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REVIEW OF THE OCCURRENCE AND MAGNITUDE OF THE CONFLICT BETWEEN MIGRATORY ANIMALS OF ALL TAXA AND RENEWABLE TECHNOLOGIES DEPLOYMENT

Background

Within the framework of a joint initiative between the Secretariats of the Convention on the Conservation of Migratory Species of Wild Animals (CMS) and the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA), on behalf of the entire CMS Family; the International Renewable Energy Agency (IRENA); and the BirdLife International UNDP/GEF Migratory Soaring Birds project, a review report on the interactions between renewable energy technologies deployment and migratory species has been compiled.

This document was produced under consultancy. It constitutes the final version of a review report, which was presented at the CMS COP11 in November 2014 and informed CMS Resolution 11.27. This work has been contributing to the implementation of the task of Technical Committee (TC) Working Group 8 on renewable energy and migratory waterbirds and the TC has been consulted in the preparatory phase of this report as well as earlier during the drafting of the Terms of Reference. At its 12th meeting in March 2015 the TC has approved this report for submission to the Standing Committee meeting and MOP6.

The production of this document was made possible thanks to financial contributions from the governments of Germany and Norway through the UNEP/CMS and UNEP/AEWA Secretariats, from BirdLife International through the UNDP/GEF *Migratory Soaring Birds* project and from IRENA.

Action requested from the Standing Committee

The Standing Committee is requested to decide on the submission of this document to the 6th Session of the Meeting of the Parties to AEWA.

Renewable Energy Technology Deployment and Migratory Species: an Overview

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Executive summary

Objective

The International Renewable Energy Agency, the Convention on the Conservation of Migratory Species of Wild Animals (CMS) and the African-Eurasian Waterbird Agreement (AEWA), on behalf of the entire CMS Family, and BirdLife International have commissioned a review of Renewable Energy Technologies (RET) deployment and their possible impacts, negative and positive, on migratory species, and guidelines for mitigating and avoiding possible conflicts with migratory species.

This review aims to present an up-to-date overview of the nature, scale and impact of RET on migratory species, including a summary of the aspects involved and gaps in knowledge. The review forms the basis for the separate guidelines document 'Renewable Energy Technologies and Migratory Species: Guidelines for sustainable deployment', that covers the technical and legislative solutions as well as suggestions for evaluating and monitoring the effectiveness of mitigation and preventive measures.

Migratory species characteristically have geographically separate breeding and non-breeding ranges connected by migration routes. Individuals and populations can therefore be affected at several points during their life cycle: in breeding areas, during migration or at migratory stopover sites, or in non-breeding areas. Impacts can be cumulative and result from combinations of comparable or different renewable energy deployments, as well as from other developments and environmental pressures.

When the potential impacts on species are known, appropriate measures can be taken to minimize these impacts. More specifically, the challenge is to identify which species are likely to be adversely affected, the locations at which adverse impacts are most likely to occur, and the specific features of the environment and man-made structures that pose the greatest risks, so that adverse effects can be avoided or mitigated. This information is particularly important in the early stages of Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA) processes.

This review focuses on the six commonest sources of renewable energy (bioenergy, geothermal energy, hydropower, ocean energy, solar energy and wind energy), and the possible impacts of their deployment on the migratory species listed by the CMS Family, and focussing on the technologies that are commercially available. The review especially covers impacts in the *operational* phase of RET. Impacts in the exploration and construction phases (*e.g.* infrastructure) are also summarised, but in less detail as these are in most cases not limited to renewable energy and are already reviewed in other studies. Cumulative impacts of renewable energy deployments are also addressed.

General conclusions

Table S1 summarizes the main impacts of renewable energy technologies deployment on migratory species groups. In general, the species groups where impacts are most likely to occur include migratory birds, mammals and fish. The main (potential) impacts of RET deployment on migratory species are habitat loss, habitat degradation, disturbance, barrier effects and direct mortality.

In general, relatively few systematic studies on the impacts of RET deployment on migratory species have been undertaken. Most papers and reviews include speculations on impacts. The review shows a few examples where population effects of RET deployment have been demonstrated (*e.g.* hydropower and fish and wind energy and raptors).

It is emphasised that the impacts of RET deployment on migratory species are very project**-** and site-specific. The nature, scale and degree of impacts will vary according to site- and project specific factors such as the specifications of the development (design, scale, technology), the habitat affected, the species involved, seasonal and diurnal patterns of use of the project site by species. With so many variables involved, it is difficult to make generalisations about impacts of RE deployment on migratory species.

Table S1. Summary of the main impacts of renewable energy technologies deployment on migratory species groups (mammals, birds, fish, reptiles, insects). Due to differences in scale and distribution worldwide effects differ substantially. - = impact on population level is negligible.

Energy source deployed	**Regionally or locally high impact, but with no significant impact on the overall species population**	**Impacts on population level known**	**Impacts on population level likely**
bioenergy		all species groups	- primates, - migrant birds (raptors forest birds)
geothermal	species of fish, birds and mammals	-	-
hydropower	species of fish, birds and mammals	several fish species, one extinction, water-birds	fish, mammals, birds
ocean energy	species of fish, sea turtles birds, crustaceans and squid	-	-
solar power	species of insects, birds and mammals	- (only small scale)	- (only small scale)
wind energy	species of birds and bats	few bird species	birds and bats

Bioenergy

The consensus of the literature is that habitat loss and degradation are the main impacts of bioenergy technology and migratory species. Of particular concern are the conversion of ‘high-nature-value’ farming to more intensive monocropping and the conversion of pristine areas (e.g. primary forests). Birds and terrestrial mammals are the primary species groups that can be affected, but also fish can be impacted. In the United States, for example, grassland birds are the primary species affected due to the conversion of native prairie habitat to biofuel production fields. Bioenergy can be produced using a variety of feedstocks and methods. Hence, the (potential and significance of) impacts of bioenergy on migratory species are variable. Moreover, the impacts are site-, and species- specific. This makes it is difficult to make generalization about the impacts. In general, bioenergy from dedicated feedstocks is characterised by relatively large land use requirements and potentially relatively large water use requirements. Land use and change and water use are the main issues of concern with respect to impacts of bioenergy on migratory species. Besides that, feedstock cultivation can lead to emission of nutrients and pesticides to aquatic systems. The subsequent processing of the feedstock into biofuels and electricity can increase chemical and thermal pollution loads from effluents and generate waste to aquatic systems. These impacts can result in degradation of key habitat for migratory fish species.

An important concern is the indirect impact of bioenergy driven change in land use. Bioenergy developments may indirectly lead to changes in land use elsewhere. A biomass plantation can be established on land previously used for grazing or crops with limited impacts on biodiversity. The previous land use might, however, shift to other (pristine) areas and result in significant habitat deterioration of migratory species.

Depending on a variety of factors, bioenergy can also lead to positive impacts on migratory species. Bioenergy plantations can be designed to provide filters for nutrient loss, to function as ecological corridors or stepping-stones, to reduce pressure on natural forests and to restore degraded or abandoned land. The impact assessments for all the determining factors, positive and negative, deserve considerably more research, data collection and proper monitoring for the careful siting and design of bioenergy projects in future. As for all RE developments the long-term and migratory species population-level consequences of large-scale deployment of bioenergy need further research.

Geothermal

Although there is quite some literature on the potential environmental impacts of the development of geothermal resources, literature on actual impacts (post monitoring studies) is limited. The general conclusion from the literature reviewed is that geothermal energy technologies generally present relatively low impact on migrating species as compared to the development of other forms of energy. This has among other things to do with the small overall footprint of geothermal energy conversion equipment and the relatively low water demand.

Geothermal development and deployment can impact migratory species, specifically birds, terrestrial mammals and fish. The significance of the impacts of geothermal development and deployment on migratory species depends upon a number of factors including the surface of land disturbed by drilling and construction activities, the number and size of well pads, the type of power plant technology used, the surface of land occupied by facilities over the life of the geothermal facility, and the facility's location with respect to critical habitat for migratory species. Geothermal development typically has an exploration phase. Activities during the exploration phase are temporary and are conducted at a smaller scale than those during the construction, operational and decommissioning phases. The noise levels in the exploration phase are relatively high due to seismic testing and drilling activities. This could potentially disturb wildlife, specifically birds and terrestrial mammals. The potential impacts of the construction & decommissioning phase are similar to other RE developments, including mortality, habitat loss, habitat fragmentation, habitat degradation and disturbance. As potential areas for geothermal energy development are often in or adjacent to nature reserves and forested areas, site-specific effects (habitat loss, degradation and fragmentation) can potentially have more severe impacts on species. Impacts during the operations and maintenance phase could occur as a result of noise disturbance and water demand during the life cycle of the project.

Hydropower

The general conclusion from the literature reviewed is that hydropower energy technologies can have serious impacts on migratory species populations. For at least one species, the Yangtze river dolphin, extinction in the wild has been recorded in recent years. Impacts on migratory fish and aquatic mammals can be significant, and although mostly occurring at the local scale may be noticed at the population level. The construction phase is in general difficult to separate from the operational phase in terms of impacts, as the construction of dams is the dominant negative impact. The positive effects are mostly a result of standing fresh water bodies behind the dams serving new habitat for species such as waterbirds and many fish species. But introduction of alien invasive species in these waterbodies can result in additional negative impacts on native (endemic) migratory species.

The species groups where negative impacts are to occur include fish, aquatic mammals and birds bound to currents and riverine habitats. The main effects of deployment of hydropower energy on migratory species are barrier effects, which in fact lead to direct habitat loss and habitat degradation.

The primary gaps in knowledge are related to the effects of mitigation measures. For many species and river systems the effects are insufficiently known. Although in general the impacts on species are known, for specific sites the effects can be unknown as information lacks on existing migratory species and crucial migratory pathways. E.g. Larinier (2001 in Marmulla, 2001) states that “almost nothing is known about migratory fish species”, particularly in developing countries. This gap in knowledge can be addressed by anticipating on effects in the construction phase and including mitigation measures such as fish passes. The long-term and migratory species population-level consequences of large-scale deployment of hydroenergy need further research.

Ocean energy

The diversity of migratory organisms that may be impacted by new and developing ocean energy technologies is compounded by the diversity of the technologies themselves, thus obscuring the ability of researchers to predict the impact of ocean energy development on the marine environment.

The current literature on the subject identifies the primary potential conflicts between these technologies and migratory species as:

1. Mortality by impingement, entrainment, entanglement, and collision of migratory species with submerged and surface structures or vessels. These potential impacts are compounded by the attraction of species to the offshore structures or prey aggregations that may form in the area.
2. Habitat loss as coastal areas are altered by development of tidal barrages or energy generation facilities, or processes impacted by offshore development. In addition, habitat loss that occurs due to expanses of ocean and coastal areas becoming impassable to migratory species.
3. Habitat degradation due to (a) increased predation risk and competition with species attracted to the physical structure of ocean energy developments and (b) increased noise and electromagnetic field disturbance, which may result in displacement and redirection of migratory species.

Review of this literature emphasizes the need for project-specific studies to better inform planners of the potential magnitude of conflict between these renewable energy sources and migratory species, based on the technology being considered and the local species and migratory corridors in the area.

Solar power

It appears likely that solar power plant impacts on migratory species, including terrestrial insects, birds and mammals are likely to be localised and technology-specific. Overall, impacts are likely to be containable if projects are located away from key habitats and migration routes of migratory species.

There is some evidence that the reflective surfaces of solar power plants attract waterbirds and insects and that habitat changes may also attract additional species, including predators to project sites.

Some solar technologies use a large amount of water and this can increase aquatic habitat availability for some waterbirds and insects. However, the impacts of heavy water extraction, if required, on the hydrology and ecology of affected waterways and wetlands needs to be considered carefully as it could ultimately reduce habitat for migratory wildlife (*e.g.*, waterbirds and fish). This is a particular concern in arid regions where such habitats are already heavily constrained by low water availability.

Solar power plants should avoid protected and sensitive sites, manage surrounding land for the benefit of wildlife, and limit the ecological disturbance created by installation and maintenance operations, as well as associated infrastructure such as fencing and power lines.

Wind energy

Wind farms can have impacts on many migratory species as well in the construction phase in terms of habitat loss, disturbance or habitat degradation as well as in the operational phase in terms of mortality and disturbance (habitat degradation). The migratory species groups where impacts are likely to occur include bats, terrestrial and marine mammals, birds, fish, crustaceans and squid, which are discussed in more detail below. The potential and significance of the impacts of wind energy development and deployment on migratory species depends upon a number of factors including site specific factors, the species involved and the design of wind farms (number, type and size of turbines, the configuration of the wind farm, etc.).This makes it is difficult to make generalization about the impacts.

To date, examples of serious impacts at local, regional or international population levels are scarce. Most striking are the impacts on vultures and there are indications for population effects on Red Kites in Germany all due to collisions. But this is all related to the current scale and number of wind farms. If the numbers of farms and turbines increases the impacts at a population level of certain migratory species might be substantial. Currently this is a major international responsibility to get better understanding of this issue especially for collision rates for birds and bats and impacts on population levels. The first steps have been taken to model and assess effects at a flyway or population level for offshore wind farms at the North Sea, which are situated at an important flyway for many birds.

Another main concern of wind energy developments is the impact of underwater noise on cetaceans and fish; especially with novel technologies, such as large submerged turbines. Besides that, EMF generated by undersea cables may also have significant potential impact to fish. Little evidence of these impacts to these taxa exist and findings of studies undertaken are ambiguous.

Wind energy developments can potentially have positive effects on migratory species, especially offshore wind farms. Fish may benefit from the creation of artificial reef and habitat around the bases of offshore wind turbines. Positive effects can also result from the lack of human disturbance or less commercial fishing activities in offshore wind farms. In turn, piscivorous birds may profit from this local increase in prey.

Recommendations

For all RET the primary gap in knowledge of (potential) impacts of RE development and migratory species lie in the detailed understanding specific migration routes and the importance of particular habitat regions as stop-over, nesting, and feeding sites. While the literature review revealed some studies that have been undertaken for specific species populations (*e.g.*, Sawyer *et al.* 2009), many species migration routes and habitat use patterns are still only generally understudied (Northrup and Wittemyer 2013) and need further research. Detailed information in these areas will be imperative to the careful siting and design of renewable energy projects.

Besides understanding of migration routes, monitoring the environmental impacts during the life cycle of existing RET is needed to learn more about the impacts on migratory species. To date, very few attempts have been made to study impacts at the larger scale, such as population level or entire migration routes (*e.g.* intercontinental "flyways" for birds). Most such studies are theoretical rather than evidence-based. For all RET developments the long-term and population-level consequences of large-scale deployments need further research.

Impacts of RET on migratory species can be avoided and mitigated by implementing good practice guidance. Good practice includes proper design, siting, construction, operation, and maintenance of RET developments. More research is needed on the measures to avoid and/or mitigate impacts of RET on migratory species and the effectiveness of measures. So far, few mitigation measures are actually in place. Especially, there is a need for cost effective measures that can greatly reduce risks to migratory species with minimal impact on RET operations.

Pre-construction assessment and post-construction monitoring are important to provide information for the planning decisions, both for already planned and future projects. As new RET projects enter the planning phase, site-specific and technology-specific studies will be required to best predict potential conflicts with migratory species in the area (pre-construction assessment) and to evaluate mitigation measures and predicted impacts afterwards (post-construction monitoring). Post-construction monitoring is now an obligatory standard for *e.g.* large wind farms and new power lines in NW-Europe in order to be able to 'keep the finger on the pulse'.

Given the often long migratory paths of migratory species, not only site or project specific planning is essential, but also risk mapping at the national and international levels through Strategic Impact Assessments (SIAs). Modelling and GIS can be helpful instruments for this, combining information about migratory pathways (*e.g.* The Critical Site Network (CSN) Tool and BirdLife Soaring Bird Sensitivity Map) and potential RET sites. The IRENA Global Atlas is useful online GIS tool in this respect that enables users to visualize information on renewable energy resources, and to overlay additional information to identify areas of interest for further prospection. Modelling should also take into account the cumulative impacts of RET developments. The cumulative assessment of impacts at population scale during the full life cycle (reproduction-, migration-, and non-reproduction phases) is currently a major conservation challenge.

1 Introduction

1.1 Background and objective

Due to increasing concerns about climate change and energy security, there is worldwide an increasing effort to switch over to renewable energy sources, including bioenergy, geothermal energy, hydropower, ocean energy, solar energy and wind energy.

Today, the world gets about 18% of its energy from renewable energy, with a little less than half of this from traditional biomass (direct use of fuelwood, charcoal, residues, etc.). The top countries for renewable power capacity in 2012 were China, the United States, Brazil, Canada, and Germany. The growth of renewable energy worldwide began in the 1990s and accelerated greatly in the 2000s. As shown in Figure 1.1 (IRENA, 2014) renewable energy sources represent a rapidly rising share of energy supply in a growing number of countries and regions, with more than half of the new electricity generation capacity in recent years coming from renewable sources. The deployment of renewables is particularly picking up speed across Asia, Latin America, the Middle East, and Africa, with new investment in all technologies (REN21 2013).

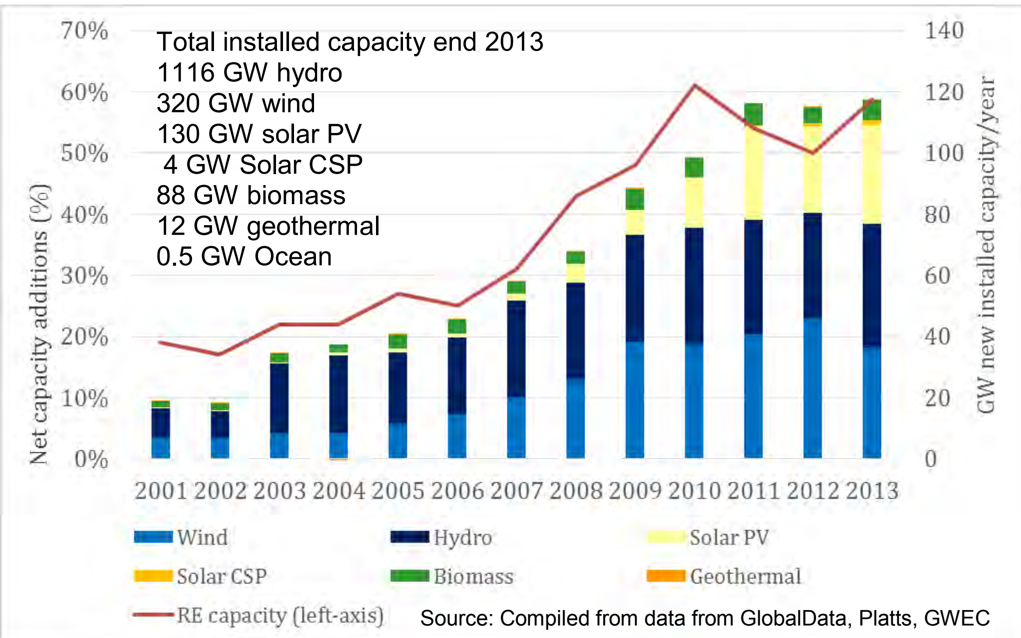

Figure1.1 Share of renewables in global new electricity generation capacity additions

The production of energy from renewable energy resources has the potential to make a significant contribution to climate change mitigation actions (*e.g.* Rogelj *et al.* 2013, Edenhofer *et al.* 2012). By contributing to climate change mitigation, the production of renewable sources also makes a significant contribution to the conservation of biodiversity worldwide (Secretariat of the Convention on Biological Diversity 2010, Gitay *et al.* 2002). Rapid climate change affects ecosystems and species ability to adapt with loss of biodiversity as a result (e.g. Simmonds & Elliot 2008). This implies substantial effort in transboundary species conservation (Trouwborst 2012).

In 2011, the UN Secretary General launched the “Sustainable Energy for All” initiative with three interlinked objectives of universal access to modern energy services, doubling the global rate of improvement in energy efficiency, and doubling the share of renewable energy in the global energy mix by 2030. IRENA’s Remap 2030 report (IRENA, 2014) shows that achieving the renewable energy objective is possible and cost effective with existing technologies, results in significant fuel savings and results in substantial environmental and socioeconomic benefits of over 10 Gt of GHG emission mitigation and over 3 million direct jobs a year.

Notwithstanding the socioeconomic benefits and positive impacts on biodiversity via climate change mitigation, the deployment of renewable energy technologies could also have negative impacts on wildlife, including migratory species, if not properly planned and designed. Wind turbines, for example, can cause direct mortality in birds or bats due to collisions with turbine rotors or towers (Drewitt & Langston 2006, Smallwood 2013, Loss *et al*. 2013, EUROBATS 2013). As a second example, manatees utilize warm-water effluent sites near coastal power plants for overwintering areas, which may be lost with the replacement of these plants by renewable energies (Smith 1997, Deutsch *et al*. 2003, Marsh *et al*. 2011). When (potential) impacts on species are known, proper measures can be taken to minimize the impacts. More specifically, the challenge is to identify which species are likely to be adversely affected, the locations at which adverse impacts are most likely, and the particular features of the environment and structures that increase the risks to species, so that adverse effects can be appropriately avoided or mitigated. This information is particularly important in the early stage of Strategic Environmental Assessment (SEA) and Environmental Impact Assessment (EIA) processes.

A number of studies, including previous reviews, have been undertaken on this subject over recent years. Significant data have been gathered, for instance on the impact of wind farms on certain species of birds and bats, and various solutions have been devised. However some of this information is scattered and not necessarily readily available. Furthermore, there is insufficient knowledge on most of the other renewable energy technologies deployment and their potential impacts on migratory animals. An overview of the magnitude of the potential or real conflict between migratory species and renewable energy deployment and identification of measures to avoid or mitigate any conflict at a global scale is lacking.

Therefore, the International Renewable Energy Agency, the Convention on the Conservation of Migratory Species of Wild Animals (CMS) and the African-Eurasian Waterbird Agreement (AEWA), on behalf of the entire CMS Family; and BirdLife International (through the UNDP/GEF funded Migratory Soaring Birds project) have joined forces to carry out a thorough review of renewable energy technology deployment and their possible impacts, negative and positive, on migratory species with a view to producing a comprehensive set of guidelines and mitigation measures, including examples of best practice, for the deployment of renewable energy technologies in ways that avoid or mitigate possible conflict with migratory species.

1.2 Scope of the review

This review document has been prepared in conjunction with a guideline document “Renewable Energy Technologies and Migratory Species: Guidelines for sustainable deployment”. The review document provided basic background information on impacts as well as measures to minimise impacts.

1.2.1 Migratory species

This review focuses on migratory species. According to the CMS definition "migratory species" means the entire population or any geographically separate part of the population of any species or lower taxon of wild animals, a significant proportion of whose members cyclically and predictably cross one or more national jurisdictional boundaries. This study focused on the migratory species listed by CMS and its associated instruments (aka CMS Family). These are the *migratory* species in the CMS Appendices I (Endangered migratory species) and II (Migratory species conserved through Agreements) and additional *migratory* species listed under the CMS instruments (AEWA, ACCOBAMS, ASCOBANS, EUROBATS, Raptors MoU, and Action Plan for the Conservation of Small Cetaceans of Western Africa and Macaronesia) (see Annex 1). These include mammals, birds, reptiles, fish and insects. A limited number of typical migratory species not listed in the CMS Family appendices have been added, such as salmon and eel.

General principles in conflicts that may arise between migratory species and renewable energy technology deployment that apply to a broad taxonomic group have been addressed as such. Thus, where appropriate impacts have been described on higher taxonomic level (see Table 1.1). Using examples or specific extensive information where available for particular species, the review addresses the impacts on lower taxonomic level (from ‘order’ to ‘species’ level).

1.2.2 Renewable energy sources

The review focused on all the six categories of renewable energy production:

1. Bioenergy;
2. Geothermal energy;
3. Hydropower energy;
4. Ocean energy;
5. Solar energy; and
6. Wind energy

The six mainstream sources of renewable energy, their technologies and the setting (broad habitat class) and the species groups that they potentially can affect are summarized in Table 1.2. This categorization formed the basis for the review study.

The technical maturity of these renewable energy technologies varies substantially. Some of these technologies are commercially available. Other technologies are at the demonstration and pilot project phase or even are at the research and development (R&D) stage. In this review we discuss effects of the technologies that are commercially available. For other developments the potential impacts and the need for further research are assessed in general.

Table 1.1 Taxonomic group levels considered for migratory species in this review and the relevant CMS Family agreements.

Appendix I/II groups	Class	Order (or subclass)	habitat	Agreement
Bats	Mammalia	Chiroptera	terrestrial	CMS, EUROBATS
Whales and dolphins	Mammalia	Cetacea	marine	CMS, ACCOBAMS, ASCOBANS, WAAM
Gorillas	Mammalia	Primates	terrestrial	CMS, GORRILLAS
Dugongs and manatees	Mammalia	Sirenia	water	CMS, WAAM
Seals	Mammalia	Pinnipedia	marine	CMS, Waddensea Seals
Elephants	Mammalia	Loxodonta	terrestrial	CMS
Ungulates	Mammalia	Ungulata	terrestrial	CMS
Carnivores	Mammalia	Carnivora	terrestrial, water	CMS
Ducks and geese	Aves	Anseriformes	water	CMS, AEWA
Penguins and divers	Aves	Sphenisciformes	marine	CMS, AEWA
Albatrosses and petrels	Aves	Procellariformes	marine	CMS, ACAP
Pelicans, tropicbirds, gannets, cormorants and frigatebirds	Aves	Pelecaniformes	water	CMS, AEWA, MOU SB
Herons, storks, ibises and flamingos	Aves	Ciconiiformes	water, terrestrial	CMS, AEWA, MOU SB
Vultures, hawks, eagles and falcons	Aves	Accipitriformes	terrestrial	CMS, AEWA, MOU SB
Rails, cranes and bustards	Aves	Gruiformes	water, terrestrial	CMS, AEWA
Shorebirds (waders, gulls, terns)	Aves	Charadriiformes	water, coastal, marine, terrestrial	CMS, AEWA
Owls	Aves	Strigiformes	terrestrial	CMS
Old World warblers	Aves	Passeriformes	terrestrial	CMS
New World warblers	Aves	Passeriformes	terrestrial	CMS
South American birds	Aves	Passeriformes	terrestrial	CMS
Sea turtles	Reptilia	Testudines	marine	CMS
Crocodiles	Reptilia	Crocodilia	river/marine	CMS
Sharks, rays and skates	Chondrichtyes	Elasmobranchii	marine	CMS
Sturgeons	Osteichtyes	Acipenseriformes	river	CMS
Catfish	Osteichtyes	Siluriformes	river	CMS

Salmon and Eel	Osteichtyes	Salmoniformes, Anguilliformes	marine/fresh	additional
Insects (butterfly)	Insecta	Lepidoptera	terrestrial	CMS

Table 1.2 Categorization of renewable energy technology deployment and species groups that they affect.

Technology		Habitat	Migratory species groups affected
Biomass	Agricultural and forestry feedstock production systems	Terrestrial	Birds, bats, large mammal herbivores, insects
Geothermal energy	Geothermal heatpumps (GHP) Enhanced geothermal systems (GHS)	Terrestrial	Birds, bats, large mammal herbivores
Wind energy–	Onshore wind turbines	Terrestrial	Birds, bats, large mammal herbivores
	Coastal and offshore wind turbines	Coastal and marine	Birds, bats, turtles, aquatic/marine mammals, fish
Hydropower	Hydro electric dams	Waterway and terrestrial	Birds, bats, aquatic mammals, fish
Ocean energy	Tidal/wave energy production Floating/submerged energy production units (EPU's) Thermal energy generating/processing plants Osmotic power transport and processing plants	Coastal and marine	Birds, bats, turtles, marine mammals, fish
Solar energy	Photovoltaic (PV) panels Concentrated solar power (CSP)	Terrestrial and coastal	Birds, bats, large mammal herbivores

In this review the different technologies are treated comparable unless stated otherwise.

This review focuses on specific impacts of RE technologies deployment. The emphasis is on the operational phases of RE projects, where the technologies involved have unique (potential) impacts on migratory wildlife. Effects during the construction phase of renewable energy projects generally reflect those for other development projects. This also applies to the infrastructure and powerline component of RE projects. The general impacts of the construction phase, infrastructure and powerlines are dealt with in a separate chapter (Chapter 2). Impacts in the construction phase specific or characteristic for renewable energy deployments are reviewed in the relevant RE chapters.

1.2.3 Impacts

Type of impacts

For each of RE source the impacts on migratory species are reviewed. Five major categories of primary ecological effects are considered:

- Habitat loss
- Disturbance
- Direct mortality
- Habitat degradation
- Barrier effects
- Displacement

Magnitude of impacts

To assess the magnitude of effects on population level, the spatial extent of the impact (impact area) was considered (local/project area, or regional/beyond the project area), as well as the duration of the impact (temporary or long-term). Impacts are considered long-term if they will continue or last for the entire operational life of the development or longer. Other impacts are considered short-term. Impacts on species population levels were categorised as either I) Minor impacts reported, but no apparent threat to populations, II) High impact, but with no significant impact on the overall species population, III) Major impact, with the risk of species extinction on a national or larger scale.

Primary impacts

This review focuses on the primary effects of RE deployment on migratory species. Secondary (indirect) effects, such as changes in land use, human settlement or resource exploitation, which may be induced by the construction of new roads and facilities are briefly discussed in chapter 2, but are further outside the scope of this review. This also applies for the indirect positive effect of RE through mitigating the effect of climate change, which has potentially severe consequences for the quality, suitability and availability of the habitat of many migratory species, as well as on the species themselves.

