 'milling' requires extra stopover days to restore fat losses and therefore may minimize the possibilities to use profitable weather. In addition, birds that have spend a night circling around a platform may need to prolong their journey in daylight, which may result in a higher predation risks.

7. BIRD MORTALITY: COLLISIONS OR STARVATION?

Poot *et al.* (2008) give no further information on the possible cause of death for birds that are attracted to light sources other than that it 'may cause direct mortality, or may have indirect negative effects through the depletion of their energy reserves'. In this chapter we provide information on this topic and rule out energy depletion as a main cause of death.

Lighthouse victims

A short glimpse on the literature concerning the condition of lighthouse victims reveal that Red Knots *Calidris canutus* were regularly found dead below the lighthouse of Westerhever, Germany. These birds typically showed body reserves similar to their live counterparts (Dietz & Piersma 2007, Dietz *et al.* 1999). A similar pattern was found among Redwings killed on 29 October 1995 at a lighthouse on Bardsey, Llyn Peninsula, North Wales (Redfern *et al.* 2000). The fat level and body mass of these birds were analyzed and the vast majority had large fat reserves and associated high body masses (Redfern *et al.* 2000, table 5A,5B). These cases clearly show that birds that got killed were in good condition.

Platform victims: a case study

Hüppop *et al.* (2006) analysed birds that fell victim on the German brightly lit FINO platform. The carcasses were taken to the laboratory, where measurements were taken and an attempt was made to establish the cause of death. This was done by thoroughly examining each individual for external injuries, contusions and fractures and additionally a few birds were X-rayed (Hüppop *et al.* 2006). A total of 442 birds of 21 species were found dead between October 2003 and December 2004 (Hüppop *et al.* 2006). The vast majority were in good physical condition, which excludes starvation as a cause of death. Only six out of 322 examined birds had a fat-score of 0 and may thus have died from energy depletion; however three of these were found also to have broken legs (Hüppop *et al.* 2006). Close examination showed that 245 individuals (76.1%) had outwardly apparent injuries, the most common of which were bleeding at the bill (41.3%), contusions on the skull and broken legs (16.8%)(Hüppop *et al.* 2006). It cannot be ruled out that the remaining quarter died from exhaustion caused by flying around the platform. Over 50% of all strikes occurred in just two nights (1 October 2003 and 29 October 2004) and both nights were characterized by adverse weather (very poor visibility, mist, drizzle). Thermal imaging camera revealed that many birds flew obviously disorientated around the illuminated platform. The results show that the majority of birds collected had collided with the structure and in only a few cases could starvation not be ruled out entirely as a mortality cause. It is a fair assumption that most of the birds fell into the sea (see figure 5C, 5D) or were taken by gulls. Thus, the actual total of collisions is presumably many times the number quoted here.

summary

In this (non-exhaustive) review it was shown that detailed analyses of bird victims associated with illuminated structures during migration reveal that the majority of victims die as a result of direct collision

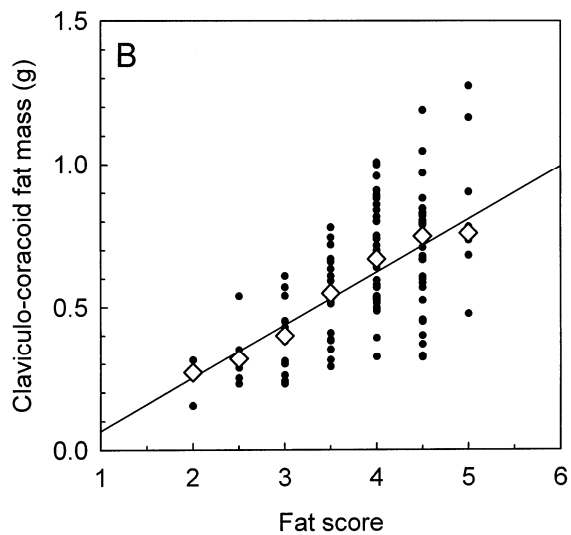
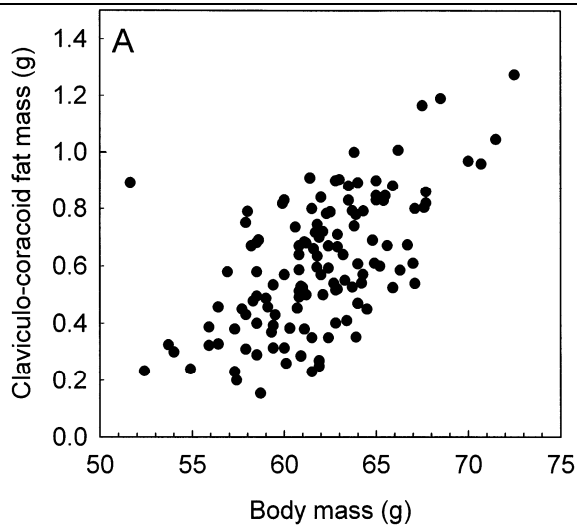


Figure 5A (top) and 5B (bottom) illustrating the frequency distribution of body mass (top) and fat score (0=very lean, 6 =very fat)(bottom) among Redwing light house victims. From Redfern *et al.* 2000 © Journal of avian biology.