Impacts are project- and site-specific

It is emphasised that the impacts of RE deployment on migratory species are very project- and site-specific. The nature, scale and degree of impacts will vary according to site- and project specific factors such as the specifications of the development (design, scale, technology), the habitat affected, the species involved, seasonal and diurnal patterns of use of the project site by species.

For example, the number of bird fatalities in a wind farm depends on the risk of a certain species to collide with a wind turbine and on the flight intensity through the wind farm. These aspects are related on the one hand to ecological characteristics (*e.g.*, species and their preferred habitat and specific behaviour), on the other hand to technological characteristics of the wind farm (*e.g.* configuration and type of wind turbines). Also, it is important to note that population level vulnerability is influenced

by demographics, *i.e.* migratory species with a long life-expectancy and a low reproductive rate, such as large bodied birds and mammals, are the most likely to experience population level effects.
With so many variables involved, it is difficult to make generalisations about impacts of RE deployment on migratory species. This review considers the potential worst-case impacts without mitigation.

This review highlights a number of examples of *potential impact hotspots* (see annex 1). Potential impact hotspots are regarded as sites with concentrations of migratory species, where RET developments might theoretically have serious impact on these species. Identification of potential impact hotspots, both spatial bottlenecks and core spatial resources, along frequently used movement paths is a critical step towards conservation of migratory routes (Wall *et al.* 2013).

1.3 Method

The review relied on existing information summarized in other studies. This information is available in published and online reviews, articles and reports. Non-published information was included where available within the team and provided by key specialists/experts. For scientific studies the internet databases ISI Web of Knowledge, Zoological Record and JSTOR were searched, whereas for other publications and reports the internet search engine Google™. Recent review papers and relevant references therein were the starting point for the review. The focus was on English literature and there was no thorough survey in other languages. It may be assumed that there will be many examples published in other languages but the important issues will be recognized in recent English reviews or overviews. Moreover, as regional experts were contacted as part of the review study, the most important findings from these regions will be included in this review. The reference lists in this first set of material were further perused for quality publications and reports and this procedure was repeated until no further relevant studies were encountered. If not encountered in any of the incorporated studies, relevant publications and references directly provided by the CMS Family on bats, cetaceans, gorillas and elephants and BirdLife International on birds were also included.

In the review sections, the information is predominantly based on scientific reports or documents with well-described effects. In many documents however, “possible effects” or assessments are listed and these are partially referred to as such and to distinguish these from well-documented effects. In some cases these are described in the gaps in knowledge section.

1.4 Report structure

The review document in general presents basic information leading to guidelines to minimise impacts on migratory species by renewable energy deployments. The review document has a focus on providing information while the guideline document focuses on the implementation of such information in policy and planning. In some chapters e.g. mitigation there is some inevitable overlap.

We have chosen to divide the report into chapters dealing with each renewable energy deployment as such. The chapters should stand-alone and provide the useful information for readers interested in one of these topics. Due to the substantial differences in information for each topic, as a result of studies and experiences, the chapters on different renewable energy deployments differ significantly in the amount of information and detail.

Chapter 2 discusses the general impacts in the construction phase and of the power line component of RE developments. Chapters 3 through 7 assess the impacts of specific RE technologies: Bioenergy (3), Geothermal energy (4), Hydropower energy (5), Ocean energy (6), Solar energy (7) and Wind energy (8). Each of the energy chapters has a short explanation of the technologies; a review of the impacts on migratory species; suggestions of mitigation measures and current gaps in knowledge. The mitigation paragraphs specifically provide information for the guideline document. In the latter a prioritisation is included. Chapter 9 presents conclusions and recommendations from the review. This chapter also addresses the issue of cumulative impacts of RE deployment. Finally, annex 1 presents some worldwide examples where renewable energy technology deployments might have impact on migratory species.

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2 Construction phase, infrastructure and power lines

2.1 Construction phase

Information for this paragraph is extracted from The Tribal Energy and Environmental Information Clearinghouse (TEEIC; http://teeic.indianaffairs.gov/):

Impacts during the construction phase of RE developments (infrastructure and power-lines not included, see below) generally reflect those for other similar construction projects and can include mortality, habitat loss, habitat degradation and disturbance of migratory species. Subsequently, these impacts can disrupt the breeding, migration, and foraging behaviour of the species involved and thus can lead to effects on reproduction, survival or distribution. The general impacts in the RET construction phases are summarized in table 2.1.

Typical activities during the construction phase that may cause impacts on migratory species include site preparation (e.g. clearing, excavation, trenching, drilling, pile driving); construction and installation of facilities (e.g. power plant, compressor stations, electrical substations, or storage facilities) and the use of vehicles (cars, trucks, construction vehicles, vessels), machinery and equipment. Activities conducted in locations other than the facility site include excavation/blasting for construction materials (e.g. sands, gravels).

Construction needs land, which can have direct impacts in terms of loss (destruction) of habitat of migratory species. Land clearing may also result in direct mortality of migratory species that are less mobile (e.g. in the breeding or wintering season). Depending on the habitat concerned and restoration measures taken the habitat can be made available for the species involved after the construction activities. Re-colonisation will depend on the duration of the construction phase and species. The construction activities likely involve the use of machinery and human activity and can lead to the disturbance of migratory species by noise, light and vibrations. This may result in the animals leaving the project area or utilising the habitat less effectively. Also, artificial lightning can disorient animals and increase their exposure to predators.

Habitat degradation may result from emission of hazardous materials and wastes to water and the surface. Chemicals in open pits used to store wastes may pose a threat to migratory species. The array of hazardous materials used in RE facility construction is generally quite similar to those used in the construction of any industrial facility. Construction-related wastes include for example lubricating oils, hydraulic fluids, coolants, solvents and cleaning agents. Wastes and hazardous materials are typically stored as a standard practice in compliance with regulations and laws. Improper storage and handling may lead to accidental spills or leaks that can lead to habitat degradation and direct mortality.

The significance of the impacts in the construction phase depends upon many factors including the scale of the development (the amount of land occupied by facilities), the equipment used (e.g., rollers, bulldozers, diesel engines), the construction techniques (e.g. the need for drilling), the duration of the construction activities, The timing of construction activities relative to the crucial life stages of wildlife (e.g., breeding season) and the facility's location with respect to migratory species habitat. Although the construction phase is generally much shorter than the operation phase of a renewable project, activities may be more intensive during construction and impacts may be higher.

In many cases, the effects of the construction phase are in fact comparable with the long-term operational phase effects, such as habitat loss or habitat degradation. In these cases the effects of the operational and construction phase cannot be separated in terms of population effects. Within the specific RE chapters this is discussed if appropriate.

2.2 Infrastructure

Most land-based renewable energy developments require the construction of access infrastructure like roads, railway lines and tracks into areas that are either pristine, poorly accessible or with existing networks that require enhancement. This is also true in relation to non-renewable technologies, which use similar infrastructure. This can impact migratory species in various ways in the exploration/construction phase and operational phase.

Spindler *et al*. (2014) summarise the impacts of infrastructure on wildlife as follows. The direct negative impacts of transport infrastructure on wildlife are habitat loss, habitat transformation, edge effects, disturbances, traffic mortality and barrier effects. Transport infrastructure cuts through habitats of animals, imposes barriers to their distribution and disrupts natural processes such as migration movements. Thereby it interrupts the genetic interchange and leads to declining and degenerated population in a long-term perspective. Additionally, traffic mortality further weakens and diminishes populations. The use of transport infrastructure produces different emissions like noise, light and air pollution, which can affect adjacent habitats and disturb animals and plants even at some distance from the infrastructure. The extent of the impact varies depending on the dimension of the infrastructure, traffic density, the surrounding area and the biology of the affected species (Spindler *et al*. 2014).

Changes in land use induced by the construction of transport infrastructure are secondary effects. New settlements may follow the construction of new regional roads and in turn induce the construction of local access roads. One of the main secondary impacts associated with infrastructure development is the increased degree of human access and disturbance. Networks of small forest roads provide hunters/poachers and tourists access to otherwise undisturbed wildlife habitats (Luell *et al*. 2003).

For a more detailed description of the impacts of infrastructure on wildlife, see Luell *et al*. (2003) and van der Ree *et al*. (2011).

2.3 Powerlines

All renewable energy systems generally require land-based electricity grids to distribute the power generated. Such grids are normally constructed above ground and therefore they present a potential hazard to migrating flying species, this is birds and bats. The two major potential impacts of power lines on birds and bats are collision with overhead electric cables and electrocution by energized overhead structures. Prinsen *et al.* (2011) present an up-to-date overview of the nature, scale and impact of the electrocution and collision of birds, with focus on the African-Eurasian region. The main conclusions of this study are drawn below. For more detailed information reference is made to the review of Prinsen *et al*. (2011) or a recent overview for the US by Loss *et al.* (2014). For bats there is no such review available. Bat casualties due to collision and electrocution have been reported for Megachiroptera (e.g. *Eidolon helvum*). Very little is known about the extent of collision by bats with power lines though.

Electrocuted straw-colored fruit bat (Eidolon helvum) in Ghana. Photo © Jakob Fahr

Conflict between migratory birds and electricity power grids
(Extracted from Prinsen *et al*. 2011)

The two major impacts of power lines on birds, electrocution and collision, show important differences in a number of temporal and spatial aspects as well as in the bird groups affected and the number of casualties.

Electrocution
Electrocution most commonly occurs at medium voltage distribution lines (1 kV to 60 kV), due to the close spacing of the structures. It often involves large perching bird species, such as storks, birds of prey and corvids, which can easily bridge the gap between two cables, or the charged parts and the power line structure.

Electrocution mainly occurs in open habitats (e.g., deserts, plains, steppes, grasslands, and wetlands) lacking natural perches or trees for nesting or roosting. It especially affects birds during the breeding season, when nest building, hunting and territorial behaviour put adult birds of e.g., White Storks, Eurasian Eagle Owls, and eagles at risk. In summer, post-breeding dispersal of juveniles and the start of migration also result in an increase in electrocution casualties.

Few studies have estimated the total number of electrocution victims at the national level, but in general annual totals are expected to be in the order of 1,000s of birds per country at the most, seldom 10,000s. For the Iberian Peninsula, average electrocution rates between 0.04 victims/pole (in Catalonia, Spain) and 1.52 victims/pole/year (in Portugal) have been published.

Although electrocution affects less bird species and the number of casualties is much lower than for collision, many of the affected species are relatively rare, have long generation times and low annual reproduction rates and, therefore, electrocution can be a major cause of mortality for these populations, possibly leading to population decline and/or local or regional extinction.

Collision
Collision can occur at all above ground power lines, although more so with high voltage power lines than low or medium voltage lines. This is because the high voltage power lines often consist of multiple sets of vertically placed phase conductors and a separate thin ground wire or neutral above these phase conductors. Low to medium voltage lines mostly have the phase conductors placed in the same horizontal plane, with the ground wire, if present, positioned slightly above them. Furthermore, high voltage lines are generally larger constructions with tall pylons (35 m or higher for 150 kV or more) and thus the wires cover a larger vertical area.

In the African-Eurasian, bird collisions with power lines occur in every habitat type, from the densely forested areas of Scandinavia, intensively cultivated areas in

Western Europe, mountain ridges in the Alps to the deserts of Africa and steppes of Asia. Collisions also involve a vast range of bird species.

Generally speaking, all flying species of bird are at risk of collision with above ground power lines, although the exposure to the risk (frequency of crossings), environmental conditions (habitat, time of day, etc.) and species traits (size, visual ability, etc.) influences the risk to individual species. Those species that regularly breed, rest or forage in the vicinity of an above ground power line are most at risk of collision. Visibility also influences the level of risk with most collisions occurring during twilight and at night, when visibility is less. Furthermore, studies show that large, heavy, less manoeuvrable birds (often species with short, round wings), as well as species with rapid flight, have the highest collision risk. This includes a number of species groups that are rarely found as electrocution victims, such as pelicans, flamingos, ducks, rails, grouse, cranes, bustards, waders and gulls. Species such as thrushes, finches and other small bird species are less found as collision victims, but it is not clear if this is caused by less detectability or indeed a lower risk of collision. Collision is less of a problem to birds of prey and storks than electrocution in large parts of the African-Eurasian region. Collision is also much more of a year-round problem than electrocution, but seasonality plays a role at many locations such as those close to congregations of wintering birds or those on important migration routes.

For many countries in the African-Eurasian region, the annual number of collision victims with above ground power lines will be in the order of 100,000s of birds, or higher; this is of course dependent on the length of the total electricity network and the numbers of birds present. This ranks collision within the major human-related causes of death for birds in many parts of the African-Eurasian region; together with traffic, collision with windows and predation by domestic cats. Published average collision rates vary widely, with 2.95 birds/km/year in nine areas representing the most typical habitats of the Iberian Peninsula, to 113 bird/km/year for a wide range of habitats in the Netherlands and 390 birds/km/year for a German wetland area.

2.4 Literature

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Table 2.1 Impact matrix renewable energy and migratory species. Assessment of the (potential) impacts of the construction and decommissioning phases of renewable energy technology on migratory species

Renewable Energy	Species group	Impact	Description of ecological impact	Spatial extent impact	Duration of impact	Magnitude of impact
Biomass energy	**Birds**	Mortality	Direct mortality of construction activities and chemical spills	Local	Short-term	I
			Collision with vehicle strikes	Local	Short-term	I
		Habitat loss and fragmentation	Construction of biomass energy facilities, access roads and power lines	Local	Short-term	I
		Disturbance	Disturbance by noise, light etc.	Local	Short term	I
		Habitat degradation	Water use, emissions of chemicals and wastes	Local	Short term	I
	Terrestrial Mammals	Mortality	Collision with vehicle strikes	Local	Short-term	I
		Habitat loss and fragmentation	Construction of biomass energy facilities, access roads and power lines	Local	Short term	I
		Disturbance	Disturbance by noise, light etc.	Local	Short term	I
	Insects	Habitat loss Habitat Degradation	Clearing of areas containing migratory monarch host plant and food source, replaced by biomass energy production crop fields	Local	Long-term	II
Geothermal energy	**Birds**	Mortality	Direct mortality of construction activities Collision with vehicle strikes	Local	Short-term	I
		Habitat loss and fragmentation	Development of geothermal power plants access roads and power lines	Local	Short-term	I
		Disturbance	Noise, light, and thermal disturbance	Local	Short-term	I
		Habitat degradation	Clearing of land via mechanical and chemical means.	Local	Long-term	I
	Terrestrial Mammals	Mortality	Collision with power plant structure and vehicle strikes.	Local	Short-term	I
		Habitat loss and fragmentation	Development of geothermal power plants and access roads.	Local	Long-term	I
		Disturbance	Noise, light, and thermal disturbance.	Local	Short-term	I
		Habitat degradation	Clearing of land via mechanical and chemical means.	Local	Long-term	I
	Fish	Habitat degradation	Runoff or other contaminant release during construction.	Regional	Short-term	I
Hydropower energy	**Fish**	Mortality	Chemical spills	Regional	Short-term	I
		Habitat loss	Modification of river channels.	Local	Short-term	I
		Barrier effects	Construction of coffer dams and hydropower dams	Local	Short-term	I
		Habitat degradation	Hydrology of downstream areas changed, disruption of food web, drainage of wetlands, release of contaminated sediments during decommissioning	Regional	Long-term	I
		Habitat alteration	Increased sedimentation and turbidity downstream.	Regional	Short-term	I
	Birds	Mortality		Local	Short-term	I
		Habitat loss and fragmentation	Clearance of water storage inundation area	Local	Long-term	II

Renewable Energy	Species group	Impact	Description of ecological impact	Spatial extent impact	Duration of impact	Magnitude of impact
		Habitat degradation	Disruption of food web	Regional	Long-term	I
Hydropower energy *continued...*	**Mammals**	Habitat loss and fragmentation	Modification of river channels..	Local	Short-term	I
	Mammals *cont.*	Barrier effects	Construction of coffer dams.	Local	Short-term	I
	Reptiles	Habitat loss and fragmentation	Modification of river channels	Local	Short-term	I
		Barrier effects	Construction of coffer dams and hydropower dams.	Local	Short-term	I
Ocean energy	**Fish**	Habitat loss and fragmentation	Temporary loss of benthic and pelagic habitat.	Local	Short-term	I
		Habitat degradation	Sediment disturbance, underwater noise and vibration disturbance.	Local	Short-term	I
	Sea Turtles	Mortality	Collision and entanglement with devices and vessels.	Local	Short-term	I
		Habitat loss and fragmentation	Temporary loss of benthic and pelagic habitat.	Local	Short-term	I
		Habitat degradation	Sediment disturbance, underwater noise and vibration disturbance.	Local	Short-term	I
	Birds	Mortality	Collision and entanglement with devices and vessels.	Local	Short-term	I
		Habitat degradation	Construction activities and noise disturbing prey.	Local	Short-term	I
	Marine Mammals	Mortality	Collision with vessels.	Local	Short-term	I
		Habitat loss and fragmentation	Temporary habitat loss.	Local	Short-term	I
		Habitat degradation	Sediment disturbance, underwater noise and vibration disturbance.	Local	Short-term	I
	Crustaceans and Squid	Habitat loss and fragmentation	Some temporary loss of both benthic and pelagic habitat availability.	Local	Short-term	I
		Habitat degradation	Some degradation due to sediment disturbance, underwater noise, and vibration disturbance.	Local	Short-term	I
Wind energy	**Birds**	Mortality	Collision with exploratory meteorological masts	Regional	Long-term	I
		Habitat loss and fragmentation	In most cases minor; land clearing,	Local	Long-term	I
		Habitat degradation	Expected to be minor; land clearing, *etc*.	Local	Long-term	I
		Disturbance/ displacement	Expected to be minor; due to construction activities.	Local	Short-term	I
	Bats	Habitat loss and fragmentation	In most cases minor especially in forest areas	Local	Long-term	I
		Habitat degradation	Expected to be minor; land clearing, *etc*.	Local	Long-term	I
		Disturbance/ displacement	Expected to be minor; due to construction activities.	Local	Short-term	I

Renewable Energy	Species group	Impact	Description of ecological impact	Spatial extent impact	Duration of impact	Magnitude of impact
	Marine Mammals	Physiological effects	Underwater noise has potential to cause auditory injury	Local	Short-term	I
		Disturbance/ displacement	Noise, especially pile driving, may cause behavioural changes up to 50 km away.	Local	Short-term	I
Wind energy *continued...*	**Terrestrial Mammals**	Disturbance/ displacement	Expected to be minor; *e.g.* U.S. study on elk (*Cervus elaphus*).	Local	Short-term	I
		Habitat loss and fragmentation	Expected to be negligible; *e.g.* U.S. study on elk (*Cervus elaphus*).	Local	Long-term	I
	Fish and Squid	Habitat loss and fragmentation	Installation of foundations and scour protection.	Local	Long-term	I
		Habitat degradation/ fragmentation	Installation of foundations and scour protection.	Local	Long-term	I
		Physiological effects	Construction noise may impact the ability of fish to communicate or navigate.	Local	Short-term	I
		Disturbance/ displacement	Expected to be minor; movements away from area.	Local	Short-term	I
		Habitat gain	Artificial reefs around wind turbines possibly provide higher prey availability, increased shelter and protection from currents.	Local	Long-term	I
	Crustaceans	Direct mortality	As a result of construction activities.	Local	Short-term	I
		Disturbance/ displacement	Individuals near the construction zone likely displaced, vibrations from pile driving.	Local	Short-term	I
		Habitat gain	Artificial reefs associated with turbine foundations may provide habitat for crustaceans.	Local	Long-term	I
		Habitat loss and fragmentation	Natural habitat around turbine foundations permanently altered.	Local	Long-term	I

Spatial extent (size of area) of the impact (local/project area, regional/beyond the project area); Magnitude (I = Effects reported, but no apparent threat to populations, II = High impact, but with no significant impact on the overall species population, III = High impact increasing the risk of species extinction). See §1.2.3.for explanation of terms used.

3 Bioenergy

A. Patterson & T. van der Have

3.1 Introduction

Bioenergy can be produced from a variety of biomass feedstocks (table 3.1), including forest, agricultural and livestock residues; short-rotation forest plantations; energy crops; the organic component of municipal solid waste; and other substances of biogenic origin. Through a variety of processes, these feedstocks can be directly used to produce electricity or heat, or can be used to create fuels (gaseous, liquid) (Chum *et al*. 2011), see figure 3.1 (reproduced from Chum *et al*. 2011).

Table 3.1 Biomass feedstocks classified according to the supply sector, as shown in the table below. Extracted from: http://www.eubia.org

Supply sector	Type	Example
Forestry	Dedicated forestry	Short rotation plantations (e.g. willow, poplar, eucalyptus)
	Forestry by-products	Wood blocks, wood chips from thinnings
Agriculture	Dry lignocellulosic energy crops	Herbaceous crops (e.g. miscanthus, reed canarygrass, giant reed)
	Oil, sugar and starch energy crops	Oil seeds for methylesters (e.g. rape seed, sunflower)
		Sugar crops for ethanol (e.g. sugar cane, sweet sorghum)
		Starch crops for ethanol (e.g. maize, wheat)
	Agricultural residues	Straw, prunings from vineyards and fruit trees
	Livestock waste	Wet and dry manure
Industry	Industrial residues	Industrial waste wood, sawdust from sawmills
		Fibrous vegetable waste from paper industries
Waste	Dry lignocellulosic	Residues from parks and gardens (e.g. prunings, grass)
	Contaminated waste	Demolition wood
		Organic fraction of municipal solid waste
		Biodegradable landfilled waste, landfill gas
		Sewage sludge

Typically, the biomass to bioenergy supply chain includes:

1. **Feedstock Production**: comprises the cultivation of biomass resources used as raw material inputs for bioenergy production.
2. **Feedstock Logistics**: comprises harvesting or collecting feedstock from the area of production, processing it for use in bio-refineries, storing it between harvests, and delivering it to the bioenergy plant.
3. **Conversion**: the industrial activity in which the raw biomass is converted into bioenergy along with one or more co products.

The range of commercial bioenergy technologies is broad (see fig 3.1). There are three main conversion technologies: thermochemical (including combustion, gasification, pyrolysis), biochemical (including anaerobic digestion, fermentation) and chemical (including trans-esterification) (Chum *et al*. 2011).

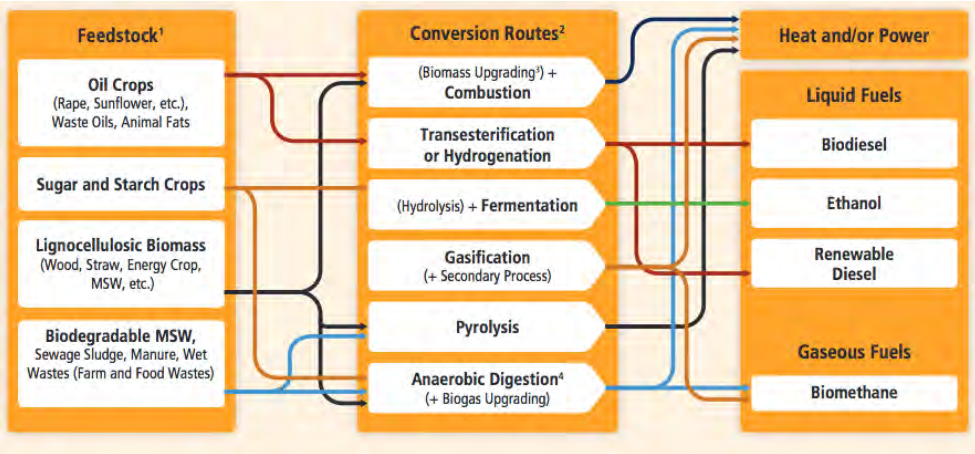

Figure 3.1 Schematic representation of commercial bioenergy technologies (reproduced from Chum et al. 2011).

For a detailed description of the bioenergy technologies, see Chum *et al*. (2011) and IRENA-IEA-ETSAP Technology Briefs.

Bioenergy generation facility, California, United States. Photo credit: National Renewable Energy Laboratory

Canada is currently the world’s third largest hydropower generator with more than 75GW of installed capacity. In Latin America, hydropower is the main source of power generation, accounting for roughly 65% of all electricity generated. Altogether, Latin America’s installed hydropower capacity totalled 153 GW at the end of 2010. South

America offers a diverse picture on renewable energy development, with some countries leading, and others still reliant mostly on fossil fuels.
Over the next 10 years, electricity consumption in Brazil is expected to grow at an average rate of 4.5% per year from 443 TWh in 2011 to 736 TWh in 2021. Industry is expected to account for around 50% of the country's electricity consumption in 2021. To meet this additional demand and to ensure national energy security, the Brazilian Government has been promoting the construction of new hydropower. Hydropower currently generates 80% of Brazil's electricity but there remains significant untapped potential.

In Colombia, within the planned and contracted generation expansion of 4GW through 2021, 3GW will be made up of hydropower. Recent studies indicate that wind power is available when Colombia's energy needs are highest; that is, during the dry seasons and in the early evenings. Policymakers are therefore investigating the joint operation of wind and hydropower plants in some basins and the creation of smart grids with storage hydropower backing up wind power and other renewables (IHA 2013).

3.2 Impact matrix

The impact matrix (table 3.1) summarizes the potential impacts of bioenergy production on the relevant species *groups* (see above). Impacts can be extrapolated to species level (Table 1.1) when bioenergy development coincides with the habitat of these species. As bioenergy, currently, is only exploited on land, only impacts on terrestrial ecosystems / onshore ecosystems are relevant. The species groups where impacts are likely to occur include bats, terrestrial mammals, birds and fish, which are discussed in more detail below. No direct impact is expected in marine mammals, marine turtles and crocodiles and these are therefore excluded from the analysis. The production of bioethanol has been suggested to impact monarch butterfly *Danaus plexippus* as well, but solid evidence for this in literature was not found. The impacts summarized in Table 3.1 are described in more detail in the next paragraphs.

Bioenergy can be produced using a variety of feedstocks and methods. Hence, the (potential) impacts of bioenergy on migratory species are variable. At one end of the spectrum, bioenergy can be produced with intensively managed monocultures of annual food crops. This method of production can have large environmental consequences, including habitat loss and the off-field impacts of fertilizer and pesticide runoff. Toward the other end of the spectrum, bioenergy can be produced by sustainably harvesting biomass from systems with high plant diversity and low agriculture input (Fargione *et al.* 2009). The impact on biodiversity in general and migratory birds, mammals and fish in particular, depends highly on to which extent natural areas will be converted to energy crops, the crop types used and how the crops will be managed (*e.g.,* Wicke *et al.* 2011, Persson 2012; Semere & Slater 2006, Engel *et al.* 2012).

In general, bioenergy from dedicated feedstocks is characterised by relatively large land use requirements (Hung 2010; Chum *et al*., 2011) and potentially relatively large water use requirements compared to other RET (Chum *et al*., 2011). If biomass from residues or organic wastes is used, additional land use is small. The water footprint of feedstock production is highly dependent on feedstock type, geographic region and local climatic conditions, and crop management practices (Chum *et al*., 2011).

In conclusion, the impacts on (migratory) species are technology-, site- and species specific

Indirect impacts are outside the scope of detailed study in this review. However, an important concern is the bioenergy driven change in land use. Bioenergy developments may indirectly lead to changes in land use elsewhere. A biomass plantation can be established on land previously used for grazing or crops with limited impacts on biodiversity. The previous land use might, however, shift to other (pristine) areas and result in significant habitat deterioration of migratory species.

Table 3.1 Impact matrix bioenergy and migratory species. Assessment of the (potential) impact of the bioenergy technology on migratory species

Process phase	Species group	Impact	Description of ecological impact	Spatial extent impact	Duration of impact	Magnitude of impact
Construction & Decommissioning	**Birds, Terrestrial Mammals, Insects**	Mortality, Habitat loss	see table 2.1			
Operational	**Birds**	Habitat loss and fragmentation	Clear-cutting during fuel production reduces habitat and increases habitat fragmentation, thereby decreasing biodiversity.	Local	Long-term	I
		Habitat degradation	Use of crop residues as biofuel decreases the availability of this resource for migratory wildlife	Local	Short-term	I
			Reduction in available water particularly in dry areas may result in the loss of wetlands and water resources at vital stopover sites for migrants. Lower food and water availability may lead to increased mortality and lower population sizes.	Regional	Short-term	I
		Habitat gain	Increased habitat for some species if fuel production fields are managed correctly.	Local	Long-term	I
	Terrestrial Mammals	Habitat loss and fragmentation	Clear-cutting during fuel production reduces habitat and increases habitat fragmentation, thereby decreasing biodiversity.	Local	Long-term	I
		Habitat degradation	Use of crop residues as biofuel decreases the availability of this resource for migratory wildlife.	Local	Short-term	I
			Reduction in available water particularly in dry areas may result in the loss of wetlands and water resources at vital stopover sites for migrants. Lower food and water availability may lead to increased mortality and lower population sizes.	Regional	Short-term	I
	Fish	Habitat degradation	Potential for water contamination by release of wastewater, chemicals, or contaminated water vapor.	Regional	Long-term	I
			Reduction in available water particularly in dry areas may result in the loss of wetlands and water resources that are vital habitats for migrants.	Regional	Short-term	I
	Insects	Habitat loss and degradation	Expansion of corn and soybean-producing agricultural areas may result in loss of milkweed host plants for migratory butterflies. Increased use of herbicide in these areas results in further loss of this habitat and food source.	Regional	Long-term	III

Spatial extent (size of area) of the impact (local/project area, regional/beyond the project area); Magnitude (I = Effects reported, but no apparent threat to populations, II = High impact, but with no significant impact on the overall species population, III = High impact increasing the risk of species extinction). See §1.2.3.for explanation of terms used.

3.3 Construction phase

In the construction phase of bioenergy production natural habitats specific for certain species are changed into new habitats not suitable for those species, with habitat loss or degradation as result. This impact is not specific to bioenergy however, as it is comparable to any agricultural development. Although the magnitude of the effects of habitat alteration is much greater in relation to the amount of land used to grow biofuels such as corn and switchgrass than the footprint of a new energy facility.

In most cases biomass plots do not lead to habitat loss but to degradation or changes resulting in shift of species composition. Exceptions to this are related to the loss of roosting sites for tree-dwelling bats, loss of milkweed host plants for the monarch butterfly and the construction of new biomass energy facilities.

Within the process of biomass plot development, habitats can be fragmented by changes in land use and construction of roads, both of which may result from the deployment of bioenergy technology.

As there is substantial overlap between the construction phase and operational phase these issues are now and then repeated in the species sections.

3.4 Birds

Literature indicated that birds, especially grassland birds, were found to be the taxon most affected by bioenergy technology. The effects to birds from this technology occur almost entirely from the cultivation of bioenergy crops, and are primarily related to habitat alteration (Cook *et al.* 1991, Murray & Best 2003, Murray *et al.* 2003, Roth *et al.* 2005, Bies 2006, Bellamy *et al.* 2009, Hartman *et al.* 2011, Robertson *et al.* 2011). Other groups at risk are forest birds. The removal of dead wood in forests may have a negative impact on biodiversity in general (Pedroli *et al.* 2013) and on hole nesting bird species in particular. Whole-tree harvest for energy-wood production is likely to be more intensive compared to conventional forestry (Berger *et al.* 2013) and lead to additional negative impact on forest birds. The removal of lower shrub layers will also impact on the quality of habitat for species that rely of these layers for foraging and nesting sites.

While no sources found in the literature search identified the construction or operation of bioenergy facilities as an impact to birds, some habitat loss would clearly result from construction of a new facility on previously-available avian habitat. This impact is not specific to bioenergy, however, and the magnitude of the effects of habitat alteration is much greater in relation to the amount of land used to grow biofuels such as corn and switchgrass than the footprint of a new energy facility.

3.4.1 Mortality

Direct mortality of adult birds was not identified in the literature as an impact of bioenergy technology. Theoretically, if crop harvest occurs during the breeding season mortality of nest young may occur and subsequently reduced breeding success.

3.4.2 Habitat degradation

Bioenergy technology has the potential for resulting in avian habitat degradation and fragmentation through the conversion of natural habitat to agricultural land for biofuel production (Cook *et al.* 1991, Murray & Best 2003, Murray *et al.* 2003, Roth *et al.* 2005, Bies 2006, Bellamy *et al.* 2009, Hartman *et al.* 2011, Robertson *et al.* 2011).

The energy production phase, rather than construction or operation, is the critical phase of bioenergy technology related to habitat degradation. Migratory grassland birds are the species primarily impacted by habitat degradation for the production of biofuels (Murray & Best 2003, Roth *et al.* 2005, Bies 2006, Hartman *et al* 2011, Robertson *et al* 2011), although forest bird species may also be affected (Cook *et al.* 1991, Laurance 2007, Danielson *et al.* 2008, Vale *et al.* 2008, Verschuyl *et al.* 2010).

A decrease in the heterogeneity of a plant community, such as in the case of the conversion of natural habitat to a monoculture, typically results in a decrease in avian biodiversity in that habitat (Cook *et al.* 1991, Danielson *et al.* 2008, Fargione *et al.* 2009, Fargione *et al.* 2010, Hartman *et al.* 2011, Robertson *et al.* 2011). In the United States, corn is the primary crop used for biomass fuel production (Bies 2006). Fargione *et al.* (2010) found a 60% decrease in overall biodiversity in corn and soybean fields in the United States compared with native habitat.

There is good evidence that recent biofuel expansion, has contributed to extensive tropical forest and savannah habitat loss of birds in south-east Asia and South America (Pearce-Higgins & Green, 2014). This has detrimental impacts on the conservation status of a number of bird species. The production of palm oil in Asia and sugar cane in the Amazon contributed to the continued deforestation and has significantly increased the extinction risk of forest bird species (Pearce-Higgins & Green, 2014). This can include migratory species.

Conversion of forest to palm orchards results in significant impoverishment of the faunal community. Most forest species are lost and replaced by smaller numbers of largely nonforest species, resulting in simpler, species poor communities dominated by a few generalist species of low conservation significance. Results of individual studies suggest that the species lost are species with the most specialized diets, those reliant on habitat features not found in plantations, those with the smallest range sizes and those of highest conservation concern (Danielsen *et al*. 2009).

For example, Aratrakorn *et al.* (2006) found that oil-palm plantations in Thailand supported fewer bird species than forests and that these species were significantly more widespread and of lower conservation status than those in forests (Danielsen *et al.*, 2009).

There are few publications describing the bird communities of sugar cane plantations, but sugar cane plantations seem to be associated with reduced raptor diversity. Reduced avian diversity is probably a result of reduced structural complexity and plant species diversity. These detrimental impacts are also likely to long distance migrant populations, which rely on natural habitats during the high-latitude winter (Pearce-Higgins & Green, 2014).

Rate of land-use change

The demand for land to grow corn as a biofuel for ethanol production in the United States *increased by 5 million ha between 2005 and 2008 (*Fargione *et al.* 2009*),* fuelled in part by federal government subsidies intended to promote bioenergy (Laurance 2007). As this trend continues, additional migratory bird breeding, post-breeding, migratory stop-over, and wintering habitat is degraded (Cook *et al.* 1991, Danielson *et al.* 2008, Fargione *et al.* 2009, Fargione *et al.* 2010, Hartman *et al.* 2011, Robertson *et al.* 2011).

Removing crop residues for use as a biofuel may also impact migratory bird species (such as the sandhill crane (*Grus canadensis*), common crane (*Grus grus*) and geese) by reducing available food resources (Cook *et al.* 1991).

Forest management

For forested habitat, clear-cutting (even-aged management) decreases forest interior habitat and increases habitat fragmentation (Cook *et al.* 1991) and removal of dead wood and undergrowth as well (Berger *et al.* 2013, Pedroli *et al.* 2013), which also leads to a decrease in avian biodiversity.

Water use

In general, bioenergy from dedicated feedstocks is characterised by potentially relatively large water use requirements (Kiniry *et al*. 2008, Gerben-Leenes *et al.* 2009). This may result in lowering of water tables and reduced water levels in rivers and lakes and subsequent salinization and loss of wetlands in areas where water resources are also threatened by population expansion and drought (Stone et al. 2010). This could potentially have significant impacts on migratory bird populations that depend on such wetland and other water resources.

Seasonality of harvesting

In North America the use of switchgrass, a perennial species native to the United States and Canada, as a biofuel may provide higher quality grassland bird habitat while also meeting the needs of biofuel producers (Paine *et al.* 1996, Murray and Best 2003, Murray *et al.* 2003, Roth *et al.* 2005, Hartman *et al.* 2011, Robertson *et al.*

2011). The timing of harvest is an important consideration for avian biodiversity in switchgrass production fields (Murray and Best 2003, Roth *et al.* 2005, Bies 2006, Hartman *et al.* 2011, Robertson *et al.* 2011). Autumn harvest is preferable for breeding birds, as it occurs after the breeding season has ended and allows time for vegetative re-growth before the following year's breeding season (Murray and Best 2003, Bies 2006). However, autumn harvest may be detrimental to wintering grassland birds, as it decreases cover (Bies 2006).

Drivers of land-use change

An indirect impact of the widespread switch from soy to corn in the United States has been an increase in deforestation in the Amazon, also known as indirect Land Use Change (iLUC; Elbersen *et al.* 2013, Marshall *et al.* 2011). As fewer US farmers grow soy, the price of the commodity has increased. This has driven soy farmers in Brazil (the world's second-largest soy producer after the United States) to increase production, resulting in accelerated deforestation in that country (Laurance 2007, Vale *et al.* 2008). Additionally, higher soy costs have the effect of raising global beef prices as soy-based livestock feed becomes more expensive. Thus, additional forested habitat for migratory bird species is cleared and converted to pasture for cattle grazing (Laurance 2007, Vale *et al.* 2008).

Management of biofuel crops

In Europe, the impact of growing *Miscanthus* and reed canary grass on farmland bird communities depended on the age of the crops and management system. Bird densities in young crops, especially when extensively managed were similar of slightly higher than traditional farmland (Bellamy *et al.* 2009, Bright *et al.* 2013, Sage *et al.* 2010, Semere & Slater 2007) and depended also on the spatial scale of the crop-field size (Engel *et al.* 2012).

*Bobolink (*Dolichonyx oryzivorus*) a North American grassland nesting bird.*

Photo credit: United States Fish and Wildlife Service

Bird densities, in particular skylark *Alauda arvensis* were generally lower in reed-canary grass fields (Semere & Slater 2007, Vepsäläinen 2010). These value of these crops for biodiversity may become less in intensively managed, older (2 – 3 years) stands growing up to several metres high.

3.5 Mammals

Few studies were found that identified impacts to migratory terrestrial mammals from bioenergy technology. However, migratory terrestrial mammals are sensitive to habitat fragmentation due to changes in land use and construction of roads, both of which may result from the deployment of bioenergy technology.

3.5.1 Mortality

Direct mortality of terrestrial mammal species was not identified in the literature as an impact of bioenergy technology.

3.5.2 Habitat degradation

Clearing of forests or grasslands for biofuel production may negatively impact migratory terrestrial mammal species by reducing habitat quality and increasing habitat fragmentation (Cook *et al.* 1991, Fargione *et al.* 2010). Migratory terrestrial mammals (such as caribou [*Rangifer tarandus*]) may be potentially impacted by habitat fragmentation from the construction of new roads (Forman & Alexander 1998, Dyer *et al.* 2002) to bioenergy facilities. While vehicle collisions on roadways do not typically limit population size, the barrier effect of roads due to habitat fragmentation and vehicle noise may have demographic and genetic consequences (Forman & Alexander 1998). Tropical mammal species may be especially sensitive to the effects of roads because many are habitat specialists, which avoid even narrow clearings and forest edges (Laurance *et al.* 2009).

In Ethiopia there is a well-documented case where biofuel development in the Babile Elephant Sanctuary (BES) has resulted in habitat destruction of an already declining population of the African elephant (Reddy & Sintayehu, 2014; Demeke, 2008; Demeke & Aklilu, 2008). A total of 10.000 hectares of biofuel plantation, approximately 80% fell within the elephant ranges movement corridors and regular feeding grounds for elephants. No Environmental Impact Assessment was prepared before commencing these activities.

Another example illustrating the potential impacts of bioenergy development on mammals are given by Maddox *et al*. (2007). They found that 34 of the 38 medium to-large mammals occurring within forest sites in Sumatra were absent from oil palm, including the Sumatran tiger and clouded leopard. Instead, the ubiquitous wild pig (*Sus scrofa*) dominated the large-mammal fauna (Danielsen *et al*. 2009).

3.6 Fish

Few studies were found that identified impacts to migratory fish from bioenergy technology. However, as bioenergy is characterised by potentially relatively large water use requirements this can potentially impact migratory fish species. Apart from the relatively high water use requirements, bioenergy technologies may result in the emissions of agrochemicals (fertilizers, pesticides) applies during crop cultivation. The subsequent processing of the feedstock into biofuels and electricity can increase chemical and thermal pollution loads from effluents and generate waste to aquatic systems (Chum *et al*. 2011). This can result in degradation of key habitat for migratory fish species.

3.7 Other species

The review of the available literature did not result in any other taxa being considered as impacted by bioenergy technology. However, the production of bioethanol has been suggested to impact monarch butterfly in the US Midwest. There is an increase in the surfaces to produce corn and soybean used in turn to produce bioethanol at the expense of other more butterfly-friendly crops or land for wildlife. The most productive habitat for monarch butterflies in the Midwest was the corn and soybean fields (where milkweed, which monarchs feed on, grew). The increased planting of genetically modified corn in the U.S. Midwest has also led to greater use of herbicides (Glyphosate), which in turn kills the milkweed that is a prime food source for the monarch butterflies. Before Roundup-ready crops (genetically engineered crops that can withstand glyphosate herbicide), weed control was accomplished by running a tiller through those fields and chopping up the weeds and turning over the soil, but not affecting the crops (Conniff 2013).

3.8 Mitigation measures

The review document has been prepared in conjunction with a guideline document in which guidelines for siting, planning and mitigation are presented and prioritised. Within this review chapter, basic background information is presented. Although siting and mitigation can overlap they are as much as possible separated. The presented information is as much as possible based on literature unless stated otherwise, e.g. in case of mitigation suggestions.

The following examples are the best practices of mitigation that have been identified for bioenergy production in grassland areas in the United states, in the available literature as real solutions to minimize or mitigate the effects of bioenergy technology deployment to migratory species. These examples can be used for other bioenergy production habitats.

Siting

- Target biofuel production to degraded and abandoned cropland to avoid converting high-quality native habitat, such as forests, to biofuel production fields (Fargione *et al.* 2010).

Mitigation

- Use native species. For example native prairie species such as switchgrass in North America, instead of row crops such as corn, increases habitat heterogeneity and results in increased avian and insect biodiversity (Paine *et al.* 1996, Murray & Best 2003, Fargione *et al.* 2009, Fargione *et al.* 2010, Hartman 2011, Robertson *et al.* 2011).
- Rotational or strip harvesting may improve biodiversity. Examples are available for migratory bird species in switchgrass fields by providing both tallgrass and shortgrass habitats (Murray & Best 2003, Roth *et al.* 2005, Bies *et al.* 2006).
- Use biofuels that do not require additional land resources, such as wood/crop residues, animal/municipal wastes, cover crops, and algae (Fargione *et al.* 2009).

3.9 Positive effects

As discussed above, the use of switchgrass as a biofuel crop in the United States has the potential to provide high-quality habitat for migratory grassland bird species (Paine *et al.* 1996, Murray & Best 2003, Murray *et al.* 2003, Roth *et al.* 2005, Hartman *et al.* 2011, Robertson *et al.* 2011). Switchgrass is native to the US and allows for heterogeneity in vegetation structure, unlike monoculture crops such as corn (Cook *et al.* 1991, Danielson *et al.* 2008, Fargione *et al.* 2009, Fargione *et al.* 2010, Hartman *et al.* 2011, Robertson *et al.* 2011). Biodiversity of grassland birds in switchgrass biofuel production fields has been found to be comparable to that in native prairie habitat (Robertson *et al.* 2011).

The use of rotational and strip harvesting techniques, as well as staggering harvest times throughout the year, can also increase avian biodiversity by creating a variety of different habitat types (Murray & Best 2003, Roth *et al.* 2005, Bies 2006, Hartman *et al.* 2011, Robertson *et al.* 2011).

Below are positive impacts summarized by Chum *et al*. (2011):

- Establishment of perennial herbaceous plants or short-rotation woody crops in agricultural landscapes has been found to improve biodiversity. Bioenergy plantations that are cultivated as vegetation filters can improve habitat quality by reducing the nutrient load and eutrophication in water bodies.

- Bioenergy plantations can be located in the agricultural landscape to provide ecological corridors through which plants and animals can move between spatially separated natural and semi-natural ecosystems. Thus, bioenergy plantations can reduce the barrier effect of agricultural lands.
- As an indirect effect, properly located biomass plantations can also protect biodiversity by reducing the pressure on nearby natural forests. A study from Orissa, India, showed that introducing village biomass plantations increased biomass consumption (as a consequence of increased availability) while decreasing pressure on the surrounding natural forests.
- When crops are grown on degraded or abandoned land (e.g. deforested areas or degraded crop- and grasslands), the production of feedstocks could have positive impacts on biodiversity by restoring or conserving soils (reduce erosion), habitats and ecosystem functions.

3.10 Gaps in knowledge

Few studies were found that examined how insect communities differ between native habitat and switch grass and corn biofuel production fields. There may be an important gap in knowledge for or the effects of biofuel production on migratory bat species, as well as insectivorous birds. In addition, little research seems to have been done on the effects of the operation of bioenergy facilities on migratory species, including air emissions and other potential environmental consequences. This may be especially relevant at facilities, which convert municipal waste to energy.

While some studies were found documenting the link between Amazonian deforestation and sugarcane production as a bioethanol crop in Brazil, little information was found regarding the specific impacts of biomass energy technology to migratory species in Latin America. Nearly all studies found in the literature review focused on grassland habitat and associated migratory bird species in the central United States. As biomass energy becomes more widely used in the developing world for generation of electricity and production of biofuels, more proactive research will be needed here to document the expected effects of the technology before deployment and the actual effects after deployment on migratory species to properly inform siting, operational, and mitigation plans.

As for all RE developments the long-term and population-level consequences of large-scale deployment of bioenergy need further research (Sathaye *et al.* 2011).

The (potential) impacts of bioenergy on migratory species are variable.. At one end of the spectrum, bioenergy can be produced with intensively managed monocultures of annual food crops. This method of production can have large environmental consequences, including habitat loss and the off-field impacts of fertilizer and pesticide runoff. Toward the other end of the spectrum, bioenergy can be produced by sustainably harvesting biomass from systems with high plant diversity and low agriculture input (Fargione *et al*. 2009). The impact on biodiversity in general and migratory birds, mammals and fish in particular, depends highly on to which extent natural areas and priority areas for conservation will be converted to energy crops, the crop types used and how the crops will be managed (*e.g.,* Wicke *et al.* 2011, Persson 2012; Semere & Slater 2006, Engel *et al.* 2012).

In general, bioenergy from dedicated feedstocks is characterised by relatively large land use requirements (Hung 2010; Chum *et al*., 2011) and potentially relatively large water use requirements compared to other RET (Chum *et al*., 2011). If biomass from residues or organic wastes is used, additional land use is small. The water footprint of feedstock production is highly dependent on feedstock type, geographic region and local climatic conditions, and crop management practices (Chum *et al*., 2011).

The impacts on (migratory) species are technology-, site- and species specific. Bioenergy can also lead to positive effects on wildlife species. The impact assessments for all the determining factors, positive and negative, deserve considerably more research, data collection and proper monitoring for the careful siting and design of bioenergy projects in future.

3.11 Conclusions

The consensus of the literature is that habitat loss and degradation are the main impacts of bioenergy technology and migratory species. Of particular concern are the conversion of ‘high-nature-value’ farming to more intensive monocropping and the conversion of pristine areas (e.g. primary forests). Birds and terrestrial mammals are the primary species groups that can be affected, but also fish can be impacted. In the United States, for example, grassland birds are the primary species affected due to the conversion of native prairie habitat to biofuel production fields. Bioenergy can be produced using a variety of feedstocks and methods. Hence, the (potential and significance of) impacts of bioenergy on migratory species are variable. Moreover, the impacts are site-, and species- specific. This makes it is difficult to make generalization about the impacts. In general, bioenergy from dedicated feedstocks is characterised by relatively large land use requirements and potentially relatively large water use requirements. Land use and change and water use are the main issues of concern with respect to impacts of bioenergy on migratory species. Besides that, feedstock cultivation can lead to emission of nutrients and pesticides to aquatic systems. The subsequent processing of the feedstock into biofuels and electricity can increase chemical and thermal pollution loads from effluents and generate waste to aquatic systems. These impacts can result in degradation of key habitat for migratory fish species.

An important concern is the indirect impact of bioenergy driven change in land use. Bioenergy developments may indirectly lead to changes in land use elsewhere. A biomass plantation can be established on land previously used for grazing or crops with limited impacts on biodiversity. The previous land use might, however, shift to

other (pristine) areas and result in significant habitat deterioration of migratory species.
Depending on a variety of factors, bioenergy can also lead to positive impacts on migratory species. Bioenergy plantations can be designed to provide filters for nutrient loss, to function as ecological corridors or stepping-stones, to reduce pressure on natural forests and to restore degraded or abandoned land. The impact assessments for all the determining factors, positive and negative, deserve considerably more research, data collection and proper monitoring for the careful siting and design of bioenergy projects in future. As for all RE developments the long-term and migratory species population-level consequences of large-scale deployment of bioenergy need further research.

3.12 Literature

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4 Geothermal energy

F. van Vliet & E. Moore

4.1 Introduction

Geothermal energy heat is stored in media beneath the Earth's surface. Heat is extracted from geothermal reservoirs using wells or other means. Resource utilization technologies for geothermal energy can be grouped under types for electrical power generation, for direct use of the heat, or for combined heat and power in cogeneration applications. Earth energy can be tapped almost anywhere with geothermal heat pump (GHP) technologies and other direct-use applications (Goldstein *et al*. 2011).

Geothermal resources can be classified as convective (hydrothermal) systems, conductive systems and deep aquifers. Hydrothermal systems include liquid- and vapour-dominated types. Conductive systems include hot rock and magma over a wide range of temperatures. Enhanced or engineered geothermal system (EGS) technologies enable the utilization of low permeability and low porosity conductive (hot dry rock) and low productivity convective and aquifer systems by creating fluid connectivity through hydraulic stimulation and advanced well configurations. Deep aquifers contain circulating fluids in porous media or fracture zones at depths typically greater than 3 km, but lack a localized magmatic heat source (Goldstein *et al*. 2011).

Currently, the only commercially exploited geothermal systems for power generation and direct use are hydrothermal (of continental subtype). Table 4.1 summarizes the resources and utilization technologies (Goldstein *et al.* 2011).

Table 4.1 Types of geothermal resources, temperatures and uses (extracted from Goldstein et al. 2011)

Type	In-situ fluids	Subtype	Temperature Range	Utilization	
				Current	Future
Convective systems (hydrothermal)	Yes	Continental	H, I & L	Power, direct use	
		Submarine	H	None	Power
Conductive systems	No	Shallow (<400 m)	L	Direct use (GHP)	
		Hot rock (EGS)	H, I	Prototypes	Power, direct use
		Magma bodies	H	None	Power, direct use
Deep aquifer systems	Yes	Hydrostatic aquifers	H, I & L	Direct use	Power, direct use
		Geo-pressured		Direct use	Power, direct use

The basic types of geothermal power plants in use today are steam condensing turbines and binary cycle units. Steam condensing turbines can be used in flash or dry-steam plants. The power plant generally consists of pipelines, water-steam separators, vaporizers, de-misters, heat exchangers, turbine generators, cooling systems, and a step-up transformer for transmission into the electrical grid (Goldstein *et al.* 2011)

The typical operational footprint for conventional geothermal power plants includes surface installations like drilling pads, roads, pipelines, fluid separators and power stations. The land use requirements differ between the geothermal technologies, but in general, geothermal energy has very low aboveground direct land use compared to other energy sources (if risk of land subsidence is not taken into account (Evans *et al.*, 2009; Goldstein *et al*. 2011).

Currently, geothermal energy is only exploited on land; no technologies are in use to tap submarine geothermal resources.

This review will focus on the impacts of electricity generating geothermal technologies and EGS. Technologies for direct use (heating and cooling) are not believed to pose any direct threat to migratory species, as they are in the majority of cases confined to developed environments.

4.2 Impact matrix

The (potential) impacts of geothermal energy deployment are summarized in Table 4.1. As geothermal energy, currently, is only exploited on land, only impacts on terrestrial ecosystems / onshore ecosystems are relevant. The species groups where impacts are likely to occur include birds, mammals and fish, which are discussed in more detail below. No direct impact is expected on reptiles and insects and these are therefore excluded from the analysis. The impacts summarized in Table 4.1 are described in more detail in the next paragraphs.

The impact matrix summarizes the impacts of geothermal energy production on the relevant species *groups* (see above). Impacts can be extrapolated to species level (Table 1.1) when geothermal energy development coincides with the habitat of these species.

The impacts of geothermal energy deployment on migratory species are project- and site-specific. The nature, scale and degree of impacts will vary according to site- and project specific factors such as the specifications of the development (design, scale, technology), the habitat affected, the species involved and seasonal and diurnal patterns of use of the project site by species.

The potential environmental impacts from geothermal deployment can be summarized as follows:

- Gaseous emission to the atmosphere
- Water pollution
- Solids emissions to the surface and atmosphere
- Noise pollution
- Land usage

- Land subsidence
- Induced seismicity
- Induced landslides
- Water use
- Disturbance of natural hydrothermal manifestations
- Disturbance of wildlife habitat and vegetation
- Catastrophic events

Most of these impacts mentioned above apply to most energy projects in construction and operation phases. The main potential environmental impacts of geothermal energy deployment on migratory species are noise disturbance from seismic surveys and drilling, impacts of geothermal fluids in case of surface disposal and loss or degradation of key habitat of migratory species. In general, geothermal generation has very low aboveground direct land use (if risk of land subsidence is not taken into account (Evans *et al*., 2009).

Geothermal energy development may result in a range of impacts on wildlife that are common to most energy or development projects, including mortality, habitat loss, habitat degradation, habitat fragmentation and disturbance.

As potential areas for geothermal energy development are often in or adjacent to nature reserves and forested areas (for example Indonesia, Japan, USA and New Zealand), site specific effects (habitat loss and degradation) can have more severe impacts on wildlife.

Local hazards arising from natural phenomena, such as micro-earthquakes, hydrothermal steam eruptions and ground subsidence may be influenced by the operation of a geothermal field. As with other (non-geothermal) deep drilling projects, pressure or temperature changes induced by stimulation, production or injection of fluids can lead to geo-mechanical stress changes and these can affect the subsequent rate of occurrence of these phenomena (Majer *et al.* 2008). A geological risk assessment may help to avoid or mitigate these hazards. The effects of local hazards are not further addressed in this study (Goldstein *et al*. 2011).

Decommissioning and Post-operation

Impacts on biodiversity during the decommissioning and post-operation phase are likely to be limited, as the wells are likely to have a life expectancy of at approximately 30 years. The only impacts that may then be expected are indirect impacts on rivers and streams, possibly through temporary increases in sediment levels due to demolition/levelling activities, and temporary release of small amounts of pollutants such as oil and grease. These impacts are therefore expected to be of adverse low significance and thus not further addressed in this study.

Table 4.2 Impact matrix geothermal energy and migratory species. Assessment of the (potential) impact of the geothermal energy technology on migratory species

Process phase	Species group	Impact	Description of ecological impact	Spatial extent impact	Duration of impact	Magnitude of impact
Exploration, Construction & Decommissioning	**Birds, Terrestrial Mammals, Fish**	Mortality, Habitat loss and fragmentation, Disturbance, Habitat degradation	see table 2.1			
Operational	**Birds**	Mortality	Collision with power plant structure and vehicle strikes.	Local	Long-term	I
		Habitat loss and fragmentation	Development of geothermal power plants and access roads.	Local	Long-term	I
			Fragmentation of habitat by roads.	Local	Long-term	I
		Disturbance/ displacement	Noise, light, and thermal disturbance.	Local	Long-term	I
		Habitat degradation	Subsidence, contamination of water and impacts to vegetation by wastewater and vapor release.	Regional	Long-term	II
		Habitat gain	Potential for gain of roost and perch sites.	Local	Long-term	I
	Terrestrial Mammals	Mortality	Collision with power plant structure and vehicle strikes.	Local	Long-term	I
		Habitat loss and fragmentation	Development of geothermal power plants and access roads.	Local	Long-term	I
			Fragmentation of habitat by roads.	Local	Long-term	II
		Disturbance/ displacement	Noise, light, and thermal disturbance.	Local	Long-term	I
		Habitat degradation	Subsidence, contamination of water and impacts to vegetation by wastewater and vapor release.	Regional	Long-term	II
	Fish	Habitat degradation	Potential for water contamination by release of wastewater, chemicals, or contaminated water vapor.	Regional	Long-term	I

Spatial extent (size of area) of the impact (local/project area, regional/beyond the project area); Magnitude (I = Effects reported, but no apparent threat to populations, II = High impact, but with no significant impact on the overall species population, III = High impact increasing the risk of species extinction, regionally or at a larger scale). See §1.2.3.for explanation of terms used.

4.3 Exploration and construction phase

Effects during the construction phase of a geothermal plant generally reflect those for other similar construction projects and include mortality, disturbance, habitat loss and habitat degradation. The level and duration of the effects witnessed vary depending on ecological and environmental factors as well as the location, timing, duration, intensity and size of the project and the construction techniques and any mitigation measures employed.

The main activities causing environmental impact of geothermal facilities are:

- Building of access roads and drilling pads
- Well drilling and well stimulation
- Well repairs, possible additional well drilling and well testing
- Laying of pipelines, electric power transformation and transmission lines
- Plant construction and equipment installation

The noise from seismic surveys and drilling potentially can to disturb wildlife species and affect their breeding, foraging, and migrating behaviour. Primary sources of noise associated with exploration include earth-moving equipment, vehicle traffic, seismic surveys, blasting, and drill rig operations. Potential environmental impacts from construction activities are generally similar to but more extensive than those during the exploration and drilling phase, but of shorter duration than those during the operations and maintenance phase (TEEIC; http://teeic.indianaffairs.gov/).

Sump pits containing high concentrations of minerals and chemicals from drilling fluids have the potential to adversely impact wildlife (TEEIC; http://teeic.indianaffairs.gov/).

4.4 Birds

Potential conflicts between migratory birds and geothermal energy development identified in the literature include loss or fragmentation of habitat via power plant and road construction, habitat degradation by contaminated cooling water and water vapour release, and noise, light, and thermal pollution.

4.4.1 Mortality

While most literature focused on habitat degradation due to geothermal energy development, migratory birds may also face mortality risk from vehicle strikes or collision with the power plant structures themselves (BLM and USFS 2008).

4.4.2 Habitat loss

Direct habitat loss would occur in areas cleared for geothermal power generation activities. Removal of steam and water from underground reservoirs also has the potential to lead to land subsidence, which may result in further loss of habitat for migratory birds (Abbasi and Abbasi 2000, Kagel *et al.* 2007).