Figure 5C (top) and 5D (bottom). Redwing fall at Fino1 illustrating that the probability of finding a casualty is low (top) and despite this numbers can still be substantial (bottom). Photo's © R. Hill from Hüppop *et al.* (2009)

8. LITERATURE REVIEW ON CONVENTIONAL LIGHTS AND BIRD ATTRACTION

Birds and attraction to lights

The phenomenon of large groups of birds attracted to artificial light sources has been known since 1895 (Gätke 1895 in Newton 2008). By the mid-twentieth century, artificial lighting was known to be responsible for causing large bird kills at airport ceilmeters, communication towers and tall buildings in inland eastern North America (for a review, see Gauthreaux & Belser 2006).

In North America, aviation obstruction lights on communication towers were documented to cause bird aggregation behaviour by Cochran and Graber (1958) and Avery *et al.* (1976). The towers in these studies had multiple tiers of slow flashing red beacons, each alternating with a tier of non-flashing red beacons in accordance with regulations. By the 1970s, bird kills at such towers were widespread in eastern North America (Weir 1976 and Avery *et al.* 1980 both in Evans *et al.* 2007), with annual mortality of more than 2,000 birds per year at some towers (Banks 1979 in Evans *et al.* 2007). One long-term study found more than 120,000 bird carcasses under a 300-m TV tower from 1957–1995 (Kemper 1996). This included 24 individual nights when over 1,000 birds were killed in the tower's vicinity (Evans *et al.* 2007). Such large nocturnal tower kills appear to be exclusively associated with low cloud cover or rain; under such conditions, a tower's aviation obstruction lights induce aggregations of migrating birds.

Evidence for wavelength dependent disorientation in birds

There are at least two described cases in the literature (Jones & Francis 2003 and Avery *et al.* 1976) where they documented the decrease in bird fatalities around lighthouses associated with a change in the light regime. Both cases involve a transition from broad spectrum incandescent light (that emits relatively more long-wavelength light) to mercury vapor lights (Jones & Francis 2003) or xenon filled lights (Avery *et al.* 1976). Both new lights were emitting much more short-wavelength light compared to long-wavelength light: mainly around 365nm, 400nm and 435nm for mercury lights and various short-wavelengths, extending into ultraviolet for xenon lights. However, both studies also involved a narrower and less powerful beam (Jones & Francis 2003) or a change from a continuous revolving beam into a flashing beam, giving light flashes intermittent with 10 seconds darkness (Avery *et al.* 1976). These studies, probably unaware of the possibility that the composition of the light might as well explain the attraction, attributed the change of bird fatalities to changes in the nature and intensity of the beam, and not to a change of composition of the light. Based on the current knowledge on wavelength dependent magneto reception, at least part of the decrease in attraction at these lighthouses must have been attributed to a change of spectrum. We regard these studies as circumstantial evidence for the occurrence of wavelength dependent attraction in the field, and given the weakness of their evidence base, we restricted our review to only two of these cases.

More than 30 years ago, Avery *et al.* (1976) urged for field studies on the reactions of night-migrating birds to lights of various intensities, wavelengths, and flash rates in order to increase our understanding of bird aggregation at illuminated structures. Up to our

knowledge (by using ‘web of science’), up to now, only four experimental or semi-experimental studies have been performed (Evans *et al.* 2007, Poot *et al.* 2008 and Gehring *et al.* 2009, Gautreaux and Belser 2006, table 6). These studies are all very recent, dating from 2006 to 2009 (Table 6).

Table 6. Main sources used to describe wavelength dependent attraction in birds.