4.4.3 Habitat degradation

Habitat degradation is the most significant conflict identified in the literature between geothermal energy development and migratory birds (Osmani *et al.* 2013). Habitat fragmentation by site clearing, road development, and power plant construction may interrupt migration patterns as well as reduce habitat quality for migrants (Forman and Alexander 1998, Abbasi and Abbasi 2000, BLM and USFS 2008). In particular, development of new roads in tropical areas may lead to locally devastating habitat degradation due to the sensitivities of rainforests to such disturbance (Laurance *et al.* 2009).

Disturbance related to construction and operation of a geothermal plant may also allow colonization by invasive vegetation, further reducing habitat value for migratory species (BLM and USFS 2008). The use of herbicides to control cleared land or accidental spills of chemicals could also be detrimental to migrants, particularly those feeding or nesting in the areas (BLM and USFS 2008). Noise pollution caused by the geothermal power development and operation can reduce habitat suitability and cause some birds to avoid the area, disrupting migration patterns (BLM and USFS 2008). In addition, release of contaminated cooling waters and water vapor may introduce mineral contaminants and other chemicals to the environment that may have adverse effects on species and vegetative habitat (Abbasi and Abbasi 2000, Northrup and Wittemyer 2013).

One of the main flyways and stop-overs for the migratory birds (Palearctic birds) are within the Rift Valley (Ollorgessailie, Kariandusi, L. Turkana), where a number of large geothermal power plants are sited. No literature has been found on actual impacts of these power plants on migratory birds. In environmental impact assessments for the development of these power plants, the potential impacts on migratory birds have been addressed. For instance, transmission power lines were thought likely to interfere with the roosting/homing behaviour of some important birds prey *e.g.* the Ruppell's Griffon Vultures (*Gyps rueppellii*), which travel long distances to feed during the day, but return in the evening to their nests on the Vulture Cliffs in the park. During operations, high voltage lines and silencers are a potential danger to birds and as such they should be constructed to avoid right angle crossing of known flight lines.

4.5 Large herbivore mammals

Potential conflicts between migratory mammals and geothermal energy development as identified in the literature are similar to those for birds, though mammals may be more impacted by habitat fragmentation and barrier effects associated with these projects.

4.5.1 Mortality

Mortality due to vehicle strikes on access roads is a potential conflict between migratory mammals and geothermal energy development (BLM and USFS 2008). In addition, collision with power plant structures may impact migratory bat species (BLM and USFS 2008).

4.5.2 Habitat Loss

Construction of geothermal power plant facilities on undeveloped lands can result in loss of that habitat to migrant mammals and other species (Osmani *et al.* 2013). Development of access roads may also affect migratory routes used by some mammals and act as barriers to movement, resulting in effective loss of habitat (Forman and Alexander 1998, Dyer *et al.* 2002, Sawyer *et al.* 2009). Subsidence caused by reduced pressure in subterranean geothermal reservoirs is another potential source of habitat loss that may impact these species (Kagel *et al.* 2007). Conversely, subsidence may lead to the creation of wetland habitats, which may benefit some species (Bell & Genske 2001).

4.5.3 Habitat degradation

Habitat degradation was the most significant impact identified by the literature on geothermal energy development and wildlife. Habitat fragmentation by site clearing and construction may interrupt migration patterns as well as reduce habitat quality for mammals migrating through the area (Forman and Alexander 1998, Dyer *et al.* 2002, BLM and USFS 2008).

Disturbance related to construction and operation of a geothermal plant may also allow colonization by invasive vegetation, further reducing habitat value for migratory species (BLM and USFS 2008). The use of herbicides to control cleared land or accidental spills of chemicals could also be detrimental to migrants, particularly those feeding or nesting in the areas (BLM and USFS 2008). Noise pollution caused by the geothermal power development and operation can reduce habitat suitability and cause some mammals to avoid the area, further disrupting migration patterns (BLM and USFS 2008). Lastly, release of contaminated cooling waters and water vapor may introduce mineral contaminants and other chemicals to the environment that may have adverse effects on species and vegetative grazing areas (Abbasi and Abbasi 2000, Northrup and Wittemyer 2013).

Geothermal development may affect wildlife by blocking ungulate movement and destroying their habitats. For example, in At Olkaria (in the Great Rift Valley of Kenya, Africa) animals concentrate more in the park during the dry season. This is because of the provision of water holes, or wastewater from human settlements. During the wet season, the animals are widespread both within and outside the park in areas that offer suitable feeding areas. During the dry season, the herbivores gradually shift from open grassland and open bushed grassland feeding areas to more bushed areas.

They do so to shelter themselves from the heat of the day. The routes (trails), which the animals use in the course of these movements are permanent and have been used for a very long time. Physical barriers contribute to habitat fragmentation, influence species distribution and ranging behaviour, and impact long-term population viability (Bw'Obuya 2002).

Most of the geothermal fields in the Rift Valley of Kenya are in semi-arid areas; therefore animals are drawn to any surface waters from well testing, disposal pipe leakage, and chemical stabilisation ponds. Green vegetation that is attractive to animals tends to grow around these waters and animals can feed on them. Toxicity monitoring of the soils and plants around the stabilisation ponds by Simiyu and Tole (1995) show accumulation of toxic constituents and therefore the water and plants around the ponds are not fit for animal consumption.

In a preliminary environmental impact assessment of geothermal exploration and development Rwanda, Namugize (2011) concluded that potential impacts on the mountain gorillas could arise caused by noise from well discharging and testing, and the unpleasant smell of hydrogen sulphide.

Exploration drilling will be carried out in the vicinity of the National Volcanoes Park; the most probable threat to mountain gorillas will be the noise and geothermal gases. Of the gases, H2S is most likely to cause problems because of its unpleasant smell. The response of mountain gorillas to noise and H2S smell is completely unknown because such a project has never been developed in a mountain gorilla habitat. But, in Hell's Gate National Park of Kenya, baboons, gazelles and buffaloes adapted to geothermal development activities (Mariita, 2010 in Namugize, 2011).

4.6 Other species

Geothermal plants sited near rivers that host migratory fish species might impact those individuals utilizing the habitat, primarily through degradation of the river water quality.

4.6.1 Mortality

Mortality effects of geothermal energy development on fish or other non-mammal and non-bird species were not readily identified as being of concern in the literature.

4.6.2 Habitat Loss

Habitat loss due to geothermal energy development was not identified as being of concern for fish or other non-mammal or non-bird species in the literature.

4.6.3 Habitat degradation

In most situations, geothermal fluids are utilized for cooling before reinjection, and therefore no freshwater is consumed (Franco and Villani, 2009). Depending on technology, resource type and cooling system used, geothermal operational water consumption can range from near zero to as much as 15 m^3/MWh (Fthenakis and Kim, 2010).

Geothermal facilities can affect both surface water quality through spillage of geothermal fluids at the surface during operation, leakage from surface storage impoundments, and through contamination of nearby freshwater wells (Brophy, 1997; Dogdu and Bayari, 2004; BLM and USFS 2008). This may lead to habitat degradation of migratory fish.

Most geothermal energy developments bring fluids to the surface in order to extract heat contained within them. Putting it into waterways or evaporation ponds, or re-injecting it deep into the ground disposes of the waste fluid. The release of contaminated cooling waters or water vapor that enters the watershed can have far reaching downstream impacts on rivers and migratory fish (Axtmann 1975, Abbasi and Abbasi 2000, Northrup and Wittemyer 2013); however most modern geothermal plants reinject spent cooling waters back into subterranean reservoirs, reducing impact on the local watershed (Kagel *et al.* 2007).

The chemistry of the fluid discharge is largely dependent on the geochemistry of the reservoir, and the operating conditions used for power generation and will be different for different fields (Webster, 1995). Most of the chemicals are present as solute and remain in solution from the point of discharge, but some are taken up in river or lake bottom sediments, where they may accumulate to high concentrations. The concentrations in such sediments can become greater than the soluble concentration of the species in the water, so that re-mobilisation of the species in the sediment, such as during an earthquake or flood, could result in a potentially toxic flush of the species into the environment. Chemicals that remain in solution may be taken up by aquatic vegetation and fish (Webster & Timperly, 1995). For example, in New Zealand, annual geothermal discharges into the Waikato River contain 50 kg mercury, and this is regarded as partly responsible for the high concentrations of mercury in trout from the river and sediment mercury levels (Hunt, 2000).

If hot waste water from a standard steam-cycle power station is released directly into an existing natural waterway, the increase in temperature may kill fish and plants near the outlet.

Extraction of groundwater could impact the hydrology of these rivers as well, decreasing habitat suitability (BLM and USFS 2008). Alterations to the hydrology of waterways by plants that require large amounts of water have potential to cause negative impacts on the ecology of waterways and the hydraulic connectivity of aquatic habitats, in turn affecting the migration of fish species. Such impacts at critical stages in the life cycle of migratory fish can lead to failure in breeding or migration that can be of significance at a catchment population scale, potentially leading to local extinction, or severe depletion in local or regional migratory fish populations.

4.7 Mitigation measures

The review document has been prepared in conjunction with a guideline document in which guidelines for siting, planning and mitigation are presented and prioritised. Within this review chapter, basic background information is presented. Although siting and mitigation can overlap they are as much as possible separated. The presented information is as much as possible based on literature unless stated otherwise, e.g. in case of mitigation suggestions.

As geothermal energy is relatively new and local, few studies on mitigation are available or not particularly related toe geothermal energy but to infrastructure in general. So there are several suggestions for mitigation measures found in literature, without post monitoring evidence that these are effective:

Siting

- Avoid development on sensitive or priority migratory habitat by conducting pre-development site-specific assessments of potential migratory species to be affected and the importance of the area to those species (Northrup and Wittemyer 2013).
- Avoid blocking animal migration routes, by burying pipes underground or elevating them to allow free movement of animals, like for instance at the geothermal power plant at Olkaria in the Great Rift Valley of Kenya, Africa. These routes were avoided during construction of infrastructure for power development. Vertical loops were provided along the geothermal steam and brine transmission pipelines, to allow free movement of wildlife (Mwangi, 2010).

Mitigation

- Employ an injection technology at geothermal reservoir wells that reduces land subsidence and the contamination of local water bodies with wastewater (Abbasi and Abbasi 2000, Kagel *et al*. 2007).
- Apply directional drilling techniques, and appropriate design of pipeline corridors, so that the land area above geothermal resources that is not covered by surface installations could still be used by migratory species (see for example Mokai and Rotokawa in New Zealand (Koorey and Fernando, 2010) and a national park at Olkaria, Kenya).
- Prevent wildlife drinking geothermal wastewater by isolating separated geothermal fluids in securely fenced high density polyethylene (HDPE) lined sump ponds, prior to disposal through re-injection back into the reservoir. Fence off the waste brine conditioning ponds from wildlife. In addition, supply potable water to wildlife at various points so that they are not tempted to drink

geothermal wastewater particularly during dry weather conditions. This was proposed for the geothermal power plant at Olkaria in the Great Rift Valley of Kenya, Africa.

4.8 Positive effects

Depending on local circumstances, subsidence caused by reduced pressure in subterranean geothermal reservoirs can also have a positive effect, as it can result in wetland habitats for migrating species. For instance, the Stodmarsh is a wetland resulting from coal mining subsidence under the valley of the Great Stour in the United Kingdom.

There were no other direct positive effects of geothermal energy development on migratory species identified in the literature.

4.9 Gaps in knowledge

Few systematic studies of the impacts of geothermal power plants on wildlife have been undertaken. It is possible to hypothesise impact pathways based on ecological principles and common sense but very few of these have been investigated in any detail, let alone enough to form definitive conclusions about the scale of the risks and impacts. In general, studies on life cycle environmental effects of geothermal power generations are scarce and country or site specific with a focus on the geothermal fields in the western USA (Bayer *et al*. 2013). As for all RE developments the long-term and population-level consequences of large-scale deployment of geothermal energy need further research (Sathaye *et al.* 2011).

As new projects enter the planning phase, site-specific and technology-specific studies will be required to best predict potential conflicts with migratory species in the area. This requires risk mapping of likely areas of potential geothermal exploitation and important areas for migratory species. Monitoring the impacts during the life cycle of existing and future geothermal power plants is needed to learn more about the impacts on migratory species, determining factors and the effectiveness of suggested mitigation measures.

4.10 Conclusions

Although there is quite some literature on the potential environmental impacts of the development of geothermal resources, literature on actual impacts (post monitoring studies) is limited. The general conclusion from the literature reviewed is that geothermal energy technologies generally present relatively low impact on migrating species as compared to the development of other forms of energy. This has among other things to do with the small overall footprint of geothermal energy conversion equipment and the relatively low water demand.

Geothermal development and deployment can impact migratory species, specifically birds, terrestrial mammals and fish. The significance of the impacts of geothermal development and deployment on migratory species depends upon a number of factors including the surface of land disturbed by drilling and construction activities, the number and size of well pads, the type of power plant technology used, the surface of land occupied by facilities over the life of the geothermal facility, and the facility's location with respect to critical habitat for migratory species. Geothermal development typically has an exploration phase. Activities during the exploration phase are temporary and are conducted at a smaller scale than those during the construction, operational and decommissioning phases. The noise levels in the exploration phase are relatively high due to seismic testing and drilling activities. This could potentially disturb wildlife, specifically birds and terrestrial mammals. The potential impacts of the construction & decommissioning phase are similar to other RE developments, including mortality, habitat loss, habitat fragmentation, habitat degradation and disturbance. As potential areas for geothermal energy development are often in or adjacent to nature reserves and forested areas, site-specific effects (habitat loss, degradation and fragmentation) can potentially have more severe impacts on species. Impacts during the operations and maintenance phase could occur as a result of noise disturbance and water demand during the life cycle of the project.

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5 Hydropower energy

J. Howes, B. Lane & M. Soes & J. Lajoie

5.1 Introduction

Hydropower is a form of power derived from harnessing the energy of falling and / or running water. The kinetic energy of flowing water (when it moves from higher potential to lower potential) rotates a turbine, which in turn drives an electricity-generating device.

Based on the size of the project, and corresponding amounts of electricity generated, hydropower can be classified into the two main types:

1. Conventional, storage hydropower projects, include large scale hydro-electric dams that require a water storage reservoir or impoundment upstream of the dam and can generate anywhere from hundreds of megawatts (MW) of electricity to over 10 gigawatts (GW) (*e.g.*, the Three Gorges Dam in P.R. China has an electricity-generating capacity of 22.5 GW). Hydro-electric dams may also deliver other services that go beyond the energy sector, including flood control, water supply, navigation, tourism and irrigation.
2. Run-of-the-river hydropower projects capture the kinetic energy in flowing rivers or streams, without the use of dams. They may include small intake basins with no storage capacity. Large-scale run-of-river projects may have some limited ability to regulate water flow especially if they operate in cascades in unison with conventional, storage hydropower in up-stream reaches. Run-of-the-river projects and can be classified as:
   - small hydro projects generating 10 MW or less of electricity, usually without an up-stream impoundment or reservoir.
   - micro-hydro projects that may provide between a few kilowatts (kW) to a few hundred kW of electricity to isolated homes, villages, or small industries.
   - pico-hydro projects are very small-scale, often used to generate electricity for one or two houses (generally less than 5 kW).

Two other forms of hydropower have been defined, but these are not considered in this review, as they are less likely to have any major impacts on migratory species. These are conduit hydropower projects that utilize water that has already been diverted for use elsewhere; and pumped-storage hydropower projects that pump water during low peak periods to a storage reservoir and release the water to generate electricity during periods of high demand.

Hydropower is a proven, mature, predictable and cost-competitive technology, with the first hydro-electric station being commissioned around 1880 (www.usbr.gov/power/edu/history.html). More than 150 countries now use large-scale hydropower generation, with China the largest hydroelectricity producer globally followed by Brazil, Canada, USA and Russia.

Hydro-electric facilities also produce cheap energy that can be effectively managed to meet fluctuating demands, and they tend to have a long service life, with some projects having a working lifespan in excess of 100 years.

Despite these advantages, hydropower projects can have a wide array of negative impacts on the environment. The building of dams, and similar structures, across flowing rivers invariably changes the hydrologic characteristics of the river. This in turn disrupts the ecological continuity of sediment transport and fish migration within a river or stream system and the seasonality of water discharges, water temperatures and other chemical characteristics. Storage hydropower in particular, requires the transforming a fast-flowing river ecosystem into stagnant, artificial lakes, having enormous significant impact on such ecosystems in both the short- and long-term. In addition, impoundments may lead directly to habitat loss and fragmentation due to submersion of forest- and other ecosystems.

This document will concentrate on the impacts of large-scale hydro-electric power schemes on migratory species; however, some consideration will also be given to the effects of smaller scale run-of-the-river and in-stream projects that may have similar impacts. Focus will be given to the operational phase of hydropower projects, but some reference will be made to construction and decommissioning phases also.

5.2 Impact matrix

The potential impacts of hydropower energy deployment are summarized in Table 5.1. Four major taxa are considered in the impact matrix. The main species group that is affected by hydropower projects is fish, and much of this analysis will focus on this group. Other taxa that use river channels for migratory movements, and will therefore be impacted, include freshwater mammals *e.g.* Irrawaddy dolphin (*Orcaella brevi-rostris*), Amazon river dolphin (*Inia geoffrensis*) and the manatees *Sirenians*, many species of freshwater turtles and terrapins, and to a lesser extent, migratory water-birds, especially species that favour rapid stream flows and riverine habitats (*e.g.* scaly-sided merganser). The impact matrix summarizes the impacts of hydropower energy production on the relevant species *groups* (see above). Impacts can be extrapolated to species level (Table 1.1) when hydropower energy development coincides with the habitat of these species. The impacts summarized in Table 5.1 are described in more detail in the next paragraphs.

Impacts on migratory species during the construction and decommissioning stage are, by their very nature, temporary. For instance, the construction of the coffer dam to allow construction of the main dam to take place, will lead to changes in river flows, increased sedimentation and destruction of habitats, they will be temporary with respect to the coffer dam construction, but will ultimately lead to permanent changes in the river following completion of a barrier or dam across a river. This will ultimately cause long-term impacts on those species.

Table 5.1 Impact matrix hydropower energy and migratory species. Assessment of the (potential) impact of the hydropower energy technology on migratory species

Process phase	Species group	Impact	Description of ecological impact	Duration of impact	Magnitude of impact
Construction & decommissioning	**Fish, Mammals, Reptiles**	Mortality, Habitat loss and fragmentation, Barrier effects, Habitat degradation, Habitat alteration	Physical obstruction for migratory fish during construction of coffer dam, Hydrology of downstream areas changed, Increased sedimentation downstream. see table 2.1		
	Birds	Mortality, Habitat loss and fragmentation, Habitat alteration	see table 2.1		
Operational	**Fish**	Mortality	During passage through turbines, impacts of water pressure, gas bubble disease and increased disease.	Long-term	III
		Habitat loss and fragmentation	Loss of shallow, fast flowing riverine habitats, riparian edges and spawning areas.	Long-term	III
		Barrier effects	Physical structure across migration pathways (amelioration through provision of fish ladders and lifts may be possible).	Long-term	III
		Habitat degradation	Downstream and seasonal hydrological changes. Loss of fish spawning sites. Proliferation of alien species. Possibility of bio-accumulation in reservoir.	Long-term	III
		Habitat alteration	Fast-flowing shallow channels become static, deep-water reservoirs. Reduced sedimentation and flood rates downstream. Changes in nutrient discharge.	Long-term	III
		Habitat gain	Creation of large, deep waterbodies.	Long-term	I
	Birds	Habitat loss and fragmentation	Loss of shallow, fast flowing riverine habitats, riparian edges.	Long-term	II
		Habitat degradation	Downstream and seasonal hydrological changes. Direct impacts on insect and fish prey species populations and vegetation, available nesting sites.	Long-term	II
		Habitat alteration	Fast-flowing shallow channels become static, deep water reservoirs.	Long-term	II
		Habitat gain	Creation of large, deep waterbodies.	Long-term	II
	Mammals	Habitat loss and fragmentation	Direct loss of fast-flowing riverine habitats and deep water channels.	Long-term	III
		Barrier effects	Physical structure across migration pathways.	Long-term	III
		Habitat degradation	Downstream and seasonal hydrological changes. Direct impacts on prey species populations and river geomorphology.	Long-term	III
		Habitat alteration	Fast-flowing shallow channels become static, deep water reservoirs.	Long-term	III
	Reptiles (turtles)	Mortality	Due to turbines.	Long-term	0
		Habitat loss and fragmentation	Direct loss of fast-flowing riverine habitats.	Long-term	I

Process phase	Species group	Impact	Description of ecological impact	Duration of impact	Magnitude of impact
		Barrier effects	Physical structure across migration pathways (unclear if freshwater turtles use fish ladders and lifts).	Long-term	II
		Habitat degradation	Downstream and seasonal hydrological changes. Direct impacts on prey species populations and availability of nesting sandbanks.	Long-term	II
		Habitat alteration	Fast-flowing shallow channels become static, deep water reservoirs.	Long-term	II
		Habitat gain	Creation of large, deep waterbodies.	Long-term	I

NOTE: For hydropower projects, the difference is between "**operational**" and '**energy production**" stages is minor. Following construction of a dam across a river, it operates as a hydropower plant producing energy, and will have direct impacts on fish migration (in particular). There will be differences in impacts when the turbines are producing energy (i.e., mortality of juvenile fish passing though turbines) as opposed to when they lie idle, but it is not clear if this is really what is meant here? Clarification required. If the foregoing information adequately addresses requirements then the two categories should be amalgamated and the above information used

Spatial extent (size of area) of the impact (local/project area, regional/beyond the project area); Magnitude (I = Effects reported, but no apparent threat to populations, II = High impact, but with no significant impact on the overall species population, III = High impact increasing the risk of species extinction). See §1.2.3.for explanation of terms used.

5.3 Construction and decommissioning phases

Focus is given to the operational phase of hydropower projects, but some references is be made to the construction and decommissioning phases in the species-group sections below.

There has been increased interest in dam decommissioning following the successes of river restoration. Numerous dams from different parts of the world are now proposed for removal. Many have simply outlived their purpose. However, dam removal is accompanied by controversies that arise from our limited scientific knowledge of the effects of dam removal. It is believed that the ecological consequences are best understood by viewing the removal process as a habitat disturbance.

Ecological outcomes will include changes that are both environmentally costly, such as invasion of exotic species, and environmentally beneficial, such as increasing access to spawning habitats for migratory fish (Stanley and Doyle 2003).

Dam removal can have positive as well as negative impacts; apart from the impacts described above, impacts following dam removal have been summarised as follows by Bednarek (2001):

Positive impacts:

- Improve fish passage;
- Increase flow fluctuations;
- Increase in number of fish species;
- Improve fish spawning through sediment changes.

Negative impacts:

- The release of sediments trapped behind a dam's walls can choke waterways, muddying the environment, reducing the diversity of river channel habitat and wiping out insects and algae, which are important food for fish.
- Sometimes the mud that had been held back by the structures is contaminated. For example, when engineers removed the Fort Edward Dam on the Hudson River in 1973, concentrations of PCBs rose in downstream fish and remained high for many years; even today the striped bass fishery remains closed because of high levels of PCBs.
- Supersaturation - dam removal will produce a short term increase in flow velocity and pressure which increases chances of gas-bubble disease in fish.
- In some cases, dams have blocked invasive species from moving upriver and into zones above the dam. The dam at Fossil Creek, for example, halted the advance of exotic fish such as bass and sun-fish, creating a sanctuary above the structure for imperilled south-western fish, including headwater chub and speckled dace.

Examples of the consequences of dam removal on waterways are provided below from the United States of America.

1. Florida's Dead Lake Dam on the Chipola River regulated the river to maintain comparatively constant flows compared with its pre-impoundment flow regime. Once the dam was removed, fluctuations in the flow of the river increased, and the diversity of species nearly doubled from 34 to 61 aquatic species. It was likely that the successful recovery of aquatic species diversity on the Chipola River was closely related to habitat restoration created by restoring natural flows to the river. Following dam removal and during natural low-flow periods; vegetation growth (i.e. alligator weed) recovered in the river. This increase in vegetation improved the spawning habitat for largemouth bass and other native fish in the area, and may have been a factor in boosting fish populations (Hill *et al*. 1993).
2. The removal of the Edwards Dam on the Kennebec River in Maine provided coastal fish populations access to previously impounded upstream habitats, including head of tide habitat. Monitoring showed that regional populations of striped bass, Atlantic and short nosed sturgeon, smelt, American shad, and blueback herring increased, in some cases significantly, due to the re-establishment of the natural interaction between the river and the sea (Dadswell 1996).
3. When the Fulton Dam on the Yahara River in Wisconsin was removed, the diversity of certain organisms that prefer lake-like conditions declined. Wet meadow grasses replaced species of cattail and sedge. Consequently duck and muskrat populations that relied on cattail and sedge for habitat were negatively impacted by the removal of the Fulton Dam. The Fulton Dam removal, however, did not have a negative impact on many other native species in the region, such as turtles, amphibians, mink, raccoon, and skunk, all of which survived well in the area following dam removal (American Society of Civil Engineering 1997).
4. The Little Goose Dam on the Snake River was drawn down in 1992, As a result Supersaturation of dissolved gas occurred in the water, turbidity levels increased, and many reservoir fish and insects perished. Fortunately, fish losses associated with this draw down were short-term with minimal impacts on overall populations. Slowly drawing down a reservoir, prior to dam removal, can significantly lessen the impact of Supersaturation on downstream species (Wik 1995).
5. Following the removal of the Woolen Mills Dam on the Milwaukee River in Wisconsin, the percent of rocky substrate compared to silt and mud found in the former impoundment significantly increased. In addition, once the dam was removed, native fish such as smallmouth bass increased in number, a positive trend that can be attributed to the reintroduction of coarser sediments to the river habitat (Kanehl *et al*. 1997).
6. Researchers believe that dam removal benefits non-migrating fish and other organisms as well. One study on the removal of the Woolen Mills Dam

determined that darter populations likely increased due to improved habitat quality and access to new river reaches created by dam removal. In addition, smallmouth bass gained access to optimum spawning conditions following the removal of the Woolen Mills Dam (Staggs *et al*. 1995).

7. The construction of the Gezhou Dam in the upper-Central Yangtze River in 1981 led to a sharp decline in the populations of three endangered and endemic ancient fish species, Chinese sturgeon (*A. sinensis*), Yangtze sturgeon (A. *dabryanus*), and Chinese paddlefish (*Psephurus gladius*), which are being prevented from reaching their traditional spawning areas in the Jinsha River (in the upper reaches of the Yangtze River) by the dam. The ongoing Three Gorges Dam Project, the largest hydroelectric dam in the world (38 km upstream from Gezhou Dam), will have catastrophic consequence for fish, most especially to the migrant species in the middle and lower reaches of Yangtze River, by damaging the new spawning sites already formed below and above the Gezhou Dam and completely blocking the upstream migration routes of fish. These large dams impact not only fish, but many other aquatic and terrestrial species as well (Ping Xie *et al*. 2006).

5.4 Fish

Migratory fish use rivers and streams to move between spawning and nursery habitats, and habitats where they grow and reach maturity. Different fish species have different migration strategies. “Anadromous” species such as Salmonids spawn in freshwater and migrate down-stream to the sea to mature; “catadromous” species, such as Eels (*Anguilla* spp.) spawn in salt water and migrate up-stream to freshwater habitats to mature; and, “potamodromous” species do not migrate between fresh- and salt-water, but are known to migrate large distances within a single river system (*e.g.* most Sturgeon species, *Acipenser* spp.).

Whatever their migration strategy, hydropower projects have a direct impact on migratory fish populations through disruptions to their migratory corridors (rivers) (Hogan, 2011; Zhong and Power, 1996a; 1996b, Agostinho *et al.* 2011, Coutant and Whitney 2000, Fette *et al.* 2007, Fjeldstat *et al.* 2012, Godinho and Kynard 2009, Hall *et al.* 2011, Ligon *et al.* 1995, Gough *et al*. 2012). In fact, migratory fish are the taxon most affected by hydropower technology. The primary impact is the interruption and obstruction of up-stream and down-stream migration patterns following construction of the barrier or dam. For anadromous species, adult fish migrating up-stream may be physically prevented from reaching spawning grounds, or the timing of spawning may be significantly disrupted resulting in lower breeding success; and juvenile fish migrating down-stream can have high levels of mortality due to direct contact with and mortality caused by operating power turbines. For catadromous species, migrating juveniles may not be able to surmount large physical barriers or have the energy to use alternative structures such as fish ladders.

Secondary impacts of hydropower projects on migratory fish include changes to the physical and chemical conditions of the water once a reservoir has been formed. These include, but are not limited to: changes in water depths and temperature; altered flows and sediment regimes; disruptions to seasonal flows and discharges; changes to littoral habitat and substrate types; re-distribution of waste products; and increased concentrations of pollutants in the system.

Biotic responses to these changes lead to tertiary impacts such as changes in species abundance and community structure; declines in the proportion of economically valued fish species; declines in productivity and changes in food webs; and, increased likelihood of diseases. Regulated discharges during energy production also lead to changes in the physical and chemical conditions of the water down-stream that can affect species abundance and community structure; changes to food-webs, etc.

Physical changes to the form of the waterway and its bed can arise as a consequence of altered flow regimes related to discharges, leading to changes or degradation and loss of aquatic habitat diversity and productivity.

5.4.1 Mortality

Introduction

A major cause of fish mortality at hydropower facilities is downstream fish passage through hydropower turbines (Brown *et al.* 2012, Coutant & Whitney 2000, Gibson & Myers 2002). Direct mortality of migratory fish within hydropower projects is mostly related to periods when fish, and juveniles in particular, “descend through the turbines”. Baxter (1977) documented the pulverization of American Eel, *Anguilla rostrata* in hydroelectric turbines. Few hydropower projects consider the need for downstream passage facilities for seaward migrating fish. Mortality (and significant injury) are caused by direct interactions between fish and turbines, and excessive changes in water pressure and hydraulic shearing during the descent. Considerable efforts have been made in recent decades to design more “fish-friendly” turbines that lead to significantly lower rates of fish mortality during the descent period (Leipzig, 2011).