Source	Method	Type	Testing for
Poot <i>et al.</i> 2008	Direct/visual observations	Field experiment	Wavelength dependent attraction
Evans <i>et al.</i> 2007	Indirect/nocturnal call frequency	Field experiment	Wavelength dependent attraction
Gehring <i>et al.</i> 2009	Direct/counting victims	Field study	Different types of lights (steady red versus other types)
Gautreaux & Belser 2006	Direct/visual observation	Field study	Different types of lights (steady red versus other types)
Johnson <i>et al.</i> 2007	Meta-analysis	Experimental Lab. study	Wavelength and intensity
Jones & Francis 2003	Direct/counting victims	Circumstantial evidence	Combination of factors (wavelength, intensity, light regime)
Avery <i>et al.</i> 1976	Direct/counting victims	Circumstantial evidence	Combination of factors (wavelength, intensity, light regime)

Studies in detail

The study by Poot *et al.* (2008) clearly demonstrates the expected wavelength dependency of disorientation and gives support for the applicability of laboratory navigation studies to the field situation. The study of Evans *et al.* (2007) contradicts the navigation studies and the known field studies as mentioned above. The method used by Evans *et al.* (2007) of measuring bird aggregation relies on the calling frequency of birds and it is assumed that a higher calling frequency involves more birds, this method has been questioned by Gehring *et al.* (2009). Evans *et al.* (2007) do not question the fact that red light causes aggregation and give several options that could explain their deviating results.

Gehring *et al.* (2009) tested simultaneously various communication tower designs and compared height, support system (guyed or non-guyed) and different types of obstruction lightning. They give strong support for the fact that of all different light types (strobe lights, flashing lights, white lights and red lights) the steady burning red-lights cause the majority of casualties and by replacing steady burning red lights with flashing lights the fatalities could be reduced by 50-70%.

Gautreaux & Belser (2006) monitored flight behaviour on 14 evenings during fall migration near a television tower with red lights, near a television tower with white strobe lights, and over a control area that had no tower. They used an image intensifier to monitor birds flying

overhead. Significantly more birds were recorded flying near the tower with red lights than flying near the tower with white strobes and over the control site.

Overview

In summary, there are three field studies available that (through direct observation) support the evidence from laboratory work that light consisting of long-wavelengths cause disorientation. There is one study, using an indirect method, that does not support this. Wavelength dependent disorientation in birds is well documented in laboratory navigation studies and sufficiently documented in field studies.

REFERENCES

- Avery, M. L., P. F. Springer & J. F. Cassel 1976. The effects of a tall tower on nocturnal bird migration—a portable ceilometers study. *Auk* 93: 281-291.
- Åkesson, S., T. Alerstam & A. Hedenström 1996. Flight initiation of nocturnal passerine migrants in relation to celestial orientation conditions at twilight. *J. Avian Biol.* 27: 95-102.
- Åkesson, S. & A. Hedenström, 2000. Wind selectivity of migratory flight departures in birds. *J. Beh. Ecol. Soc.* 47: 140-144.
- Barton, C. & C. Pollock 2009. Study to evaluate the significance of impact of UK offshore installations on migratory birds. Cork Ecology publication, Cork, Ireland.
- Berthold, P. 1996. Control of bird migration. Chapman and Hall, London.
- Bruinzeel, L.W., J. van Belle, L. Davids m.m.v F. van de Laar 2009. The impact of conventional illumination of offshore platforms in the north Sea on migratory bird populations. A&W report 1227, Altenburg & Wymenga Ecological Consultants, Veenwouden, 38 p.
- Buurma, L. S. 1987. Patterns of high bird migration over the North Sea area in October. *Limosa* 60: 63-74.
- Cochran, W. W. & R. R. Graber 1958. Attraction of nocturnal migrants by lights on a television tower. *Wilson Bulletin* 70: 378- 380.
- Dietz, M. W & T. Piersma 2007. Red knots give up flight capacity and defend food processing capacity during winter starvation. *Functional ecology* 21: 899-904.
- Dietz, M. W., A. Dekinga, T. Piersma & S. Verhulst 1999. Estimating organ size in small migrating shorebirds with ultrasonography: an intercalibration exercise. *Physiological and Biochemical Zoology* 72 :28-37.
- Evans, W., Y. Akashi, N.S. Altman & A.M. Manville II 2007. Response of night-migrating songbirds in cloud to colored and flashing light. *North American Birds* 60:476-488.
- Gauthreaux, S. A., Jr., & C. G. Belser 2006. Effects of artificial night lighting on migrating birds. In: *Ecological Consequences of Artificial Night Lighting*. (eds. C. Rich and T. Longcore), pp. 67-93. Covelo, California: Island Press.
- Gehring, J., P. Kerlinger & A.M. Manville II 2009. Communication towers, lights and birds: successful methods of reducing the frequency of avian collisions. *Ecological applications* 19: 506-514.
- Hedenström, A & J. Petterson 1987. Migration routes and wintering areas of Willow Warblers *Phylloscopus trochilus* (L.) ringed in Fennoscandia. *Ornis Fennica* 64: 137-143.