Levels of mortality in conventional, storage hydropower projects are likely to be far higher than in run-of-the-river projects and, especially those projects that incorporate new technologies such as hydrokinetic turbines (EPRI, 2012).

Contributing factors and causes

Turbine-related mortality is different among species and turbine types, but figures from Canada suggest mortality rates of between 18% and 46% for juveniles of a range of species are the norm (Zhong & Power, 1996b). Incremental rates of mortality through a series of hydropower dams on a single river could have significant and dramatic impacts on mortality of juvenile fish during the migration descent.

Fish communities below a dam can also be directly, physically impacted, and killed (depending on the operational schedule of the dam), particularly during periods when control gates are opened and closed. This is attributed to factors such as excessive water pressure and hyper-saturation of the water with air as it is forced through the turbines. This causes “gas-bubble disease” (similar to the “bends” in divers). When a fish ingests such water, the gas may come out of solution as bubbles and lodge somewhere in the fish’s body, causing serious injury or death (Baxter 1977).

A turbine passage simulation study was done on juvenile Chinook salmon *Oncorhynchus tshawytscha* to mimic the hydraulic pressures of large turbines. Fish were exposed to various acclimation pressures and subsequent exposure pressures. The main factor associated with mortality was the ratio between acclimation pressure and exposure pressure, *i.e.* the likelihood of mortality increased with greater pressure ratios (Brown *et al.* 2012). Additionally, draft tubes leading to tailraces downstream from the turbine have increased spiral flow and pressure changes that can disorient and injure fish that are leaving the turbine. This may lead to mortality or increase vulnerability to predation by aquatic and avian predators (Coutant & Whitney 2000). Also, a fish’s lateral line system, a sensory system that provide spatial awareness and the ability to navigate in space, may not be effective in rapid passage through hydropower turbines causing major disorientation (Coutant & Whitney 2000).

These aspects are related on the one hand to ecological characteristics (*e.g.* fish species and their preferred habitats), and on the other hand, to technical specifications of the project (*e.g.* location, configuration, operating procedures and turbine types).

Ecological differences
Anadromous species such as Salmonids are likely to sustain higher mortality rates during down-stream migration of the more delicate juveniles through hydropower turbines, than catadromous species where adults migrate down-stream. Larkin (1984) showed that although Coho salmon (*Oncorhynclzus kisutclz*) may spawn successfully above a dam, high mortalities of seaward-migrating smolts can occur when they descend through the turbines. Conversely, juvenile catadromous species may have higher mortality rates when migrating upstream due to inability to negotiate fish ladders and lifts, or when no by-pass mechanism is used at all.

There may also be some ecological differences between fast and slow moving fish species.

Location
Hydropower dams may be located on the main stream or tributaries of rivers. Dams in main stream localities are likely to have a higher impact on migratory fish populations than those associated with tributaries. Construction of main stream dams on large rivers with high levels of migratory species such as the Mekong River (with approximately 800 fish species (Source: FishBase) home to the second highest fish

biodiversity in the world after the Amazon River) will have a much greater impact than dams built on smaller rivers and tributaries with lower fish diversity and fewer migratory populations.

Configuration of the hydropower project

Conventional hydropower storage projects will have a more significant impact on migratory fish mortality than small-scale hydropower and run-of-the-river projects.

A series of hydropower projects along a single river will have a greater cumulative impact on fish mortality in that catchment than single projects.

Turbine type

The design and operation of conventional turbines results in high flow velocities, abrupt changes in flow direction, relatively high runner rotational and blade speeds, rapid and significant changes in pressure, and the need for various structures throughout the turbine passageway that can be impacted by fish (*e.g.,* walls, stay vanes, wicket gates, flow straighteners) (EPRI, 2012).

Turbine-related mortality is different between fish species (and sizes) and turbine types (Zhong & Power, 1996b).

Studies in Canada indicate that average juvenile mortalities for trout, alewife and yellow perch spp. were estimated at 18-25%, 14% and 13.6% respectively, when they passed through a “tube-type” turbine (Ruggles, 1990). Down-stream passage through a “Straflo turbine” resulted in a 46.3% mortality rate amongst juvenile clupeids (Stokesbury & Dadswell, 1991). Major injuries were suffered by fish caused by changes in water pressure (64.5%) and mechanical contact with turbines (33.9%). Hydraulic shearing accounted for only 1.7% of fish injuries. Hogans & Melvin (1985) estimated mortality rates of 21.5 to 46.3% for American shad passing through a Straflo turbine [References sourced in Zhong & Power (1996b)].

More recent studies have shown that turbine passage survival rates for conventional hydropower projects range from about 70 to 97% (Franke *et al.* 1997), with the lower survival rates being representative of larger fish and/or “Francis” turbines (*i.e.*, large number of blades and high rotational speeds) and the higher survival rates being representative of smaller fish and/or “Kaplan” turbines (fewer blades and lower rotational speeds). Hydrokinetic turbines, in run-of-the-river series, have been shown to reduce fish mortality to less than 2% (EPRI, 2012).

Operating conditions

Fish mortality will vary according to seasonality of operation and water discharge volumes. Avoidance of turbine operation during peak downstream migration periods for significant species can reduce losses. Lowering discharge volumes may be more problematic, as the primary function of the dam is to produce power and this is closely linked to the amount of water flowing across the turbines.

Species involved and magnitude of problem

Levels of mortality due to turbine strike, and water shear and pressure changes when passing through hydropower turbines has been shown to impact juvenile fish far more than adult fish. In addition, species of anadromous fish (and especially Salmonids) are more likely to be impacted as during their juvenile life-stages they migrate downstream and therefore through operating turbines (Zhong & Power, 1996b give some insights into this and species involved for Canada).

Supra-national aspects

The world's largest rivers, in areas of high biological diversity such as tropical zones that are known to support high levels of fish species biodiversity and regional endemism, such as the Mekong, Zambezi, Congo and Amazon are especially vulnerable for hydropower developments. This also goes for the Russian river systems.

5.4.2 Habitat loss

Introduction

The construction and operation of hydropower facilities fragment river systems, act as barriers to migratory fish movements, and change the flow of water, sediment, nutrients, energy, and organisms (Agostinho *et al.* 2011, Coutant & Whitney 2000, Fette *et al.* 2007, Fjeldstat *et al.* 2012, Godinho & Kynard 2009, Hall *et al.* 2011, Ligon *et al.* 1995). Reservoirs are created behind conventional hydropower dams, leading to increases in water surface area and depths, and a shift from moving (lotic) to static (lentic) conditions. This has direct impacts on fish species composition and abundances. Run-of-the-river hydropower projects will affect far less habitat.

The direct loss of all shallow, fast-flowing riverine habitats within the hydropower reservoir can be a major contributing factor to local species extirpation. Fast-flowing riverine habitats are essential spawning and breeding habitats for many species of fish and the resultant deep, slow-flowing reservoirs inhibit successful spawning.

Contributing factors and causes

Ecological differences

Essential ecological differences are found between fish species that breed and spawn in fast-flowing, highly oxygenated water and those that can breed in slow-flowing, oxygen poor conditions. Increased water depths are likely to decrease spawning in some species and increase it in others. Reservoir draw-down, and increased exposure of littoral zones will also adversely impact spawning in some species.

Increased shoreline erosion in reservoirs has also been recorded, leading to increased turbidity and sedimentation of the water body, with associated impacts on spawning success and embryonic development. High turbidity can also shift primary productivity from nutrient-limited to light-limited due to low light penetration in turbid water.

Water surface temperatures in reservoir waters generally increase as the water surface area exposed to sunlight increases and water movements decrease, although this may not always be the case. Water quality can deteriorate in situations where organic material settles in reservoirs and decomposes anaerobically, reducing the biological assimilative capacity of the river (especially in reservoirs with long retention times). In some situations this can lead to mass fish kills due to rapid oxygen depletion.

Bio-accumulation of mercury in fish can also be observed in many reservoirs. Bio-accumulation of mercury is caused by bacterial methylation stimulated by decomposition of flooded organic matter and soils. Methyl mercury is directly absorbed through gill membranes in fish and accumulates in body tissues.

Location
Location of hydropower dam sites will determine the size and extent of upstream impoundment reservoirs. Larger dam structures will generally result in larger reservoir areas. Dam structures on the mainstream of major rivers will have a greater impact on habitat loss (and gain) than those on (smaller) tributary rivers.

Conventional hydropower projects with large storage reservoirs upstream will result in large scale, direct habitat losses. Run-of-the-river hydropower projects are likely to have a far less significant impact on habitats upstream (and downstream) of the project, as no large-scale water storage impoundment is created, and the river is allowed to run more-or-less freely.

Operating conditions
Not likely to have any major impact on habitat loss. Drawdown of reservoirs will create a wider, exposed littoral zone along the reservoir edge, and this may, in the short-term, reduce spawning habitats further for some species.

Species involved and magnitude of problem
Populations of all fish species that require fast flowing oxygenated freshwater for breeding and spawning will be impacted. As a result, fish in need of these habitat types, are most effected as the obligatory travel long distances upstream with a fair chance to encounter more than one power station. Estuarine spawning species in this respect are less affected.

The Belorybitsa (*Stenodus leucichthys*) is a relatively well-known example of a species that became extinct in the wild after the construction of hydropower dams (Freyhof & Kottelat, 2008). All of its spawning grounds have been lost because of dam construction. Prior to the construction of dams this Caspian species migrated *e.g.* 3000 km to reach its spawning grounds in the upper Volga, Because of its long distance travels this species is especially vulnerable. Nowadays, the survival of this species depends on stocking programs. Also in the US the consequences of dam building on the Muddy Missouri resulted the pallid sturgeon, a Missouri River native, to be listed as an endangered species (http://www.fws.gov/garrisondam/faqs.htm#e).

In many developing countries (*e.g.* Cambodia), migratory and resident freshwater fish potentially affected by hydropower projects make up a significant proportion of the protein in the diets of local people.

Supra-national aspects

The impacts of new hydropower projects in areas of high fish diversity, and along rivers where migratory fish dominate the fish community are likely to be extreme. ICEM (2010) report that construction of an additional 12 mainstream hydropower dams along the mainstream lower Mekong will result in biodiversity losses that would be most significant for fish species, which could see losses of up to half the recorded species in some zones. New development of hydropower projects in areas such as the Mekong, where historically projects have been few, are likely to have much greater impacts on fish diversity than existing hydropower projects in more developed nations, where hydropower projects have already reached saturation point on many rivers.

5.4.3 Barrier effects

Introduction

The physical construction of dams across migration pathways (rivers) for fish is a major obstruction to their migratory movements. Historically, impacts have been mitigated through the provision of fish ladders, fish lifts and other means to assist fish across the barrier. Recent research has found that many of these devices are simply not effective (Glenn, 2013) and over the last two decades have contributed very insignificantly to the restoration of fish populations along rivers with numerous hydropower projects. Hydropower projects where no fish by-pass structures exist provide an insurmountable barrier to fish migration.

In recent years, many hydropower dams that are no longer economically valuable have been decommissioned and removed in an effort to restore river habitat connectivity for migratory fish movements. One of the largest such projects was the removal of two dams in the Elwah river, Washington, United States. Removal of the downstream barrier, the Elwah Dam, was completed in 2012, and within months there was evidence of the return of diadromous salmon to native spawning grounds upriver (Nijhuis 2014).

In contrast, run-of-the-river hydropower projects, where little or no water storage reservoir is created, essentially provide no physical barrier to fish movement. In-stream hydropower projects (and especially small-, micro- and pico-scale projects) also provide few barriers to most migratory fish species.

Contributing factors and causes

Ecological differences

Migratory fish species have evolved to surmount natural obstacles such as rapids and low waterfalls within the rivers along their migration routes, but find it impossible to pass man-made obstacles such as large-scale hydropower dams. Even small-scale hydro-dams may be insurmountable, depending on height of the barrier, fish species and water regime operated by the project. Atlantic salmon spp., for instance has an ability to leap about 3.3 metres only (SNH, updated). Strong-swimming taxa such as Salmonids may pass through obstacles that slower-swimming species such as Cyprinids find impossible to pass.

Fish ways, fish ladders, and fish lifts are used to assist fish by-pass dams, but their effectiveness has proved to be highly variable, across a range of situations and between individual fish species in the same system. The swimming abilities and preferred flow velocities of different fish species are quite variable, ensuring that a one-type solution rarely suits all. Even when fish ladders or other such devices are used, they often lead to interruptions in the timing of migrations and ultimately, to fish spawning patterns. An ineffective fish ladder may also expose fish to greater levels of predation or cause severe overfishing due to disruption of the spawning migration. As noted above, Glenn (2013) and Neraas & Spruell (2001) found that fish-ladders played an insignificant role in allowing fish to by-pass hydropower projects.

Configuration and type of the hydropower project

Series of hydropower projects along a single river will have a greater cumulative impact on obstructing movements than those that are placed singularly.

Large-scale, conventional hydropower projects will provide a far greater obstacle to migratory fish than small-scale projects and run-of-the-river projects. Development of new designs for fish by-passes to suit a wider variety of species, and to suit specific fish communities in specific rivers is necessary.

Run-of-the-river hydropower projects and in-stream projects are believed to have virtually no impact on fish movements upstream during migration.

Species involved and magnitude of problem

Marmulla (2001) provides a comprehensive overview of the effectiveness of different types and designs of fish ladders, passes and lifts globally in relation to the many migratory fish species.

Supra-national aspects

Larinier (2001 in Marmulla, 2001) states that “almost nothing is known about migratory fish species”, particularly in developing countries. He further states that this must not be a pretext “to do nothing” at a dam and in the absence of good knowledge on the species, the fish passes must be designed to be as versatile as possible and open to modifications. FAO’s view on this is pertinent with relation to the myriad of proposed hydropower projects in regions where less is known about migratory fish species than in the developed countries.

5.4.4 Habitat degradation

Introduction

Habitat degradation and alteration is a major impact during the construction and operation phases of conventional hydropower projects, and can have profound impacts on populations of migratory fish species. There may also be smaller-scale and short-term issues related to habitat degradation and alteration during decommissioning phases of all types of hydropower projects.

Construction of dams leads directly to loss of habitats as discussed above, and consequent degradation of habitats both upstream and downstream of the project. One of the most significant habitat changes will be in the hydrology of downstream areas. This is manifested in fish populations and migrations through: changes to the seasonality of river flows; reduced sedimentation and flow rates; loss of fish spawning sites; changes in river water temperatures; and changes in downstream riverine habitats, due to changes in water flows and depths, and to river bed morphology. The changes in flow regimes may also impact coastal regions due to alterations in nutrient discharge into the marine environment (ICEM, 2010; McCall, 2008).

While in most cases the decommissioning and removal of hydropower dams is expected to have positive effects on migratory species through restoration of river channels and migratory corridors for diadromous fishes, habitat degradation may also occur through several mechanisms. Release of impounded sediments during dam removal may increase downstream sedimentation and reduce water clarity for days to months. Sediments that have been impounded by dams may also contain high contaminant loads, including PCBs, PAHs, and metals, which become mobilized and spread through the downstream environment upon release. In addition, dam removal may remove a barrier to the range expansion of invasive species and hatchery-reared individuals, exposing native diadromous species to additional competition and genetic contamination (Stanley and Doyle 2003, Nijhuis 2014).

Contributing factors and causes

Ecological differences

The ecological differences between an unregulated, natural river system, and that of a regulated system due to a conventional hydropower project are significant. The loss of fluvial connectivity in river systems due to the construction and operation of hydropower facilities impact species that rely on spawning migrations and restrict movement of these species to important migratory, spawning, and nursery habitat (Agostinho *et al.* 2011, Coutant & Whitney 2000, Fette *et al.* 2007, Fjeldstat *et al.* 2012, Godinho & Kynard 2009, Hall *et al.* 2011, Ligon *et al.* 1995). For instance, temperature changes downstream of a reservoir can influence distribution and movement of fish, particularly in species where temperature changes are a stimulator of migration – this can have profound impacts on the timing and success of spawning.

Natural flow rates and seasonality of flows are also impacted by storage projects. Changes in water volumes, flows and water depths due to fluctuating discharge volumes from hydro-electric projects will have significant effects on downstream fish habitats.

Research in China has shown that the distribution, growth, reproduction, abundance and species composition of fish in rivers is greatly influenced by changes in water level, discharges, and velocity following hydro-electric power developments (Zhong & Power, 1996a). There is some evidence that the environmental impacts of impoundment and flow regulation can extend several hundreds of kilometres downstream from a dam. For instance, in the Mekong River system, mainstream dams are predicted to reduce organic matter transport downstream, severing one of the important longitudinal bio-chemical connections between the headwaters and floodplains of the Mekong system (ICEM, 2010).

Location

Location of hydropower dam sites will determine the size and extent of degradation and alteration of downstream habitats. Larger dam structures will generally result in more significant impacts downstream. Dam structures on the mainstream of major rivers will have a greater impact on the scale of habitat degradation and alteration than those on (smaller) tributary rivers.

Configuration and type of the hydropower project

Conventional hydropower storage projects will have a more significant impact on downstream habitat degradation and alteration than small-scale hydropower and run-of-the-river projects.

The cumulative effects of a series of hydropower projects along a mainstream river are likely to be higher than those of a single project, or those located along tributaries. Hall & Kshatriya (2009) model cumulative impacts for the Mekong River.

Species involved and magnitude of problem

Habitat degradation and alteration will have impacts on virtually all migratory fish species. Many fish species survive in specialised and limited niches within the riverine environment, and when these niches change, the most specialised species often cannot adapt to the rapid changes. Impacts may be slow and cumulative, with restricted range (endemic) and specialised species gradually being replaced by more generalist, wide ranging species.

Supra-national aspects

Habitat degradation and alteration in regions characterised by high levels of fish endemism and fish diversity are likely to be more significant than areas where these levels are lower. The damming of large tropical river systems for hydropower will impact a wider range of habitats and ecosystems than in temperate zones.

5.5 Birds

The effects of hydropower projects on migratory birds can mainly be categorized into two areas of direct habitat loss (and habitat gain), and, habitat degradation and alteration, particularly in downstream habitats. Direct mortality, barrier effects and disturbance are not considered to be significant.
Nilsson and Dynesius (1994) concluded that the two most negative effects of river regulation on birds were the permanent inundation of vast areas of land, and the disruption of the seasonal flood regime along the river.

Most impact takes place over the longer term during the operational phase of the project, but immediate and direct habitat loss caused by clearing of habitats prior to inundation of water storage reservoirs during the construction phase are also considered, although this may impact resident bird species more significantly than migratory species. However, this might not be the case where tropical forest are cleared, as these habitats are important wintering sites for many northern migrant passerine birds.

There are few examples of the direct impacts of hydropower projects on migratory birds, such as the flooding of breeding areas of Pink-footed Geese (*Anser brachyrhynchus*) in Iceland (https://wcd.coe.int/com.instranet.InstraServlet?command-=com.instranet.CmdBlobGet&InstranetImage=1326337&SecMode=1&DocId=1437248&Usage=2). However, many reports highlight the loss or change in suitability of downstream floodplain wetlands and the impacts this has on migratory waterbird populations (Nilsson & Dynesius, 1994; Bosshard, 1999; Kingsford, 2000, Green *et al.* 2011). Other habitats, such as forests, may also be lost water is taken away from underwater aquifers (Bosshard, 1999). In other cases, reservoirs, created as a result of impoundment upstream by hydropower dams, have created new habitats for migrating and over-wintering waterbirds. For example, Pong Dam in India now holds 40,000 Bar-headed Goose, over 50% of the population of the species (Asian Waterbird Census 2014, unpublished). Species such as mergansers and goosanders and the South American torrent duck (*Merganetta armata*) require free, fast-flowing river habitats during some stage of their life cycles and are directly impacted by loss and degradation of these habitats both upstream and down-stream of hydropower projects.

Since the middle of the 20th century, several hundreds of dams have been constructed upstream of the West African inner deltas and floodplains of the Niger and Senegal river. Significant impacts from hydropower dams have identified and well documented by Zwarts *et al.* (2009). Hydropower dams cause here higher water evaporation as well as a change in seasonal variation of the river discharge, with

consequent lower water levels. For instance the *Sélingué* dam in the Niger river (Mali) reduced the floodplain area by 600 km^2 in September-December. New planned dams (Djenne and Fomi) would increase the loss of floodplains in the inner Niger Delta to about 15-20% or 2500-3000 km2 (Zwarts *et al*. 2009). The impacts of dams in the Senegal river are even more significant although part of the floodplain was restored in 1971. The inner Niger river and Senegal floodplains are important for millions of migrant waterbirds from Europe, Asia and Africa. They are situated in semi-arid Sahel savannah in central Mali. The area is a floodplain comprising permanent lakes and vast seasonally-flooded plains. Within the Inner Niger Delta Ramsar site (Wetlands of International Importance) a number of Important Bird Areas (IBAs) have been identified. Collectively, they support huge numbers of waterbirds —both resident species and migrants from across Eurasia, who time their arrival with the onset of the wet-season. The number of waterbirds that the delta can support is directly related to the extent of flooding during this period. In good years, peak counts can include 900,000 Garganey *Anas querquedula*, 300,000 Northern Pintail *Anas acuta*, 315,000 Cattle Egret *Bubulcus ibis*, 50,000 Purple Heron *Ardea purpurea*, 183,000 Squacco Heron *Ardeola ralloides*, 25,000 Glossy Ibis *Plegadis falcinellus*, 9,000 Gull-billed Tern *Gelochelidon nilotica* and 3,500 Caspian Tern *Hydroprogne caspia* (Zwarts *et al*. 2009).
The reduction in floodplain size will result in irreversible losses in these bird populations (Zwarts *et al*. 2009, BirdLife International 2014).

Before it was dammed, the Waitaki River in New Zealand was highly unstable, flooded frequently, and had a constantly changing channel. After damming the river flood runoff is now stored in the reservoir to produce electricity. This increased the stability of the sandbars downstream, allowing colonisation by vegetation, which further stabilised the channel. The increased flow stability has benefited New Zealand Chinook Salmon (*Oncorhynchus tshawytscha*) populations, The beneficial change for salmon has been detrimental to the Black Stilt (*Himantopus novaezealandiae*), a native species. This bird is so endangered that fewer than 100 individuals remain. They nest exclusively on the large exposed sandbars isolated from the shore, a habitat that was maintained by the unstable nature of the river. The vegetation that has proliferated and stabilised the gravel bars has increased the cover for predators, and predation of adult stilts, eggs, and nestlings has increased.

At a smaller scale downstream impacts on dams on birds can be the loss of nesting or feeding sites by either floods within basins or lower water levels causing habitat change or increased predator pressure (e.g. http://www.forestandbird.org.nz/saving-our-environment/threats-and-impacts-/hydro-electric-schemes or http://www.un.org/esa/sustdev/sdissues/energy/op/hydro_basson_paper.pdf).

5.5.1 Mortality

Hydro electric project related bird mortality has not been reported nor is it likely to occur on a regular basis. It is unlikely that hydropower projects will have anything but incidental occurrences of bird mortality. Factors such as attraction of night-flying migratory birds to powerful lights at remote construction sites are not considered to be any different from other construction projects.

5.5.2 Habitat loss and degradation

Introduction

Documentation of habitat losses for migratory birds directly resulting from hydropower projects is scarce. Much of the literature cites loss of downstream floodplain wetland habitats, due to changes in hydrology, such as reduced flooding frequency, resulting from dam operation, and recorded decreases in waterbirds populations may be linked to this.

A more direct impact is the loss of fast-flowing riverine habitats important for some species of waterbird and the creation of large, deep water reservoirs for water storage that may benefit other species.

Contributing factors and causes

Ecological differences

Specialist groups of waterbirds, some of which are migratory, have adapted to riverine habitats dominated by steep, fast water flows (torrents), rocky substrates, and dense riverine vegetation. These include shorebird (Charadriiformes) and duck (Anatidae) species in the sub-family Merginae, such as the scaly-sided merganser (*Mergus squamatus*) in NE Asia, goosander, (*Mergus merganser*) and red-breasted merganser (*Mergus serrator*) of northern temperate climates; and, Brazilian merganser (*Mergus octosetaceus*) of South America. As well as other species such as the Torrent Duck (*Merganetta armata*) of the Andes and the New Zealand blue duck (*Hymenolaimus malacorhynchos*). Direct loss of these habitats leads to direct loss of these species. In most cases, they require dense riverine woodlands with tree cavities for nesting, adjacent to clean, fast-flowing streams and rivers for hunting fish.

Pernollet *et al.* (2013) found that in Central Chile, torrent ducks tended to avoid the river sections downstream of the hydropower intakes and this was determined to be a result of modifications to the river channel by the hydropower project. In Central China, Barter *et al.* (in litt.) found the endangered scaly-sided merganser restricted in its winter habitat to fast-flowing clear water rivers of 50-350 m width, with riffles, islands or sand banks in hilly/mountainous areas with low levels of human disturbance.

The presence of large hydropower dams and the subsequent regulation of flows that change seasonality and volumes of water released downstream has direct impacts on bird prey species, and the habitats in which these prey species live. Many of the birds associated with these habitats are piscivorous and may experience disruption to food availability due to altered fish communities. Populations of other prey organisms, such as freshwater crustaceans, insect larvae and amphibians, will also be impacted. Cross and colleagues (2013) studied riverine food web dynamics in the Colorado River (Arizona, USA) and showed that communities nearest the dam exhibited weaker food web interactions and lower stability when exposed to experimental flood disturbance when compared to communities further from the habitat alteration. The regulation of river flow through hydropower dams may also make systems more vulnerable to invasive species, further disrupting all trophic levels of the food web (Cross *et al*. 2013).

Studies showed that the number of flying insects is lower along regulated rivers than along free-flowing rivers. The abundance of insect-feeding animals were compared along similar river stretches at four regulated and four free-flowing large rivers in northern Sweden and the Finnish Kemi River. The research showed that birds are adversely affected by river regulation. The results showed that adult Pied Flycatchers breeding along regulated rivers lost more weight after their eggs were hatched and fewer of the chicks survived, because their food resource -- the insects -- was less abundant. Along one of the regulated rivers, the survival of the chicks was even lower than what is required for the species to persist. There were also signs of whole bird communities being impacted by river regulation (Strasevicius, *et al*. 2013; Jonsson *et al*. 2012).

In Australia, The flow regime is regarded by many aquatic ecologists to be the key driver of river and floodplain wetland ecosystems, one that has been highly modified as a consequence of reservoirs, including hydro electric dams, along many Australian rivers. The consequent impacts of altered flow regimes could be summarised in the following four principles:

- Firstly, flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition;
- Secondly, aquatic species have evolved life history strategies primarily in direct response to their natural flow regimes;
- Thirdly, maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species;
- Finally, the invasion and success of exotic and introduced species in rivers is facilitated by the alteration of flow regimes.

The impacts of flow change are manifest across broad taxonomic groups including riverine plants, invertebrates, birds and fish.

Riverine fringes and available nesting sites may also be degraded due to higher (or lower) water levels, bank erosion and loss of fringing habitats. Lastly, fast-flowing shallow channels become static, deep water reservoirs unsuitable for specialist bird species.

The operation of hydropower facilities can lead to fluctuations in water levels of reservoirs that can influence the amount of riparian habitat available for migratory birds and may impact the use and quality of remaining habitat (Green *et al.* 2011). A study at Arrows Lake Reservoir, a reservoir influenced by hydropower dams in the

Columbia River system in the USA and Canada, found that reduction of riparian habitat from increased water levels did not influence mass gain or the number of warblers found in the area as expected. However, due to lack of studies, they could not conclude that hydropower facilities have no impact on migratory songbirds (Green *et al.* 2011). Other factors, such as behaviour and stress, may play an important role in stopover habitat use near hydropower facilities and should be considered as variables in future studies.

Location

Locating hydropower plants in habitats used by specialists, and often rare and threatened bird species, will lead to habitat loss and subsequent species declines. Replacing shallow, fast-flowing riverine habitats with deep, static water reservoirs may create some new habitats for waterbirds, but these are generally less significant for species conservation and as migration and wintering habitats. The comparatively unstable water level of hydro-electric and irrigation storage reservoirs results in low biological diversity and productivity on the shorelines of these water bodies (*e.g.* Liu *et al.* 2013). This factor results in habitats not being as productive for migratory waterbirds as equivalent natural habitats that follow natural seasonal water level fluctuations to which local plant and animal life is adapted.

Location of hydropower dam sites will determine the size and extent of degradation and alteration of downstream habitats. Larger dam structures will generally result in more significant impacts downstream. Dam structures on the mainstream of major rivers will have a greater impact on the scale of habitat degradation and alteration than those on (smaller) tributary rivers.

Configuration and type of the hydropower project

Many of the rivers surveyed by Barter *et al.* (in litt.) in Central China had cascading series of hydropower dams along their lengths (*e.g.* Wenchuan river has four dams over a 23 km stretch). They noted that one of the main impacts of these dams was to reduce the length of river that was free-flowing and to reduce habitats available for mergansers. Indeed they observed no mergansers on any of the reservoirs, only in the downstream stretches.

Hydropower projects in series along a single river will lead to a greater cumulative loss of riparian habitats than those that are placed singly. Series that are placed very close to each other may destroy most intervening riverine habitats.

The impacts of run-of-the-river hydropower projects and in-stream projects on migratory waterbirds have yet to be fully researched so no conclusions can be reached. Given that these projects do not completely remove riparian habitats, their impacts on the migratory birds that rely on such areas are likely to be less significant.

Species involved and magnitude of problem

Loss of waterbird habitats in floodplain wetlands downstream of large-scale hydropower plants will impact a wide diversity of waterbirds, including migratory species. Examples could be taken from virtually any major river basin in the world.

ICEM (2010) state that in the Mekong River basin, an additional 12 proposed mainstream dams would result in habitat loss for bird species that rely on exposed sand bars and riverbanks for breeding and nesting. These include species such as river lapwing spp. and small pratincole spp. in the mid-reaches; and various stork spp. (painted and woolly necked), Greater and Lesser Adjutants, and ibises such as the Great Ibis, Black-shouldered Ibis, River Terns, Indian skimmer and the endemic Mekong wagtail in the lower reaches. It is likely that hydropower projects in other tropical and sub-tropical countries would affect ecologically similar species to those existing projects along the Mekong River's course from a dam site to the lower floodplain.

In Australia, riverine and floodplain wetland ecosystems are naturally highly seasonal, relying on winter-spring filling and summer-autumn drying to remain diverse and productive (Kingsford 2000; Frazier & Page 2006). Alterations to flow regimes as a consequence of river regulation for hydro-electric power generation and to meet irrigation demand have altered the seasonal timing, duration and frequency of flow events that fill floodplain wetlands, leading to changes in vegetation characteristics and the capacity of these wetlands to support migratory waterbird species (Lane 1987, Kingsford 2000).

Regional aspects

The impacts of habitat loss in river basins located within the major bird migration flyways of known conservation significance for migratory bird will have the greatest consequences for migratory birds. For example, the Lower Mekong basin contains globally significant wetlands of international importance to rare and threatened migratory waterbirds using the East Asian-Australasian Flyway, such as the Eastern Sarus Crane (*Grus antigone sharpii*). This river is the subject of extensive hydro-electric power project development. In Central China, the impacts of the Yangtze River Three Gorges Dam on downstream wetlands in Dongting Lake and Poyang Lake (the main wintering site for 99% of the global population of the Critically Endangered and migratory Siberian Crane (*Grus leucogeranus*) may already be changing the dynamics of the wetlands and the populations of birds they support. Similarly, this area seems to be important for the globally threatened Lesser White-fronted Goose (*Anser erythropus*), which uses the recessional wetlands in this area (Xin *et al*. 2013)

5.6 Mammals

For the purposes of this review, the major taxa of mammals impacted by hydropower projects are identified as freshwater cetaceans (whales and dolphins; particularly the group known as "river dolphins"), sirenians (manatees and dugongs), and otters (Lutrinae). However, the migratory behaviours of both CMS-listed species of otter (i.e. marine otter, *Lontra felina* and southern river otter, *Lontra provocax*) are poorly known and described (Valqui 2012); neither the IUCN descriptions for these species nor the thorough literature search revealed any information on migratory behaviour or seasonal movements (Alvarez and Medina-Vogel 2008, Sepulveda *et al*. 2008).

Freshwater cetaceans include the South Asian river dolphin (*Platanista gangetica*), with Ganges and Indus river sub-species; Yangtze river dolphin or baiji (*Lipotes vexillifer*), which may already be extinct; and, Amazon river dolphin (*Inia geoffrensis*), with three sub-species. A forth river dolphin, the La Plate river dolphin (*Pontoporia blainvillei*) lives in more estuarine environments than the other species. Several other cetacean species are found in major river systems, these include the Irrawaddy dolphin (*Orcaella brevirostris*), found in the Mekong, Mahakam, and Ayeyarwady Rivers; the Yangtze finless porpoise (*Neophocaena asiaeorientalis asiaeorientalis*) found in the Yangtze River; and, the Tucuxi (*Sotalia fluviatilis*) found in the Amazon River.

Like many large river fish, these mammals range over large areas within river systems and have specific movements between habitats associated with hunting, breeding, birthing, and seasonal conditions which may be significantly impacted by construction of hydropower dams. Wakid *et al*. (2010) clearly state that three rivers in the Brahmaputra River system (Siang, Dibag and Lohit) have seasonally migrating dolphin populations. Manatees (*Trichechus manatus*) in Florida and other states of southeastern United States move from coastal habitats to nearshore, estuarine, and riverine winter refuge areas where water temperatures remain warm (Deutsche *et al*. 2003). In contrast, Amazonian manatees (*Trichechus inunguis*) engage in seasonal migration seemingly to avoid predators (Arraut *et al*. 2009).

Research on the impacts of hydropower projects on movements or migrations of these aquatic mammal species is scarce, because in most cases the species themselves are rare. Smith *et al*. (2000) highlight the impacts of 19 large dams on the Ganges river dolphin in India, Nepal and Bangladesh; eight large dams in Pakistan and their impact on Indus river dolphins; as well as four large dams in China and their impact on Yangtze river dolphin. Conventional hydropower dams across rivers would be expected to have much the same impacts on mammals as they do on fish. However, as most river dolphin, manatee, and otter populations are now critically low, the impacts are likely to be more threatening to species and entire populations. In addition, mammals cannot use fish ladders, fish lifts, or other mitigation structures designed for fishes, so populations will become increasingly fragmented as they become restricted to small stretches of river channel separated by an increasing number of reservoirs behind dams. Dam construction will change the type and seasonal availability of fish prey species, change the geomorphology of mammal habitat and disrupt the natural flow regime of the river (Wakid *et al*. 2010).

According to Xie & Chen (1998; quoted in Ping, *et al*., 2003) riverine mammals including manatees, dugong, and the Chinese river dolphin are even more susceptible than fish to the effects of the dam. Sedimentation, altered food web and physical injuries and noise disturbance from increased navigation are all likely to lead to a population decline in these species (Ping, *et al*., 2003) (Reynolds, 2011).

A summary is provided below of from the *Action Plan for the Conservation of the West African Manatee (UNEP, CMS, WATCH)*. This demonstrates that the migration movements of manatees in this region are potentially disrupted by dam construction and operation.

Recent developments including the construction of dams, barrages and other hydrological works is a specific threat to manatees, especially from structures that completely cross main river channels. There are numerous dams throughout western Africa. These include relatively small dams that control flow to/from lakes or irrigated areas, such as hydrological developments in the wetlands of the Senegal Delta and Lac de Guiers. There are anti-salt dams in coastal wetlands of Guinea-Bissau and other countries where rice is grown behind mangroves. There are also large dams along the main rivers of the region and their tributaries, such as the Kainji Dam in Nigeria, the Diama Dam in the lower Senegal River and the Selingué and Markala dams of the Niger River in Mali. Other planned dams in the Niger Basin include the Fomi in Guinea, and the Talo and Djenné on the Bani River in Mali. Dams and barrages can have both positive and negative impacts on manatees. Some reservoirs or lakes created behind dams can provide excellent habitat for manatees, such as Lake Volta in Ghana, formed by the Akosombo Dam. However, a key threat posed by such developments is genetic isolation of populations, as manatees lose the ability to move between different sections of rivers and their associated wetlands. This can lead to local extinctions as small isolated populations die out. The potential consequences of inbreeding are not well known.

5.6.1 Mortality

Manatees may be killed in the turbines or control gates of dams, with reported cases from Kainji in Nigeria (Powell 1996). There are also reports of manatees caught in control sluice gates of dams, for instance in the Senegal Delta, whilst in Guinea, construction of the dam and ferry port at Fatala impacted manatee occurrence and movements in the Fatala estuary. The building of a dam in the Upper River Region Bank at Sami Wharf Town in The Gambia around 1993 is believed to have caused the death of many manatees (Information from the Action Plan for the Conservation of the West African Manatee).

No references to the impacts of run-of-the-river hydropower projects on aquatic mammal populations have been found. It seems likely that any impact of such projects may not be as significant as conventional hydropower dams provided they occupy only part of a river channel and do not block that channel. There is a possibility that a larger-scale run-of-river project could reach across an entire river channel, blocking the movement of aquatic mammals and this impact must be considered in planning and designing such projects.

5.6.2 Habitat loss and degradation

Introduction

Mammal habitats are lost either directly through inundation of rivers following development of storage dams, or through changes in river flows and hydrology that affect habitat and prey species downstream. Reduced sediment flows downstream change the geomorphology of downstream habitats, eroding and reducing the numbers of sand bars and islands favoured by dolphins (Wakid *et al.* 2010); overall no perceived gains in dolphin habitat result from hydropower projects.

The physical construction of dams across mammal migration pathways (rivers) for river dolphins prevents migratory movement into different parts of their natural range. This potentially disrupts the normal annual cycle of the species, which may affect the capacity of the species to breed and, therefore, the survival of the species. It is also possible that the barrier created by a conventional hydro power project dam leads to the genetic isolation of populations, populations, particularly for river dolphins, with consequences for the fitness of isolated populations. Manatees, which require winter refuge areas with warm water and freshwater vegetative food sources, may be blocked from accessing upstream freshwater springs by construction of dams (Smith 1997, Deutsch *et al*. 2003, Marsh *et al*. 2011).

Mammal habitats downstream of hydropower projects are degraded and altered significantly through changes in river flows, hydrology and sediment transport patterns. Due to the extremely low levels of many river dolphin populations these impacts are determined to be regionally or locally high, with an associated increase in the risk of species extinction.

Lastly, there is evidence of impacts to another group of mammals by hydropower development: the bats. The construction of the Alqueva dam in Portugal in 2001, created Europe’s largest reservoir and submerged and area covering 250 $km^{2.}$ Bat activity was found to have reduced in the flooded area, although increased in the surrounding areas. The key feeding and roosting areas were limited to riparian and forested areas with the bats making limited use of the flooded area (Rebelo & Rainho, 2008).

Nilsson and Dynesius (1994) concluded that the two most negative effects of river regulation on mammals were the permanent inundation of vast areas of land, and the disruption of the seasonal flood regime along the river.

Contributing factors and causes

Ecological differences

Development of hydropower typically results in major alterations of habitat, including creation of deep reservoirs in place of shallow river systems, alteration of sediment transport rates and downstream bank formation, reduced downstream flows, and subsequent ecological changes which may result in loss of habitat or habitat quality for migratory mammals. For instance, river dolphins require extensive stretches of deep river channels, with deep pools, sand bars and islands, they do not utilise deep water reservoirs unless trapped upstream of a dam. Abundant prey fish populations are also necessary. Post dam construction, reduced sediment loads may reduce hunting ability, as all river dolphins are evolved to hunt in sediment laden murky waters. Some species, including the Tucuxi, Irrawaddy dolphin and finless porpoise, require unhindered connection to estuarine and coastal areas and may not persist upstream of a hydropower project dam. A clear example is the populations of the Indus river dolphin that are isolated by barrages.

Location

The level of impact of a particular hydropower project will be closely tied to its location. For example, the location of hydropower project sites will determine the size and extent of upstream impoundment reservoirs. Larger dam structures will generally result in larger reservoir areas. Dam structures on the mainstream of major rivers will have a greater impact on habitat loss (and gain) than those on (smaller) tributary rivers.

In addition, some river systems are more heavily used than others by migratory mammals. Populations and habitat ranges of river dolphins are generally well understood; any hydropower project located in a known river dolphin locality is likely to have a catastrophic impact on obstructing movements and migrations, downstream habitat quality, and thus on populations.

Run-of-the-river hydropower projects should essentially provide no physical barrier to mammal movement, but this has not been tested. It is possible that run-of-river projects could create a barrier and this should be investigated wherever such projects are proposed within the range of these species.

Configuration and type of the hydropower project

Series of hydropower projects along a single river will have a greater cumulative impact on habitat losses (and gains) than those that are placed singly.

Conventional hydropower projects with large storage reservoirs upstream will result in large scale, direct losses of river reaches that may be suitable habitat for and support a population of an aquatic mammal. Run-of-the-river hydropower projects are likely to have a far less significant impact on habitats upstream (and downstream) of the project. No large-scale water storage impoundment is created, and the river is allowed to run more-or-less freely.

Species involved and magnitude of problem

River dolphins have no evolutionary adaptation to by-passing obstacles that impede water flows in their river channel habitats. Populations isolated by hydropower projects therefore have an elevated extinction probability.

Due to the extreme rarity of most river dolphins, hydropower development is likely to lead to a regionally or locally high impact on populations that will increase the risk of species extinctions. Migratory sirenians and otter species are also relatively rare and limited in their distribution; even a single poorly sited hydropower project could threaten a large proportion of their populations.

Regional aspects

In recent years surveys of river dolphin populations have been undertaken in India, China, Laos and Cambodia to assess the conservation threat of large hydropower dams on these populations (Schelle 2013). The results are alarming. In India a comprehensive survey of 2500km of the Ganges River for Ganges river dolphin located a total of 671 individual river dolphins; in China, surveys of the Yangtze have not recorded a Yangtze river dolphin since 2001; and also in China surveys for the Yangtze river porpoise at Dongting and Poyang Lakes showed significant declines due to habitat loss, and along the mainstream Yangtze only 39 individuals were recorded (about 30% of the number recorded six years previously). At the Khone Falls along the Mekong River on the Laos/Cambodia border, only six Irrawaddy dolphins were recorded recently (Schelle 2013).

5.7 Other species

Consideration should also be given to movements of freshwater turtles and terrapins (chelonians) within river systems impacted by hydropower developments.

Large tropical river systems, such as the Amazon and Mekong, have a high diversity of freshwater turtle and terrapin species, many of which utilise large areas of river and flooded forest, and make significant movements up and down rivers. Very few studies have been made on the impacts of hydropower projects on freshwater turtle and terrapin movements in these rivers. Alho (2011) however noted that the formation of deep water reservoirs upstream of hydropower projects in the Amazon River basin caused habitat loss for chelonians. He also noted that reservoir formation effects natural flooding and drying cycles along the riverbanks and that these have an adverse impact on turtle breeding and feeding cycles. In the Mekong River basin ICEM (2010) predicted a significant reduction in the populations of most species of freshwater turtles living in the Mekong, including the Asian giant soft-shell turtle (*Pelochelys cantorii*), due to loss of sand-bars and seasonal breeding habitats downstream of proposed hydropower projects.

A study by Limpus & Limpus (2008) in Queensland, Australia showed that freshwater turtles are impacted significantly by even fairy small-scale dams and hydropower projects. They showed that dams are a direct barrier to turtle movements along the river as most species cannot utilise existing fish-ways and fish-ladders; and, that numerous turtles were killed, maimed or injured at dams during periods of high-velocity water release as they were hurled against hard substrates or drowned on trash filters.

Limpus & Limpus (2008) also recorded significantly lower turtle biodiversity in deep-water habitats associated with impoundments and dams. They attributed this to an anoxic layer with reduced dissolved O2 levels the deep water column that many species of freshwater turtle have not adapted to. The greater energy demands of frequent surfacing for air (especially amongst juveniles) has a profound impact on survival rates.

In regions with high chelonian diversity, and endemic or restricted range species, the impacts of hydropower developments could be of regionally or locally high impact, but are unlikely to have any significant impact on the overall species population except for species with restricted range.

5.8 Mitigation measures

The review document has been prepared in conjunction with a guideline document in which guidelines for siting, planning and mitigation are presented and prioritised. Within this review chapter, basic background information is presented. Although siting and mitigation can overlap they are as much as possible separated. The presented information is as much as possible based on literature unless stated otherwise, e.g. in case of mitigation suggestions.

As hydropower energy has a long history, many different types of mitigation measurements have been taken and studied. Several key references on mitigation measures on environmental impacts and mitigation of hydropower energy are available such as:

Gough, P., P. Philipsen, P.P. Schollema & H. Wanningen, 2012. From sea to source; International guidance for the restoration of fish migration highways.

Hydropower Sustainability Assessment Protocol. http://www.hydrosustainability.org/Protocol.aspx.

International Energy Agency, 2006b. Implementing agreement for hydropower technologies and programmes - Annex VIII, Hydropower good practice:

environmental mitigation measures and benefits. New Energy Foundation, Japan.
International Hydropower Association, 2010. Hydropower Sustainability Assessment Protocol.
Lewis, F.J.A., A.J. Harwood, C. Zyla, K.D. Ganshorn, and T. Hatfield. 2013. Long term Aquatic Monitoring Protocols for New and Upgraded Hydroelectric Projects. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/166. ix + 88p.
World Commission on Dams framework: http://www.internationalrivers.org/resources/dams-and-development-a-new-framework-for-decision-making-3939

Fish

Mitigation

- Installation of artificial fish passageways to reconnect fragmented rivers and restore fish movements. Although artificial fish passageways have been implemented at many hydropower facilities in attempts to reconnect fragmented rivers and restore fish movement potential, many have functional deficiencies and were installed with minimal ecological evaluation (Agostinho *et al.* 2011, Godinho & Kynard 2009, Holbrook *et al.* 2009, Pompeu *et al.* 2012).
- The critical point In upstream fish passage design is the location of the fish pass entrance and the attraction flow, which must take into account river discharge during the migration period and the behaviour of the target species in relation to the flow pattern at the base of the dam. Some sites may require several entrances and fish passes (Marmulla, 2001).
- Impacts on downstream habitats and fish populations can, in part, be mitigated by the management of flow variations from the project site (SNH, undated).
- Increase flow rates at fish passageway entry points to deter fish passage through turbines and to encourage downward migration (Fjelstad *et al.* 2012).
- There are many studies that investigate success rates of fish passageways for upward migration due to the importance of spawning success (Agostinho 2011, Godinho & Kynard 2009, Holbrook *et al.* 2009). A study of Atlantic salmon on the Lower Penobscot River in Maine was conducted to assess upward passage success at three different hydropower facilities over a two-year period. During the first year, only 30% of salmon passed all three dams and during the second year, only 8% passed all three dams. Migrants that failed to pass the second upstream dam fell back into the estuary, presumably reserving energy for additional migration attempts. This data was compared with previous years of data. For all ten years of combined studies the median passage success was 64, 72, and 93% for all three dams and the median cumulative passage past two of the dams was only 71% and ranged from 8% to 87% among years. Both upward and downward migration success are important to community structure, recruitment, and population viability.
- Additionally, the creation of tailraces, water channels below a dam that carry water away from a turbine, from construction and operation of hydropower facilities can affect upward migration (Scruton *et al.* 2007). A study on Atlantic salmon in Canada found that hydropower dams cause delays and increased

energy expenditure during upriver migration, as migratory fish are attracted to high water velocities and discharge at tailraces. All salmon in the study were attracted at some degree to the tailraces with varying residency times and showed searching behaviour to find an upstream passage route. Increased energy expenditure was associated with tailrace attraction. Fish may use too much energy in the tailraces searching for a viable route, not leaving enough energy for the rest of their migration, for gonad production, or for spawning (Scruton *et al.* 2007).

- Utilize technologies such as acoustic or electric guidance or deterrence systems steer fish away from turbine intakes (Smith-Root, 2013)
- In some facilities, wire fencing is placed in front of the turbine entrances to encourage fish movement to artificial fish passage locations; however, the wire fencing can also cause collision mortality (Coutant & Whitney 2000).

Post construction monitoring

. Over the years, fish passages have not always been successful due to installation with unclear objectives, lack of species-specific studies before installation, and lack of monitoring (Agostinho *et al.* 2011, Godinho & Kynard 2009, Holbrook *et al.* 2009, Pompeu *et al.* 2012). Installation of fish traps and monitoring should account for both upstream and downstream migration movements, species migration routes, river flow rates and discharge before and after a facility, spatial distribution of habitats, behaviour of species, population recruitment dynamics, and life history stages (Agostinho *et al.* 2011, Godinho & Kynard 2009, Pompeu *et al.* 2012).

Birds

- Maintaining suitable habitats for waterbirds below hydropower projects may be possible if flows can be regulated appropriately (e,g, Pernollet *et al.* 2013) .
- Impacts on downstream habitats and waterbird populations, can in part, be mitigated by the management of flow variations from the project site. Too much flow variation and un-seasonal flows can reduce available habitats and be lethal for species that only survive within specific habitats and flow limits (both birds and their aquatic prey species) (SNH, undated).

Mammals

- Schelle (2013) suggests that dam operators can play a key role in dolphin conservation by adjusting dam operations to facilitate environmental flow regimes that help sustain downstream habitats and floodplains.
- Proper siting to avoid essential manatee and otter habitat should be encouraged.

5.9 Positive effects

Creation of large, deep water bodies also provides new habitats for some species of migratory fish. However, it is generally suggested that loss of habitats encourages the proliferation of generalists and alien species that can breed within the body of the reservoir and do not require specialised habitats or hydrological triggers to induce spawning (ICEM, 2010; Darwall *et al.* 2011). Fish populations often increase rapidly within new reservoirs, partly because of the expansion of water volume, and partly because food organisms may temporarily increase in the impoundment. Development of commercial fisheries in reservoirs is therefore considered to be a potential beneficial effect of hydro-electric development.

Hydropower facilities may provide a significant source of winter roost sites for bats as Kurta & Teramino (1994) documented a hibernating colony of 15,000 bats in a hydroelectric facility in the Central Great Lakes Basin, Mainistee County, Michigan, USA.

Reservoirs created by hydropower dams may create new habitats for some migratory bird species, but are rarely used by the species adapted to fast-flowing habitats described above. Depending on the shallowness, and extent of littoral shallow fringes, reservoirs may be important refuges for migratory ducks, geese and other waterbirds. However, deep-water reservoirs offer limited food sources for many species of waterbird, and may only be used as safe roosting (not foraging) sites during migration periods. Nonetheless, many have developed significant conservation value leading to designation as Ramsar Sites.

5.10 Gaps in knowledge

There are many species-specific variables that affect migratory movements including migration routes, habitat preferences, habitat distribution, life history, population dynamics and behaviour. A lot of this information has not been studied and has not been considered when designing, building, and monitoring hydropower facilities and artificial fish passageways. In the available literature, salmon species were the most studied migratory fish in terms of the impacts of hydropower technology. This is likely due to the commercial importance of this species and non-commercial migratory species, depending on their ecology, are likely to be subject to similar impacts. Other species should be considered including migratory lamprey, steelhead, shad, sturgeon and eel spp. to name a few. Artificial fish passageways are restrictive to both upstream and downstream migrations (Agostinho *et al.* 2011, Godinho & Kynard 2009, Holbrook *et al.* 2009, Pompeu *et al.* 2012, Scruton *et al.* 2007). A study at the Lajeado Dam in Brazil (Agostinho *et al.* 2011) assessed upstream and downstream fish movements through a fish passage over one year. The fish passage was restrictive to many species in both directions; however, almost all fish captured in the passage way were ascending migratory fish, indicating that the passage way was limited and did not allow for downstream passage (Agostinho *et al.* 2011). It is known, however, that migratory fish are attracted to flowing water and actively avoid standing waters (Agostinho *et al.* 2011, Fjeldstad *et al.* 2012, Scruton *et al.* 2007). It was speculated that the passage way may not be the limiting factor in restricted downstream migration but that the reservoir created from the hydropower facility discouraged downstream migratory movements as fish have no incentive to disperse downstream across standing waters (Agostinho *et al* 2011). A study done by Fjeldstad *et al.* (2012) on Atlantic salmon smolt migration past hydropower intakes indicated that flow rates in bypass areas are important to successful migration. Water flow was artificially increased and as a result, bypass migration through passage ways increased (Fjeldstad *et al.* 2012). This type of fish behaviour is still poorly understood. Understanding the seasonal hydrology and the ecological requirements of the main fish species is necessary to implement effective mitigation measures.

Additionally, research on the impacts of hydropower facilities is focused on migratory fish species and seldom investigates migratory birds and terrestrial mammals. Information is lacking on the effects to migratory bats, which are using hydropower dams as hibernaculum.

The impacts of run-of-the-river hydropower projects and in-stream projects on migratory waterbirds have yet to be fully researched so no conclusions can be reached. Given that these projects do not completely remove riparian habitats, their impacts on the migratory birds that rely on such areas are likely to be less significant.

5.11 Conclusions

The general conclusion from the literature reviewed is that hydropower energy technologies can have serious impacts on migratory species populations. For at least one species, the Yangtze river dolphin, extinction in the wild has been recorded in recent years. Impacts on migratory fish and fresh water cetaceans can be significant, and although mostly occurring at the local scale may be noticed at the population level. The construction phase is in general difficult to separate from the operational phase in terms of impacts, as the construction of dams is the dominant negative impact. The positive effects are mostly a result of standing fresh water bodies behind the dams serving new habitat for species such as waterbirds and many fish species. But the losses of floodplains in crucial stopover and wintering habitats for millions of waterbirds in the Sahel are more significant. But introduction of alien invasive species in these waterbodies can result in additional negative impacts on native (endemic) migratory species.

The migratory species groups where negative impacts are to occur include fish, fresh water mammals and birds bound to currents and riverine habitats. The main effects of deployment of hydropower energy on migratory species are barrier effects, which in fact lead to direct habitat loss through flooding and habitat degradation due to the failure to maintain environmental flows.

The primary gaps in knowledge are related to the effects of mitigation measures. For many species and river systems the effects are insufficiently known. Although in general the impacts on species are known, for specific sites the effects can be unknown as information lacks on existing migratory species and crucial migratory pathways. E.g. Larinier (2001 in Marmulla, 2001) states that “almost nothing is known about migratory fish species”, particularly in developing countries. This can be addressed by anticipating effects in the construction phase and including mitigation measures such as fish passes in a conservative approach to minimize impacts known to occur in other systems. Similarly, where specific marine and aquatic migratory mammal pathways are unknown, a conservative approach would include avoidance of any known areas used as habitat by these species. The World Commission on Dams published a report (2000) with the mission to improve the development outcomes of future dam-construction projects, for hydropower or otherwise, by compiling the lessons learned from existing dams and the often unnecessary and unforeseen consequences of their construction on the environment. The recommendations in the report should be used to guide decision makers as they approach construction, decommissioning and other questions associated with hydropower dams, to minimize negative societal and environmental impacts, including those to migratory species.

5.12 Literature

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6 Ocean energy

E. Moore & S. Bouma

6.1 Introduction

Ocean energy comprises several technologies that capture the electricity-generating potential of oceanic waters, including through thermal energy conversion (*i.e.*, the temperature differential between deep and surface waters), mechanical energy (*i.e.*, tides, currents, and waves), and osmotic power (*e.g.*, the salinity gradients between salt and freshwater).

While technologies to capture ocean energy sources have been implemented or planned in several European and Asian locations, the potential for ocean energy in the western hemisphere is still in early stages of development (IHS EER 2010). High potential for ocean thermal energy in the western hemisphere occurs along Central America's coasts and the Caribbean, as well as along the Atlantic coast of South America (Lewis *et al.* 2011, USEPA 2013). High wave energy potential exists along Canada's Pacific coast and along the Pacific coast of South America (Lewis *et al.* 2011). Potential for tidal energy generation is high in areas with high tidal amplitude, including the northeast Atlantic off of the United States and Canada (Boehlert *et al.* 2008, Lewis *et al.* 2011, USEPA 2013). Current energy potential is typically highest between islands, in narrows, where water is funnelled and flow rates are high and predictable (Finkl & Charlier 2009). Osmotic power potential is high in all coastal areas, however development of these technologies is most desirable in populated areas, to utilize the desalinated water produced as a by-product for residential or industrial purposes (Lewis *et al.* 2011).

Tidal and wave energy conversion are most mature of these technologies at this time, with several installations operating at near-commercial-level production worldwide (Lewis *et al.* 2011). Tidal and wave energy sites are however still relatively uncommon. The development of tidal energy sites has been concentrated in Europe, in Scotland in particular. Outside of Europe, the USA, Canada, India and South Korea in particular are developing tidal energy sites. Globally there are 63 tidal energy sites both test and commercial in various stages of development (James 2013). The development of wave energy sites has been concentrated in Europe and especially in Scotland. Outside of Europe, Russia, the USA, Australia in particular are developing wave energy sites. There are 59 wave energy sites globally in various stages of development (James 2013).

Ocean energy technologies are diverse, however most consist of some combination of floating and/or submerged energy production units (EPUs) or other hard structures anchored to foundations on the sea floor and submarine transmission cables used to transport the generated energy to land. Ocean thermal energy generation requires bringing cold sea water from the depths up to the surface via large diameter intake pipes where processing plants are able to convert it into electricity. Such plants may be constructed on land, built on the continental shelf, or float, anchored to the sea floor (USEPA 2013). Osmotic power similarly requires large intake pipes and construction of processing plants in coastal areas (Lewis *et al.* 2011). Wave energy may be captured and converted to electricity via buoys or other floating EPUs, whose up-and-down motion creates mechanical energy that is converted to electricity and transmitted along an undersea cable (Jacobson 2008).

Tidal energy, in contrast, is generally captured through turbines or fences, consisting of rotors or blades that turn with both the ebb and flow of the tidal cycle (USEPA 2013). These turbines and accompanying generators may extend to the surface or remain submerged near the sea floor. The rotors may be open and exposed to the water, or enclosed within a narrowing duct, concentrating flow through the turbine (Jacobson 2008). Another type of tidal energy generation is accomplished by building containment pools that capture water during high tide behind a barrage (dam), and release the water through turbines, similar to hydroelectric dams (USEPA 2013).

The environmental impact of wave and tidal energy is rather unknown, since these two energy sources are in an initial phase. The literature on potential conflict between ocean energy development and migratory species focuses primarily on operational impacts of (a) mortality due to impingement, entrainment, collision, entanglement, or other interaction with energy producing equipment or structures, (b) habitat loss due to installation of energy conversion structures and facilities in the coastal and marine environment, and (c) habitat degradation due to altered hydrodynamic regimes, thermal regimes, sediment transport patterns, nutrient delivery, larval dispersal, and increased noise and electromagnetic fields in the surrounding region (Gill 2005, Cada *et al.* 2007, Boehlert *et al.* 2008, Finkl & Charlier 2009, Shumchenia *et al.* 2012). Additional habitat degradation through chemical contamination may occur due to contaminant mobilization through disturbed sediments, flaking and wear of anti-fouling paints from structures, as well as potential accidental leak or spill of lubricants, fuels, or other fluids.