- Helseth, A., Å. Lindström & M. Stervander 2005. Southward migration and fuel deposition of Red Knots *Calidris canutus*. *Ardea* 93: 213-224.
- Hüppop, O., J. Dierschke, K.-M. Exo, E. Friedrich & R. Hill 2006. Bird migration studies and potential collision risk with offshore wind turbines. *Ibis* 148:90-109.
- Hüppop, O and R. Hill, K. Hüppop, F. Jachmann 2009. Auswirkungen auf den Vogelzug Begleitforschung im Offshore-Bereich auf Forschungsplattformen in der Nordsee FINOBIRD. Institut für Vogelforschung „Vogelwarte Helgoland“, Germany.
- Johnson, S., E. Mattern & T. Ritz 2007. Light-dependent magnetoreception: quantum catches and opponency mechanisms of possible photosensitive molecules. *Journal of experimental biology* 210: 3171-3178
- Jones J. & C. M. Francis 2003. The effects of light characteristics on avian mortality at lighthouses. *Journal of avian biology* 34: 328-333.
- Karlsson, L., K. Persson, J. Pettersson & G. Walinder 1988. Fat-weight relationships and migratory strategies in the Robin *Erithacus rubecula* at two stop-over sites in south Sweden. *Ringing & Migration* 9: 160-168.
- Kemper, C. 1996. A study of bird mortality at a west-central Wisconsin TV tower from 1957-1995. *Passenger Pigeon* 58: 219-235.
- Kvist, Å., A. Lindström, M. Green, T. Piersma & G.H. Visser 2001. Carrying large fuel loads during sustained bird flight is cheaper than expected. *Nature* 13: 730-732
- Liechti, F. & B. Bruderer 1998. The relevance of wind for optimal migration theory. *J. avian biol.* 29: 561-568.
- Metcalf N.B. & S.E. Ure 1995. Diurnal variation in flight performance and hence potential predation risk in small birds. *Proc. R. Soc. Lond. B*, 261: 395-400.
- Muheim, R., J. Bäckman, & S. Åkesson 2002. Magnetic compass orientation in European Robins is dependent on both wavelength and intensity of light. *Journal of Experimental Biology* 205:3845-3856.
- Newton, I 2008. The migration ecology of birds. Academic press, London.
- Pennyquick, C.S. 2009. Flight v 1.22. (Computer program).
- Poot, H., B.J. Ens, H. de Vries, M.A.H. Donners, M.R. Wernand & J.M. Marquenie 2008. Green Light for Nocturnally Migrating Birds. *Ecology and Society* 13(2): 47. Online Open Access: www.ecologyandsociety.org/vol13/iss2/art47/
- Rappl, R., R. Wiltschko, P. Weindler, P. Berthold & W. Wiltschko 2000. Orientation behavior of Garden Warblers (*Sylvia borin*) under monochromatic light of various wavelengths. *Auk* 117:256-260.
- Redfern, C.P.F., A. E. J. Slough, B. Dean, J.L. Brice & P. Hope Jones 2000. Fat and body condition in migrating Redwings *Turdus iliacus* *J. Avian Biology* 31:197-205.

Reed, J.R., J.L. Sincock & J.P. Hailman 1985. Light attraction in endangered procellariiform birds: reduction by shielding upward radiation. *Auk* 102: 377-383.

Rodriguez, A., & B. Rodriguez 2009. Attraction of petrels to artificial lights in the Canary Islands: effect of the moon phase and age class. *Ibis* 151: 299-310.

Salewski, V., M. Kéry, M. Herremans, F. Liechti & L. Jenni 2009. Estimating fat and protein fuel from fat and muscle scores in passerines. *Ibis* 151: 640-653.

Schaub, M. & L. Jenni 2002. Fuel deposition of three passerine bird species along the migration route. *Oecologia* 122:306-317.

Wiese, F. K., W. A. Montevecchi, G. K. Davoren, F. Huettmann, A. W. Diamond & J. Linke 2001. Seabirds at risk around offshore oil platforms in the northwest Atlantic. *Marine Pollution Bulletin* 42:1285-1290.

Wiltschko, W., & R. Wiltschko 2007. Magnetoreception in birds: Two receptors for two different tasks. *Journal of Ornithology* 148 (Supplement 1):61-76.

Wiltschko, R., K. Stapput, H.-J. Bischof & W. Wiltschko 2007. Light-dependent magnetoreception in birds: Increasing intensity of monochromatic light changes the nature of response. *Frontiers in Zoology* 4:5.

Wiltschko R. & W. Wiltschko W. 2009. Avian navigation. *The Auk* 126: 717-743.