Visual simulation of wave energy attenuator devices. Image credit: US Dept. Of Energy

In January 2013 a report on 'Environmental Effects of Marine Energy Development around the World' was prepared by the Pacific Northwest National Laboratory for the Ocean Energy Systems Initiative (OES; Copping *et al.* 2013). The report contains case studies of specific interactions of marine energy devices with the marine environment including physical interactions between animals and tidal turbines, acoustic impacts of marine energy devices, and impacts to physical marine systems due to energy removal. Each case study described in the report also includes a description of environmental monitoring efforts and research studies in place, information learned from previous studies to inform future development, and listing of remaining information gaps. Much of the research summarized in the report is compiled on the Tethys database website, produced by the Pacific Northwest National Laboratory in support of the U.S. Department of Energy (PNNL). This repository for research and literature is contains a wealth of information on the impacts of ocean energy development on the environment, including migratory species.

6.2 Impact matrix

The (potential) impacts of ocean energy deployment are summarized in Table 6.1. Terrestrial species are not relevant and are therefore excluded from the analysis. The species groups where impacts are likely to occur include marine mammals, crustaceans and squid, fish, sea turtles and birds, which are discussed in more detail below. The impacts summarized in Table 6.1 are described in more detail in the next paragraphs.

The impact matrix summarizes the impacts of ocean energy production on the relevant species *groups* (see above). Impacts can be extrapolated to species level (table 1.1) when ocean energy development coincides with the habitat of these species.

Table 6.1 Impact matrix ocean energy and migratory species. Assessment of the (potential) impact of the ocean energy technology on migratory species

Process phase	Species group	Impact	Description of ecological impact	Spatial extent impact	Duration of impact	Magnitude of impact
Construction & Decommissioning	**Fish, Sea Turtles, Birds, Marine Mammals, Crustaceans and Squid**	Mortality, Habitat loss and fragmentation, Habitat degradation	Collision and entanglement with ocean energy conversion devices and vessels, Some degradation due to sediment disturbance, underwater noise, and vibration disturbance, construction activities and noise disturbing prey, barrier effects of tidal barrages; see table 2.1			
Operational and Energy Transmission	**Fish**	Mortality	Impingement and entrainment within EPUs, collisions, entanglement.	Local	Long-term	II
		Habitat loss and fragmentation	Some loss of benthic and/or pelagic habitat and food sources.	Local	Long-term	I
		Barrier effects	Avoidance of the area or blocked migration routes.	Local	Long-term	I
		Habitat degradation	Underwater noise, altered hydrodynamics, competition and predation pressure surrounding "artificial reefs" and electromagnetic field emission.	Local	Long-term	II
		Habitat gain	Structures may attract fish as "artificial reefs".	Local	Long-term	I
	Sea Turtles	Mortality	Collision and entanglement with ocean energy conversion devices and vessels.	Local	Long-term	II
		Habitat loss and fragmentation	Loss of benthic habitat and/or food sources.	Local	Long-term	I
		Barrier effects	Some obstruction to migratory movements due to physical and sound barriers.	Local	Long-term	I
		Habitat degradation	Some degradation due to ongoing underwater noise and vibration disturbance, altered hydrodynamic environment.	Regional	Long-term	II
		Habitat gain	Structures may attract turtles or their prey as "artificial reefs".	Local	Long-term	I
	Birds	Mortality	Collision and entanglement with ocean energy conversion devices and vessels.	Local	Long-term	I
		Habitat loss and fragmentation	Loss of coastal habitat due to construction of facilities onshore or in surrounding waters.	Regional	Long-term	II
		Habitat degradation	Altered food availability and quality of coastal riparian habitat.	Regional	Long-term	I
		Habitat gain	Assumed minor: surface structures provide roosting habitat.	Local	Long-term	I

Marine Mammals	Mortality	Collision and entanglement with ocean energy conversion devices and vessels.	Local	Long-term	I
	Barrier effects	Obstruction to migratory movements due to physical and sound barriers.	Local	Long-term	I
	Habitat degradation	Altered prey availability; Increased entanglement potential in areas with energy conversion devices; noise disturbance.	Local	Long-term	I
Crustaceans and Squid	Habitat loss and fragmentation	Loss of benthic and/or pelagic habitat and food sources.	Local	Long-term	I
	Habitat degradation	Underwater noise, altered hydrodynamic environment, increased competition and predation pressure surrounding artificial reefs, and electromagnetic field emission.	Local	Long-term	II
	Habitat gain	Ocean energy conversion devices and other foundational structures serve as artificial reefs.	Local	Long-term	I

Spatial extent (size of area) of the impact (local/project area, regional/beyond the project area); Magnitude (I = Effects reported, but no apparent threat to populations, II = High impact, but with no significant impact on the overall species population, III = High impact increasing the risk of species extinction). See §1.2.3.for explanation of terms used.

6.3 Construction phase

Effects during the ocean energy construction phase generally reflect those for other marine construction projects and activities and include mortality, habitat loss and disturbance. The level and duration of the effects witnessed vary depending on ecological and environmental factors as well as the location, timing, duration, intensity and size of the project and the construction techniques and any mitigation measures employed. Although the construction phase is generally much shorter and more local than the operation duration of a wind farm, activity may be more intensive during construction and acute responses may be evident.

The construction phase is the most acoustically diverse and the noisiest phase (Thomsen *et al.*, 2006). In this phase there is a large amount of shipping movements in and out of the area, seismic surveys at the start of the project, and construction noise. If the energy devices require piling, then the predominant noise issue will be associated with pile driving, which is currently of greatest concern for its effects on acoustically sensitive species (Thomsen *et al.*, 2006). More terrestrial-based projects, such as tidal barrages, the impacts from the construction of infrastructure and associated structures are likely to be similar for other renewable energy projects.

Construction of tidal barrages in particular would create effects similar to the construction of hydropower dams, including the barrier effect to migratory species moving through the area. As with hydropower dams, the construction of the coffer dam to allow construction of the main barrage to take place will lead to changes in bay/river flows, altered sedimentation, and destruction of tidal habitats. The few studies that have been undertaken to date to identify the environmental impacts of a tidal power scheme have determined that each specific site is different and the impacts depend greatly upon local geography. For instance, it has been estimated that in the Bay of Fundy, tidal power plants could decrease local tides by 15 cm (http://www.oceanenergycouncil.com/ocean-energy/tidal-energy).

While these impacts will be temporary with respect to the coffer dam construction, they will ultimately lead to permanent changes following completion of a barrier or barrage across a river or bay. This will ultimately cause long-term impacts on those migratory species.

6.4 Fish

Development of ocean energy projects within the coastal and marine environment has the potential to impact migratory fish during all phases of production. A review of pertinent literature indicates that known impacts to fish from ocean energy projects vary depending on the scale of the project, the location, and the species groups of fish being considered. Migratory fishes in the western hemisphere include the oceanic highly migratory species (*e.g.*, tunas, swordfish, and some sharks) known to traverse great distances across oceans, typically following food sources, as well as diadromous species (*e.g.*, American eel *Anguilla rostrata*, salmon, clupeids), which migrate between freshwater and the seas on reproductive cycles. The discussion below includes description of potential impacts to these and other migratory fish species.

Copping *et al.* 2013 summarises various studies on the effects of tidal turbines on fish including observations of fish around a tidal turbine in Cobscook Bay, Maine USA. Ocean Renewable Power Company's (ORPC) Cobscook Bay Tidal Energy Project (CBTEP) is planned as a commercial installation of three cross-axis turbine generator units (TGUs) in 26 m of water in Cobscook Bay in coastal Maine, USA. Average current speeds at the test site are around 1.0 m/s; maximum current speeds reach 2.0 m/s.

Monitoring was conducted to classify fish behaviours in reaction to the turbine in a natural environment, quantify the observed behaviours, and assess the effects of time of day (day or night), fish size, and turbine movement (still or rotating) on fish behaviour. Two acoustic (Dual-Frequency Identification Sonar [DIDSON]) cameras were mounted fore and aft of the turbine, angled to observe a cross section of the device and support structure, and data were collected over a 24-hour period. Fish behaviour was classified into categories for analysis. Reaction distance, the distance between the fish and the turbine at which fish were seen to actively alter course to avoid the turbine, was recorded for all fish that exhibited avoidance behaviour. Researchers analysed the effect of time of day (day/night), fish size, and current speed on the proportion of fish interacting with the turbine and the type of interaction observed. Researchers also established the baseline abundance and distribution of fish species in the bay and documented changes in benthic habitat and benthic communities in the vicinity of the turbine.

It was clear from the acoustic camera data that fish did not entirely avoid the area occupied by the turbine and barge; they regularly approached it closely. Results from the study showed that a higher proportion of fish interacted with the turbine when it was still than when it was rotating and that during these interactions the predominant behaviour was fish entering the turbine. The study was not able to discover the disposition of the fish that passed through the turbine, although there were no incidences of dead or dying fish recorded after passage through the operating turbine. Visibility may be an important factor in determining fish behaviour around the turbine: at night, the reaction distance of fish was shorter, more medium-and large-sized fish interacted with the turbine, and the behaviour of small-and medium-sized fish shifted from avoiding to entering the turbine.

Most of the fish detected by the cameras were already located above or below the turbine when they entered the field of view, which may indicate that they were able to detect the turbine prior to the distance 2.5 m upstream of the turbine captured by the DIDSON cameras. Large fish (older herring, mackerel) appeared to have a greater ability to avoid the turbine than small-and medium-sized fish (sticklebacks and juvenile herring). Interestingly, schooling fish also appeared to be better able to detect and avoid the turbine than individual fish. Observed fish were almost always present in the wake of the turbine when the current was strong enough to generate a wake (regardless of the turbine rotating or still), with greater numbers observed in the wake than observed entering the turbine. This may indicate a preference for lower-energy regions of the water column, such as those caused by the presence of the turbine. Large fish appeared to have a greater ability to avoid the turbine than small-and medium-sized fish (sticklebacks and juvenile herring). Interestingly, schooling fish also appeared to be better able to detect and avoid the turbine than individual fish.

6.4.1 Mortality

Mortality of migratory fish due to operational impacts of ocean energy projects is most often due to physical injury caused by collision with or passage through turbines used to generate tidal energy. Physical strikes with the turbine or rotor blades is the most common cause of mortality in larger fishes (*e.g.*, sturgeon, bass), however smaller fishes (*e.g.*, clupeids) may also be impacted by impingement on screens over intake pipes or ducts, shear stresses, and abrupt pressure change within the turbine draft tube (Dadswell & Rulifson 1994). The magnitude of potential impact of these energy projects on migratory fish populations is largely related to their location. For instance, tidal energy facilities sited near the entrance to bays and estuaries utilized by diadromous species may have greater impact due to natural funnelling of high volumes of individuals through these areas on reproductive migrations (Dadswell & Rulifson 1994, Viehman & Zydlewski 2014). In addition, configuration, spacing, and areal extent of ocean energy conversion devices may affect the ability of migratory fish to avoid the entire area or individual devices along their route (Cada *et al.* 2007). Diversion systems, including those that utilize high-frequency sound to deter fish from energy generation areas, may mitigate some of the mortality impacts to migratory populations, however these have not proven effective for all species (Gibson & Myers 2002).

6.4.2 Barrier effects

Ocean energy development has the potential of creating barriers to migratory pathways, impacting many species. In particular, tidal barrages that operate across entire river mouths or bay openings to the sea can block safe passage of anadromous fish and manatees moving from coastal or offshore habitat inland to bays or upstream freshwater (PNNL 2014).

6.4.3 Habitat loss

Installation and operation of EPUs and other hard structures in the marine environment as part of ocean energy development would result in the loss of existing benthic and pelagic habitat, including potential loss or alteration of the existing prey availability for migratory species (Boehlert *et al.* 2008, Witt *et al.* 2011). However, new hard structures associated with these projects may act as attractors, or artificial reefs, leading to increased abundances of some fish and invertebrate species in the area, many of which may serve as prey for migratory fish species (Boehlert *et al.* 2008, Witt *et al.* 2011). If the ocean energy conversions system were to be decommissioned, this would result in loss of the artificial habitat, again altering the local habitat.

6.4.4 Habitat degradation

Ocean energy projects have the potential to affect migration corridors, particularly when they are sited to take advantage of the same currents utilized by migratory species (Boehlert *et al.* 2008). While an increase in structure may increase the habitat value for some species and individuals attracted by the artificial reef effect, foraging among the EPUs and anchor lines could lead to entanglement or other injury (Boehlert *et al.* 2008). In addition, the structure may attract increased abundances of predators or invasive competitors (Boehlert *et al.* 2008). Electromagnetic fields and underwater noise generated by the EPUs and/or transmission cables may also impact the orientation of migratory fish species (Boehlert *et al.* 2008, Gill *et al.* 2012). There is evidence that eels can temporarily respond to electromagnetic fields from cables during their migration by diverting from their path of movement (Westerberg & Lagenfelt, 2008).

6.5 Reptiles

Literature on migratory sea turtle impacts with ocean energy development is sparse; however the impacts can be inferred from published expectations of impacts to other migratory species. For instance, entanglement and collision with submerged and surface structures is of concern for sea turtles as it is for marine mammals and migratory fish, as is disruption to orientation by electromagnetic fields (Boehlert *et al.* 2008).

6.5.1 Mortality

The largest potential cause of mortality to sea turtles by ocean energy development is through entanglement with offshore and coastal structures (Cada *et al.* 2007, Finkl & Charlier 2009). As with other species groups, this impact could be compounded if turtles are attracted to increased prey densities surrounding these structures (Cada *et al.* 2007, Boehlert *et al.* 2008). Direct collision with structures and/or service vessels is also of concern for these organisms (Cada *et al.* 2007, Finkl & Charlier 2009, Shumchenia *et al.* 2012)

6.5.2 Habitat loss

Direct habitat loss was not identified in the literature as an expected conflict between ocean energy development and migratory sea turtles, however habitat degradation due to electromagnetic fields or noise disturbance may lead turtles to avoid these areas and thus be diverted on migration routes (Boehlert *et al.* 2008, Shumchenia *et al.* 2012).

6.5.3 Habitat degradation

Ocean energy development may result in sea turtle habitat degradation due to increased noise and light disturbance in the area as well as electromagnetic fields generated by energy conversion activities (Boehlert *et al.* 2008, Shumchenia *et al.* 2012). All of these impacts may result in disorientation and stress to these organisms during migration through the area.

6.6 Birds

The published literature on the effects of ocean energy development on migratory birds suggests potential impacts to feeding areas by alteration of coastal and oceanic habitat as well as concern for entanglement and collision with submerged or surface equipment. Specific impacts and interactions are discussed below. Impacts on intertidal mudflats in estuaries caused by tidal barrages can be significant (Burton et al. 2006).

6.6.1 Mortality

Migratory birds may become entangled in cables/structures associated with ocean energy projects, particularly if they are attracted to increased prey abundance related to artificial reef effects (Cada *et al.* 2007, Boehlert *et al.* 2008, Grecian *et al.* 2010). These impacts are most likely to affect diving birds (Furness *et al.* 2012). Collision with surface or submerged structures by diving birds, and entrainment within turbines is also a potential source of mortality to these species (Cada *et al.* 2007, Langton *et al.* 2011, Grecian *et al.* 2010, Furness *et al.* 2012).

6.6.2 Habitat loss

Installation of tidal barrages at coastal bays and estuaries alters the surrounding wetland habitat, resulting in loss or degradation of potential migratory bird feeding areas (Clark 2006, Frid *et al*. 2012). For instance, a barrage built across Cardiff Bay, UK in 1999 created a large freshwater impoundment, reducing mudflat habitat for shorebirds, and thus experienced a drop in species abundance and diversity (Burton 2006, Burton *et al*. 2010). Though this is not an energy-producing barrage, the impacts are expected to be analogous to the impacts of a tidal-energy barrage, which includes retention of water at high tide. Similarly, migratory birds may avoid developed areas (Shumchenia *et al*. 2012), thus being diverted from offshore or nearshore areas developed for ocean energy projects.

6.6.3 Habitat degradation

Development of ocean energy projects may impact the quality of habitat for migratory birds in several ways. These birds may be attracted to lighting, surface structures, or prey organisms that these structures also attract, however this may result in injury or mortality if birds collide with structures or become entangled in equipment (Boehlert *et al.* 2008). In addition, initial construction and maintenance related to ocean energy projects may create disturbance that leads to avoidance or displacement of birds utilizing the habitat. There is evidence that displaced birds may not return to the area in the same numbers, leading to relocation in nearby areas with potentially-lower habitat quality (Burton *et al*. 2002, Burton 2006). These nearby habitats may also experience high densities, increasing competition for space and food; displaced birds have also shown evidence of reduced fitness in later years (Burton 2006, Burton *et al*. 2010).

Alteration to coastal habitats by the presence of tidal barrages can impact bird feeding areas by altering the surrounding riparian habitat (Burton 2006, Clark 2006, Burton *et al*. 2010, Frid *et al*. 2012). Tidal barrages may also alter tidal patterns and timing of ebb and flow cycles, thus altering feeding time for wading birds (Burton *et al*. 2010). Food availability and quality (e.g., rooted vegetation and invertebrates) may also change due to alterations of sedimentation regimes due to tidal barrage presence (Burton et. al. 2010). Similarly, offshore ocean energy projects may alter local hydrodynamic, chemical or thermal regimes, which in turn may result in regional changes to habitat quality and prey availability in the surrounding waters or nearshore areas (Boehlert *et al*. 2008).

6.7 Mammals

Both bats and marine mammals (including sirenians and otters) have the potential to interact with ocean energy projects during migrations.

While bats may utilize offshore structures associated with this energy production, there is very little in the literature speculating on potential conflicts with this group, though they may risk collision and entanglement related mortality effects similar to migratory birds (see Section 5.5).

Literature on conflicts between ocean energy developments and migratory marine mammals focuses on the potential of such developments to obstruct migratory pathways and introduce acoustical disturbances during both construction and operational phases. These conflicts may lead to collisions and entanglements of marine mammals with ocean energy conversion structures, avoidance of developed areas of the ocean, and disorientation of these species. Although not specific to ocean energy projects, many forms of marine construction pose a threat (physiological harm or death) to marine mammals that are sensitive to high decibel levels. These impacts can be mitigated with noise shielding devices and significant on-board marine mammal (and turtle) monitoring during installation.

Copping *et al.* (2013) summarises several projects where the effects of tidal turbines on marine mammals have been measured and/or observed including SeaGen observations of marine mammals in Strangford Lough, Northern Ireland. Marine Current Turbine's SeaGen is a tidal energy device consisting of two 16-m open-bladed rotors attached to a pile in the seabed in 26.2 m of water; its surface expression includes a turret supporting an observation platform. The rotor blades can be raised and lowered for maintenance and can be feathered to slow or stop rotation. The deployment site is in the centre channel of the Narrows in Strangford Lough, Northern Ireland, where tidal currents reach up to 4.8 m/s. The presence of harbour seals (*Phoca vitulina*), grey seals (*Halichoerus grypus*), harbour porpoises (*Phocoena phocoena*, and otters (*Lutra lutra*), as well as the diverse array of habitats, has led to the designation of Strangford Lough as a conservation site under international, European Union (EU), and national legislation. In an effort to eliminate strike risk to seals during operation of the SeaGen turbine, the turbine has a shutdown mechanism initiated by either direct observation by a marine mammal and/or alerted by a sonar unit mounted on the pile.

Monitoring programmes were designed to measure the following environmental effects caused by the presence of the tidal device:

- the presence of harbour and grey seals near the tidal blades, based on observations made by marine mammal observers and sonar (active acoustics).
- blade strikes on marine mammals, based on post mortem evaluations of stranded marine mammal carcasses.
- a barrier effect and/or displacement of marine mammals (common seals, harbour seals, harbour porpoises and grey seals) from Strangford Lough and seal haul out sites from the tidal device, based on visual observations made by marine mammal observers, observations from boat surveys and aerial surveys, acoustic monitoring for harbour porpoises using Timing Porpoise Detectors (TPODs) and tracking of tagged seals.
- the effect of noise from the tidal turbine on seal behaviour, based on visual observations made by marine mammal observers and sonar (active acoustics), correlated with the acoustic output of the turbine measured by a hydrophone (passive acoustics).
- Changes in relative abundance of seals in Strangford Lough, based on visual observations made by marine mammal observers, observations from boat surveys and aerial surveys, TPOD acoustic monitoring, and tracking of tagged seals; overall population changes were measured by comparing historical data to aerial survey and seal telemetry data.

The turbine shutdown procedures did not allow for observations of direct interactions of the animals with turbine blades, and post mortem evaluation of all recorded marine mammal carcasses did not reveal any evidence of fatal strike to a marine mammal by the SeaGen device. However, the monitoring program was also designed to document effects outside the immediate vicinity of the blades, and it showed no major impacts on marine mammals, birds, or benthic habitat from the tidal turbine. Harbour seals and porpoises were seen to swim freely in and out of the Lough while the turbine was operating and they were not excluded from the waterbody, a phenomenon commonly known as the barrier effect. Similarly, no significant displacement of seals or porpoises was observed, although the marine mammals appeared to avoid the centre of the channel when the turbine was operating.

Harbour porpoises were temporarily displaced from the Narrows during construction, but other areas around the project site maintained baseline abundance, and porpoises returned to normal baseline in the Narrows once construction was complete. SeaGen did not cause a significant change in the use of harbour seal haul out sites. Harbour seals exhibited some redistribution on a small scale (a few hundred meters) during turbine operation. Seal telemetry data showed that seals transited farther away from the centre of the Narrows after SeaGen installation.

James (2013) provided an overview of the present extent of the wave, tidal and wind energy developments across the globe as of February 2013, the technology involved and the consideration of how they may affect cetaceans. They stated that the severity of any impacts on cetaceans can be expected to differ at each site based on a number of variables including the type of device used, the type of foundation, location (near-shore, offshore, deep, estuaries etc.), topography, nature of the sea bed, water depth and scale, as well as the species encountered, the value of the site for that species and the opportunity to move away. They identified the following potential impacts: displacement, entrapment, entanglement or collision, contamination of the local environment, electrical and electromagnetic disturbance and other habitat degradation. Specific examples of such impacts (extracted from this study) are provided in the following paragraphs.

6.7.1 Mortality

Marine mammals may become entangled in cables associated with ocean energy system structures, depending largely on the spacing and nature (e.g., slack vs. taut) of such devices (Cada *et al*. 2007, Boehlert *et al*. 2008, Finkl & Charlier 2009, Dolman & Simmonds 2010, Witt *et al*. 2011). Tidal barrages present similar risks to marine mammals as hydropower dams, including entrapment; at a tidal energy site in Canada for example two humpback whales became entrapped (James 2013). The first was trapped in the upper part of the river for several days in 2004 after swimming through the sluice gates. In 2007 the body of a Humpback whale *Megaptera novaeangliae* was discovered and the post mortem investigation suggested that the whale had followed the fish through the sluice gates and also became trapped (Nova Scotia Power 2012, in: James, 2013). In addition, manatees migrating through flood-control dams or other barriers analogous to tidal barrages have been crushed by closing gates (Ackerman *et al*. 1995).

In Scottish waters more than 50% of stranded Minke whales *Balaenoptera acutorostrata* showed signs of having been entangled (Northridge *et al.* 2010, in: James 2013). Sometimes whales will actively rub against cables, which can get them entangled (Thompson *et al.* 2013). Collision with submerged or floating structures and/or service vessels is also of concern for this group (Cada *et al.* 2007, Boehlert *et al.* 2008, Finkl & Charlier 2009, Dolman & Simmonds 2010, Shumchenia *et al.* 2012, Witt *et al.* 2012). Some marine mammals may also be attracted to offshore ocean energy projects if prey organisms are aggregated there, increasing their risk of collision or entanglement with these structures (Cada *et al.* 2007, Boehlert *et al.* 2008). Mortality during construction is also a significant risk to migratory marine mammals that may be present within the area of the project site.

6.7.2 Habitat loss

Depending on the areal extent of an ocean energy project, and the density and layout of associated EPUs, the habitat covered by the project may be lost to marine mammals if it becomes impassable due to physical obstruction and/or noise barriers to migratory movements (Boehlert *et al.* 2008, Dolman & Simmonds 2010).

Most of the wave generators in a relatively advanced stage of development are floating platforms of some sort and also have minimal contact with the seabed. Although wave generators will have mooring and/or anchor systems, they are unlikely to have a major impact on the available habitat in comparison with the scale of foraging area used by marine mammals (Thompson *et al.* 2013).

Individual tidal turbines are relatively small and many designs have only minimal structures in contact with the sea bed. There may be some downstream changes in sedimentation or benthic communities as a result of disruption of tidal flow patterns and there may be changes in shorelines due to changes in wave patterns, but again, on the scale of marine mammal foraging ranges, these would not be expected to significantly reduce foraging habitat availability and would, at most, have a small effect on several animals or a larger effect on a small number (Thompson *et al.* 2013). Tidal barrages, in contrast, have the potential to block migration routes between coastal open areas and upstream bays, estuaries, and rivers. These habitats are used by manatees in particular as warm water winter refuge (Deutsch *et al.* 2003).

6.7.3 Habitat degradation

Degradation to marine mammal migratory habitat is most likely to occur through acoustical impacts due to noises coming from construction, maintenance, and decommissioning activities as well as operational buoys and cables (Dolman & Simmonds 2010). If these impacts do not make the area impassable, they may affect the behaviour of marine mammals in the area, cause physiological harm, or deter prey organisms from the area (Boehlert *et al.* 2008). Other acoustical communication between individuals may also be obscured by noise generated by the ocean energy development (Boehlert *et al.* 2008). It is worth noting that acoustical deterrents are being studied as a potential mitigation technique precisely to influence marine mammals to avoid ocean energy devices and areas (OSU 2010).

Point absorber buoy for capturing wave energy.
Image credit: US Dept. of Energy

6.8 Other species

Squid and crustaceans are known to undergo long distance migrations (Pierce *et al.* 2008, Guerra-Castro *et al.* 2011), however the literature review revealed very little attention to conflicts between these groups and ocean energy projects. There is research on potential impacts to these species from the EMF fields generated by the undersea electrical cables that would link offshore energy equipment to the shore. Disturbance by the EMF field is believed to be capable of disrupting or even blocking migratory pathways of lobster, which migrate based primarily on cues from the natural EMF field of the earth. Other potential impacts to squid and crustaceans can be inferred based on predictions for other species groups and are summarized below.

6.8.1 Mortality

Literature reviewing the potential causes of mortality of crustaceans and squid by ocean energy projects focused primarily on the potential for impingement and entrainment within EPUs, primarily turbines. As these organisms come within a close proximity of ocean energy developments, they may be subject to the same causes of mortality as small fishes, including mechanical injury caused by impingement on intake screens, impact with turbine rotor blades, or injuries due to shear stress and pressure flux (Abbasi & Abbasi 2000). In addition, increased mortality through increases in predation pressure may be an indirect effect of the attraction of both migratory organisms and their predators to the artificial structures installed in these habitats (Langhamer & Wilhelmsson 2009).

6.8.2 Habitat loss

Direct habitat loss was not identified in the literature as a significant potential impact to migratory crustaceans or squid. Instead, degradation in habitat quality was identified as a potential conflict with these species (see section 5.7.3 below).

6.8.3 Habitat degradation

Installation of ocean energy developments in coastal and marine habitats may lead to degradation of habitat quality for crustaceans due to the altered physical structure of the habitat as well as operational noise and electromagnetic field generation. While the addition of structure may initially represent a positive gain in artificial reef habitat (see section 5.9 below), increased predator presence among the structure of ocean energy developments may increase predation pressure on migratory crustaceans (Langhamer & Wilhelmsson 2009). In addition, novel structure may be colonized by invasive species, or otherwise result in altered species distributions and relationships (Witt *et al.* 2011).

Habitat degradation through increases in operational noise and electromagnetic fields generated by the EPUs and/or transmission cables may result in disorientation of various migratory crustacean species or other alterations in behaviour within the region (Boehlert *et al.* 2008, Pine *et al.* 2012).

6.9 Mitigation measures

Much of the research on ocean energy includes suggestions for mitigation measures or siting practices to minimize potential impacts to wildlife (PNNL 2014 and references therein). The review document has been prepared in conjunction with a guideline document in which guidelines for siting, planning and mitigation are presented and prioritised. Within this review chapter, basic background information is presented. Although siting and mitigation can overlap they are as much as possible separated. The presented information is as much as possible based on literature unless stated otherwise, e.g. in case of mitigation suggestions.

As ocean energy is relatively new and local, few studies on mitigation are available or not particularly related to ocean energy but to infrastructure in general. So there are several *suggestions* for mitigation measures found in literature:

Siting and planning

- Construction, maintenance, and decommissioning activities should be scheduled to avoid important migration periods when migratory species would potentially be in the area, including shore-based activities (e.g., nesting) potentially impacted by coastal construction of tidal barrages or other service stations.

- Thorough site selection review to avoid major migration corridors and sensitive habitats (Boehlert *et al.* 2008), particularly in the case of tidal barrages.
- Adaptive monitoring of new developments through the planning, construction, and operational phases through carefully designed protocols to inform similar and future projects being proposed (Witt *et al.* 2011, ORPC 2013).

Mitigation

- Minimizing use of slack or loose tether and anchor lines to reduce entanglement risk to species (Boehlert *et al.* 2008).
- Use of observers onboard construction, maintenance, and decommissioning vessels to detect animals in time to be sure disturbance can be limited in the work area.
- Use of noise deflecting devices (*e.g.* bubble walls, baffles, etc.) around the work site during high-decibel generating phases of construction.
- Burial of undersea cables within the EPU array and for the shoreline connection to depths within the sediment that will minimize or eliminate the impacts from EMF.
- Shut down procedures for tidal turbines based on identification of the presence of marine mammals by marine mammal observers and/or sonar techniques (see SeaGen observations, Northern Ireland).

6.10 Positive effects

The potential positive effects identified in the literature associated with ocean energy developments are speculative and each include the potential for indirect subsequent negative impacts. For example, a potential positive effect is the artificial reef effect of submerged and floating structures associated with offshore ocean energy development (Gill 2005, Cada *et al.* 2007, Langhamer & Wilhelmsson 2009). The increased habitat complexity provided by EPUs and offshore processing equipment would likely attract fish, crustaceans, and other marine species, possibly increasing forage/food availability for migratory fish, birds, turtles, and mammals. However, the artificial habitat may also attract predators and invasive species, thus reducing habitat value for others (Witt *et al.* 2011). While tidal barrages may lead to loss of mud flat habitat for some wading shore birds, other species would likely benefit from the creation of reservoirs or impoundments behind the barrage (Burton *et al.* 2010).

Offshore floating structures also provide roosting sites for birds; however their attraction to these structures may lead to greater entanglement risk (Cada *et al.* 2007, Grecian *et al.* 2010). Lastly, ocean thermal energy generation may act as artificial upwelling, bringing nutrient rich water to the surface, which may increase the productivity in the area surrounding the generation plant; however excessive nutrients may lead to eutrophic conditions and potentially negative alterations to the ecosystem (Abbasi & Abbasi 2000).

In contrast, another potential positive effect of ocean energy developments on marine species would be the necessary restriction of fishing activity within expansive areas being used for ocean energy development offshore, reserve effects that may benefit several trophic levels (Cada *et al.* 2007, Grecian *et al.* 2010, Witt *et al.* 2011). While creation of these de facto reserves may benefit the marine species in the area, economic considerations and local fishing industries may come into conflict with these developments (Cada *et al.* 2007, Boehlert *et al.* 2008).

James (2013) identified the following potential benefits of the deployment of Marine Renewable Energy Devices: the devices may function as artificial reefs increasing the local biodiversity (Inger *et al.* 2009), but this may depend on the location, size and type of device (Witt *et al.* 2012), the extensive mooring systems may act as fish aggregation devices that in turn may attract marine mammals feeding on these fish (Witt *et al.* 2012), reduced vessel activities due to a ban on other activities around the renewable energy devices.

6.11 Gaps in knowledge

The major data gaps that affect our ability to best understand the potential for impacts to migratory species by ocean energy are in our understanding of specific migratory routes and mechanisms used by various species (Boehlert *et al.* 2008). While general migratory corridors for many species groups are known, siting of ocean energy projects will require a local understanding of the importance of the area for each species (*e.g.*, Whitt *et al.* 2013).

Similarly, the effects of disturbance from electromagnetic, acoustic, and underwater noise generation by these projects will vary depending on species sensitivities, local background levels, and their importance to migratory orientation and individual communication (Boehlert *et al.* 2008, Gill *et al.* 2012). There is a general lack of knowledge regarding the sound levels generated by ocean energy project construction and operation, the transmission of such sound through the water, and thresholds of sound reception by migratory species (James 2013). As ocean energy conversion projects are planned throughout the world, regional studies will be required to understand how each case may impact species migrations.

Lastly, most research on existing ocean energy projects has been conducted during early development and operation of pilot studies, involving one or few EPUs (*e.g.*, ORPC 2013). The impact of these early projects will be very different from the potential impacts of an extensive array of EPUs required for commercial generation of energy through ocean sources (Cada *et al.* 2007).

The magnitude of positive effects versus indirect negative effects of ocean energy projects remains to be studied as more projects enter the development and operational phases

6.12 Conclusions

The diversity of migratory organisms that may be impacted by new and developing ocean energy technologies is compounded by the diversity of the technologies themselves, thus obscuring the ability of researchers to predict the impact of ocean energy development on the marine environment.

The current literature on the subject identifies the primary potential conflicts between these technologies and migratory species as:

- Mortality by impingement, entrainment, entanglement, and collision of migratory species with submerged and surface structures or vessels. These potential impacts are compounded by the attraction of species to the offshore structures or prey aggregations that may form in the area.
- Habitat loss as coastal areas are altered by development of tidal barrages or energy generation facilities, or processes impacted by offshore development. In addition, habitat loss that occurs due to expanses of ocean and coastal areas becoming impassable to migratory species.
- Habitat degradation due to (a) increased predation risk and competition with species attracted to the physical structure of ocean energy developments and (b) increased noise and electromagnetic field disturbance, which may result in displacement and redirection of migratory species.

Review of this literature emphasizes the need for project-specific studies to better inform planners of the potential magnitude of conflict between these renewable energy sources and migratory species, based on the technology being considered and the local species and migratory corridors in the area.

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7 Solar energy

B. Lane, J. Howes & T. van der Have & J. Lajoie

7.1 Introduction

Solar energy technologies convert the irradiance of the sun into electricity and heat. There are a variety of ways this can be achieved. The main technologies used in solar energy developments can be broken down into three categories:

- Solar thermal, which includes both active and passive heating of buildings, domestic and commercial solar water heating and process heat for industry;
- Photovoltaic (PV) electricity generation via direct conversion of sunlight to electricity by photovoltaic cells;
- Concentrating solar power (CSP) electricity generation by optical concentration of solar energy to obtain high-temperature fluids or materials to drive heat engines and electrical generators.

This chapter will concentrate on Concentrated Solar Power (CSP) and Photovoltaic (PV) technologies, as these technologies are widely deployed, particularly solar PV with a global installed capacity of over 100 GW in 2013, and could affect migratory species. Roof mounted solar PV is only discussed briefly as it relates to insect populations.

To date, there are few studies that document the effects of utility scale solar technologies on migratory species, which was also noted in several recent reviews of environmental impacts of solar energy technologies on wildlife in general (Lovich & Ennen 2011, Turney & Fthenakis 2011, Northrup & Wittemeyer 2013). However, there is some evidence that both the structures and the operation of industrial scale solar power plants can have a negative impact on migratory species. The majority of information relates to birds (*e.g.*, Migratory Soaring Bird Project 2011, McCrary *et al.* 1986)

Concentrated Solar Power Technologies
A brief description of the CSP technologies in commercial use is provided below. The different infrastructures and modes of operation are important factors when considering the impact they have on migratory species.

Parabolic trough systems have linear, interconnected parabolic reflectors in troughs that focus the suns irradiance to an absorption tube where oil is superheated. The heat from the oil creates steam to drive steam powered electric turbines. This technology does not use a tower to collect the concentrated irradiance. This technology requires the least area for each megawatt of power produced (6-8 m^2/MW). This is currently the most common type of CSP power plant (representing 20 of the 29 active CSPs in 2012).

Parabolic dish systems have an array of parabolic reflectors in dishes that focus the sun's irradiance to a Stirling engine above each dish. The Stirling engine converts the sun's concentrated energy into mechanical work that is then converted into electrical energy. This system does not require steam to generate electricity thereby minimising disruption to the local hydrological system. It does require a greater area per megawatt of power produced (8-12 m^2/MW). Only one out of the 29 active CSPs in 2012 used this technology.

Fresnel reflectors (or linear reflectors) have long parallel mirror strips that concentrate the sun's irradiance to either a receiver above each unit or to a fixed linear receiver tower. The energy is then converted to steam that drives an electric turbine. Three out of the 29 active CSPs in 2012 used this technology. Of all concentrated solar power technologies, Fresnel systems have some of the lowest land-use requirements (e.g., 4-6 m2/MW).

Solar power towers have an array of mirrors that reflect and concentrate the sun's irradiance to the top of a receiving tower. This energy is then used to drive steam powered electric turbines. Tower heights vary from 55 to 165 metres. This technology requires around the same area per megawatt of power produced as parabolic dish systems (8-12 m^2/MW). Five out of the 29 active CSPs in 2012 used this technology (Pavlovic *et al.* 2012).

7.2 Impact matrix

The (potential) impacts of solar energy deployment are summarized in table 7.1. As solar energy, currently, is only exploited on land, only impacts on terrestrial ecosystems / onshore ecosystems are relevant. The species groups where impacts are likely to occur include birds, terrestrial mammals and insects (monarch butterfly), which are discussed in more detail below. No direct impact is expected on reptiles and fish and these are therefore excluded from the analysis. The impacts summarized in Table 7.1 are described in more detail in the next paragraphs.

The impact matrix summarizes the impacts of solar energy production on the relevant species *groups* (see above). Impacts can be extrapolated to species level (Table 1.1) when solar energy development coincides with the habitat of these species.

Table 7.1 *Impact matrix solar energy and migratory species. Assessment of the (potential) impact of the solar energy technology on migratory species.*

Process phase	Species group	Impact	Description of ecological impact	Spatial extent of impact	Duration of impact	Magnitude of impact
Concentrated Solar Power (CSP)						
Construction & decommissioning			Expected to be small compared to operational phase. Relevant impacts described under Operation.			
Operation	**Birds**	Mortality	Collision structures, in particular nocturnal migrants.	Local	Long-term	I
			Collision after attraction to reflective surfaces (panels, mirrors, heliostats) mistaken for water.	Regional	Long-term	I
			Leakage of chemicals (*e.g.*, coolants) into waste water evaporation ponds or waterbodies.	Local	Long-term	I
			Incineration by concentrated irradiance (no studies found quantifying this effect).	Local	Long-term	N/A
			Higher temperatures around receiving towers could cause heat-stress and additional mortality.	Local	Long-term	N/A
		Habitat loss and fragmentation	Large-scale CSP plants and associated infrastructure can result in large-scale habitat loss, degradation or fragmentation, but type and scale of impact depends highly on the location relative to migration routes and stopover sites.	Local	Long-term	II
		Disturbance/ displacement	Attraction to water storage sites, usually required at CSP plants, in arid and desert areas may lead to additional mortality at these unsuitable habitats.	Local	Long-term	I
			Illumination of collecting towers could attract or disorient nocturnal migrants.	Local	Short-term	N/A
		Habitat degradation	Reduction in available water particularly in dry areas may result in the loss of wetlands and water resources at vital stopover sites for migrants. Lower food and water availability may lead to increased mortality and lower population sizes.	Regional	Long-term	II
			CSP plant infrastructure may lead to changes in microclimate and vegetation and subsequent changes in food resources and nesting habitat.	Local	Long-term	I
	Mammals	Mortality	Collision with fences, some terrestrial mammals.	Local	Long-term	I
		Habitat loss and fragmentation	Large-scale CSP plants and associated infrastructure can result in large-scale habitat loss, degradation or fragmentation, but type and scale of impact depends highly on the location relative to migration routes.	Local	Long-term	II
		Disturbance/ displacement	Attraction to water storage sites, usually required at CSP plants, in arid and desert areas may lead to additional mortality at these unsuitable habitats	Local	Long-term	I
		Habitat degradation	Reduction in available water particularly in dry areas may result in the loss of wetlands and water resources at vital stopover sites for migrants. Lower food and water availability may lead to increased mortality and lower population sizes.	Regional	Long-term	II
			CSP plant infrastructure may lead to changes in microclimate and vegetation and subsequent changes in food resources and nesting habitat. The scale of impact will depend highly on scale and location of CSP plants relative to home range.	Local	Long-term	I
			Leakage of chemicals (*e.g.*, coolants) into waste water evaporation ponds or waterbodies.	Local	Long-term	I

	Insects	Habitat loss and fragmentation	Large-scale plants and associated infrastructure can result in large-scale habitat loss, degradation or fragmentation, but type and scale of impact depends highly on the location relative to migration routes.	Local	Long-term	I
		Disturbance/ displacement	Attraction to water storage sites, usually required at CSP plants, in arid and desert areas may lead to additional mortality at these unsuitable habitats.	Local	Long-term	I
		Habitat degradation	Reduction in available water particularly in dry areas may result in the loss of wetlands and water resources at vital stopover sites for migrants. Lower food and water availability may lead to increased mortality and lower population sizes.	Regional	Long-term	I
			Infrastructure may lead to changes in microclimate and vegetation and subsequent changes in food resources and reproduction habitat.	Local	Long-term	I

Photovoltaic Cells

Construction & decommissioning			Expected to be small compared to operational phase. Relevant impacts described under Operation.			
Operation	**all species**	Habitat loss	Large-scale plants and associated infrastructure can result in large-scale habitat loss, degradation or fragmentation, but type and scale of impact depends highly on the location relative to migration routes.	Regional	Long-term	I

Spatial extent (size of area) of the impact (local/project area, regional/beyond the project area); Magnitude (I = Effects reported, but no apparent threat to populations, II = High impact, but with no significant impact on the overall species population, III = High impact increasing the risk of species extinction). See §1.2.3.for explanation of terms used.

7.3 Construction and operation phase

CPS and PV plants are relatively large and it is assumed that the spatial use and infrastructure during construction is relatively small compared to the area used during operation. Therefore, no distinction was made between these phases in the analysis.

A major general impact is therefore habitat loss and this is directly related to the site and the scale of the projects. This can have impact on all species dealt with hereafter.

7.4 Fish

No information could be found regarding the effect industrial scale solar power plants have on migratory fish species. Alterations to the hydrology of waterways by plants that require large amounts of water have potential to cause negative impacts on the ecology of waterways and the hydraulic connectivity of aquatic habitats, in turn affecting the migration of fish species. Such impacts at critical stages in the life cycle of migratory fish can lead to failure in breeding or migration that can be of significance at a catchment's population scale, potentially leading to local extinction, or severe depletion in local or regional migratory fish populations.

7.5 Birds

It is difficult to determine the overall effect that industrial scale solar production may have on migratory bird populations. Few studies were found that document the impacts and these are short-term studies on individual plants (*e.g.*, McCrary *et al.* 1986). However, there is more documentation about some of the infrastructure that is associated with solar plants and the hazards that these pose to migratory birds.

Many of the impacts appear to be relatively limited for example, collisions with infrastructure, mainly for CPS. However, if the plants are sited on habitat or along migration flyways, they may have a significant impact at a population scale especially if the scale is substantial and situated in critical habitat. Factors such as poor visibility and adverse weather conditions at the time of migration can create periods of high hazard of collision with solar power plant infrastructure. Collisions may also occur with fences around plants, which may be a problem for species with a large body mass (bustards, cranes, swans, etc.).

In the case of CPS the mortality rate of birds, at an experimental heliostat solar power site, was estimated at 0.7-0.7% per week. The mortality was caused by collisions with infrastructure of birds were burnt if the passed the concentrated beam of solar energy. The plant was situated near ponds attracting many birds (review in Pearce-Higgins & Green 2014). Industrial solar plants (CPS, heliostats) may attract migratory birds and effectively lure them from their migration routes into areas of high hazard. Solar plants are often sites with available water, shimmering reflective surfaces, shade and lighting that can all be attractive to migratory birds. This can result in enhanced habitat availability for waterbirds but equally brings a risk of birds landing on surfaces that appear superficially like water. This affect may be enhanced if natural water sources are scarce, such as for waterbirds migrating over deserts or attraction to unsuitable areas/habitats. Photovoltaic plants are dark without reflection so it is unlikely that birds get attracted at night (Pearce-Higgins & Green 2014).

Solar power plants can also alter the function of the surrounding habitats. For example, the requirement for large amounts of water for some forms of solar plants may change the hydrology of a waterway and/or associated wetlands. Such habitats could be particularly critical in arid regions.

7.5.1 Mortality

The physical structures associated with CSP plants can represent a collision risk for flying birds, resulting in death. Bird mortality has been shown to occur due to direct collisions with solar panels, heliostats and solar collector towers. There is also evidence of incineration of birds that stray into the vicinity of the central receiver or when entering standby focal points (McCrary *et al.* 1986, Birdlife International n.d., Tsoutsos *et al.* 2005).

Pollution caused by the leaching of chemicals into cooling ponds and the wider catchment has also been identified as a potential risk of death to birds (Tsoutsos *et al.* 2005). Although there are no reports of this occurring, many of the chemicals used in transferring solar irradiance into heat and then electricity have potential to be toxic to animals should an accident occur where these chemicals leak into the environment.

Collision

Collision risks are influenced by many factors including the size and type of structures at the solar plant, the location of the plant relative to wildlife habitats and movement paths, and weather conditions. Some bird species, *e.g.*, nocturnal migrants, also appear to be particularly vulnerable to collision due to their behaviour and morphology. If the solar plant is within a migration route and species travel in flocks there is potential for individuals to collide. For rare species, collision rates may be of significance at the population scale.

The size of a structure has been found to have a significant influence on bird strikes. Some migratory birds appear to be less likely to strike towers with heights lower than 60 to 150 metres (Drewitt & Langston 2008). Some solar collection towers are higher than this. Fencing around PV arrays also represents a collision risk for some species. Migratory bird species with a large body mass are particularly at risk, including bustards, cranes and swans.

Pollution

There is no literature on the effects of soil, water or air pollution resulting from industrial scale solar plants on migratory species. However, it has been hypothesised that there are some pollution risks associated with their development and operation. Appropriate site management is likely to greatly reduce these risks.

Some of the pollution risks are generic and apply to any industrial development. These include pollution and runoff that occurs because of soil disturbance in the construction process and waste from the building of the plant and associated infrastructure.

Other pollution risks are more directly linked to the specific requirements of solar plants. Chemicals in heat transfer and cooling fluids may include substances that have a considerable negative impact on habitat if they leach into wastewater evaporation ponds or even local waterways in the catchment area. Contaminated liquids in hyper-arid regions could be detrimental to large numbers of migratory waterbirds if they affect wetland habitats in arid regions. These chemical leaks could be a significant risk in particular if a large proportion of a population is using the receiving waters of a leak, in which case impacts could be significant at a population scale. Other substances are a fire risk that could in turn alter habitats and directly affect migratory wildlife.

In the normal operation of solar plants, pollution from these sources would not be considered a high risk. At times when the plant malfunctions and when the coolant liquids need to be changed (every 2-3 years) there would be a higher risk of accidents (Tsoutsos *et al.* 2005, Birdlife International n.d).

Incineration and heat effects

Incineration and heat induced mortalities for birds around industrial scale solar plants represent a risk to migratory wildlife. Concentrated beams of solar energy and heat around central receiving towers can incinerate birds. When the heliostats are in standby mode they project their beams away from the central solar tower. This appears to be a particularly dangerous situation for flying birds (McCrary *et al.* 1986, Tsoutsos *et al* 2005).

The incineration of migratory species at CSP plants is not sufficiently documented to determine the magnitude of the problem and the effect it may have on migratory bird populations. In the McCrary *et al.* (1986) study in the Mojave Desert, it was found that 19% of bird deaths were from burning from the reflection from the heliostats in their standby positions. Nearly half of the 70 fatalities recorded over the 40-week study involved aerial foragers (swifts and swallows) appear to be more susceptible to this form of mortality. Swifts, swallows and similar species spend most of their time on the wing and their feeding behaviour may cause them to stray into the concentrated beams of energy (Tsoutsos *et al.* 2005, McCrary *et al.* 1986).

There is also potential for birds to be affected by excessive heat around the solar plant. Heliostat based technologies can create temperatures in excess of 1000 °C. Birds flying near or resting close to these areas of concentrated heat are likely to be negatively affected. No literature was found detailing the level of risk related to increased temperatures around CSP plants.

7.5.2 Disturbance: bird attraction to industrial scale solar power plants

Some of the characteristics of industrial-scale solar facilities are thought to attract migratory birds, effectively luring them into harm's way. Solar panels, mirrors and heliostats attract birds, as they appear to mistake them as water bodies. When they attempt to land on the water they collide with these structures and die. Waterbirds are particularly susceptible. In dry and desert locations where water is scarce, the reflective surfaces appear to be strong attractants that lure migratory species. The extent of the effect on populations of migratory species is unclear but for rare and threatened species, particularly those that move in flocks, it has the potential to be significant at a population scale.

The availability of water in ponds, the provision of shade from the infrastructure, the shimmering of the photovoltaic cells and heliostats, and the presence of lights are all reported as being attractants to birds (*e.g.*, Drewitt and Langston 2008, McCrary *et al.* 1986, Tsoutsos *et al.* 2005).

These attractive features may result in more birds being present around a solar plant than in the surrounding area. The solar plant sites may become ecological traps for some migratory species. Birds are attracted to the site because of real or perceived resources then they are subject to the range of mortality risks at the power plant. The siting of CSP plants in migratory pathways, especially in areas with low available water could lure significant portions of the population to sites where there is no water. The extra energy expended and lack of water could increase mortality with population scale impacts.

This process is well demonstrated by the Solar One solar energy power plant in the Mojave Desert, California. This early industrial scale CSP plant used solar tower technology with heliostats directed towards an 86 metre high tower. McCrary *et al.* (1986) found that birds were particularly attracted to the facility with many more species being found at the facility than in the surrounding area (107 species at the facility and less than 20 species in a similar ecosystem with none of the habitat features created by the plant). Many of the additional species were migratory bird species.

It was reported that birds were particularly attracted to Solar One because of a large, permanent, man-made water impoundment at the site. This was a particularly attractive feature to birds in the Mojave Desert as naturally occurring open water sources are rare and usually ephemeral. This would also be an attractant at other solar plants in other dry or desert areas where there is a water impoundment.

Polarised Light

Photovoltaic panels are a new source of polarised light in the landscape (Horváth *et al.* 2009). The large areas of reflective surfaces and polarised light in industrial scale solar facilities are believed to be confused with large water bodies by birds. Not only does this create a collision risk as birds attempt to land on the panels, it can also cause the disorientation of flying birds (*e.g.*, Tsoutsos *et al.* 2005, McCrary *et al.* 1986, Birdlife International n.d).

The impacts on migratory birds, especially in arid regions could be substantial. Disruption of their natural patterns of behaviour and luring birds to sites where there is no water or suitable habitat may greatly reduce their chance of a successful migration.

Light Traps

Light traps are a phenomenon that occurs when birds are attracted to lit areas and appear to become trapped within the lit zone. Once some birds enter the lit zone they remain flying within the light. Birds are known to be attracted to and disorientated by lights particularly on overcast, drizzly or foggy nights. It appears that migrating species are reluctant to leave the lit area and may collide with the structure or expend considerable amounts of energy, increasing risk of predation, starvation and reducing their chance of a successful migration. The magnitude of the effect on migratory birds is unclear. If CSPs are located in habitat for migratory species or in flyways lighting may lead to a significant impact. Night-migrating species are at particular risk.

Many migratory birds that fly at night appear to be attracted to and disorientated by lighting, particularly on cloudy nights. The mechanism for this response is unclear, but it is thought that the lightning obscures the visual cues for migration such as the location of the horizon, the moon and stars (Drewitt & Langston 2008, Travis *et al.* 2004).

Although no specific references were found to attraction to lighting at solar plants, if the solar plants are brightly lit at night it is reasonable to assume that lit structures at solar power plants are likely to cause the same problems for migratory birds as other lit structures. Lighting of the tall collector towers would seem to be particularly problematic. Warning lights on the top of buildings for airplanes to warn airplanes of their location can also disorient birds. Bright lighting also has the potential to attract insects, which in turn attract migratory bat species.

7.5.3 Habitat loss and degradation

Habitat loss and degradation are likely to be the largest impact of industrial scale solar power plants. The ecological significance of the impact will be site and scale specific. An assessment of the ecological value of the development site is vital, information to identify the risks to migratory wildlife, particularly its location in relation to migratory bird habitats and migration flyways (*e.g.*, Tsoutsos *et al.* 2005*,* Birdlife International n.d.). This will help to inform conclusions about the significance of the impact habitat loss will have on migratory wildlife.

As an example, in Europe, solar power plants tend to be located in grassland areas that are not suitable or are marginal for agriculture. As these areas have not been extensively disturbed, they are often those most favoured by grassland birds, including migratory species. It has been reported that grassland birds and species that specialise in open habitat such as bustards are particularly at risk of losing habitat when industrial scale solar plants are developed (BirdLife Europe 2011).

The assessment of cumulative impacts of other infrastructure in the area is also vital in assessing the effect of habitat loss.

Changes to habitat function due to infrastructure development may also alter the habitat values of a site. Changes to microclimate such as increased shading, changing water regimes and associated altered vegetation patterns are all likely to affect residents and migratory wildlife. These factors may cause indirect impact on breeding and resting animals by changing food sources (*e.g.*, seeds, insects, plants and animals) and also nesting structures for birds (Tsoutsos *et al.* 2005). There are some reports that bird species of grasslands and open habitats are particularly vulnerable to loss of core habitat through the siting of CSP plants in remnant indigenous grasslands that are not considered valuable for agriculture and therefore remain as depleted examples of once more extensive habitats.

Catchment Impacts

One of the main concerns in dry climates is the amount of water CSP plants require and the impact that this could have on catchments that already have very limited water. CSP plants can be high water users depending upon the plant design. Water may be required for cooling, steam powered electricity turbines and for cleaning the reflective surfaces. Changes may occur in local and regional hydrology due to extraction and storage of water, particularly in arid regions.

Reduction in available water particularly in dry areas may result in the loss of wetlands and water resources that are vital stopover sites for migratory wildlife. There may be significant losses from populations of migratory species from dehydration and exhaustion due to expending energy to visit sites where there is no longer habitat. Disruption to traditional migratory wildlife stopovers has the potential to have population scale impacts on species, particularly on rare and threatened species, if present.

One of the main areas considered to have great potential for CSP plants is North Africa. However, wet cooling systems are likely to be unsustainable in this water stressed environment (Damerau *et al.* 2011). Existing technologies that use dry or hybrid cooling systems are likely to make industrial solar plants a far less water intensive operation. These alternative cooling systems come at a cost premium but this needs to be balanced against the scale and risks of altering water regimes in habitats in arid regions.

7.6 Mammals

No information could be found regarding the effect industrial scale solar power plants have on migratory mammals. It is considered that factors such as locating solar plants on migratory pathways or between core habitat areas may potentially block mammal movement.

An alteration to the hydrology of areas due drawing large amounts of water from a catchment has potential to cause negative impacts to migratory mammals. These impacts are likely to be similar to be those found in migratory birds.

7.7 Other species

Large scale mortality of insects including Monarch butterflies have been observed during testing of the Ivanpah Solar Energy Generating System (ISEGS), California, in 2013 (USFWS 2013). It is unclear yet what exactly caused the mortality, but it may be related to the above mentioned elevated temperatures between mirrors and receiving towers. The mirrors may function as a funnel when the dead insects fall on them. The ecological effects of these mass insect mortalities have not been studied yet and may lead to greater levels of mortality than have been anticipated. In particular, dead insects are likely to draw insectivorous and omnivorous migratory songbirds and raptors, which may increase the risk of bird collisions and related mortalities (see §7.5).

7.8 Mitigation measures

The review document has been prepared in conjunction with a guideline document in which guidelines for siting, planning and mitigation are presented and prioritised. Within this review chapter, basic background information is presented. Although siting and mitigation can overlap they are as much as possible separated. The presented information is as much as possible based on literature unless stated otherwise, e.g. in case of mitigation suggestions.

As solar energy is relatively new and local, few studies on mitigation are available or not particularly related to solar energy but to infrastructure in general. The main on-site mitigation measure is pre-development assessment of potential locations by integrating spatial data on biodiversity value (including migration routes), solar energy potential and development potential (Cameron *et al.* 2012, Northrup & Wittemeyer 2013). This approach could prevent displacement and loss of migratory routes.

BirdLife Europe (2011) gives several management suggestions and enhancement opportunities, including for example:

- Placing of white strips along the edges of the panels, to reduce the similarity of panels to water, to deter birds and insects.
- Appropriate management of the space between and beneath solar panels. Good maintenance practices (such as confining vehicular access to defined tracks) can also minimise environmental impacts.
- Some CSP use 'dry' cooling technologies. Although more expensive, these can reduce the amount of water extracted from the local environment;
- For CSP technology, reflective surfaces which are parabolic (curved) in shape reduce the likelihood of skyward reflection, whereas flat heliostats have an increased risk of being reflective;
- Trough Receivers should use evacuated glass tubes or similar technology, to reduce heat loss, which results in low receiver temperatures which will not burn birds;
- Ensure evaporation ponds are not accessible to birds and other fauna, by using fencing and wire grid. This is to reduce the possibility of a) attraction b) drowning c) poisoning;

7.9 Positive effects

As research on the impacts of solar electricity plants on wildlife has been limited, examples of direct positive impacts have been hard to find, and are more obvious if solar energy technologies replace traditional power generation (Turney & Fthenakis 2011). This does not mean that positive impacts are not possible, only that they are not conspicuous or have not yet been described.

Notwithstanding this, the addition of water storage areas to the landscape at large scale solar plants in particular in arid regions has the potential to provide additional aquatic habitat for migratory wildlife. That said, if this comes at the expense of flows in natural waterways, some migratory species, such as fish, might be adversely affected.

The provision of additional perches for predatory birds may be beneficial for those birds but it may in turn put surrounding wildlife populations under greater predation pressure, ultimately leading to a decline in populations in the vicinity of this artificial habitat.

7.10 Gaps in knowledge

Based on background research for this document, it became very evident that few systematic studies of the impacts of solar power plants on wildlife had been undertaken, which has been noted in several recent reviews (Lovich & Ennen 2011, Turney & Fthenakis 2011, Northrup & Wittemeyer 2013). Therefore, predicting the impacts of such technologies on migratory wildlife, and migratory species in particular, is difficult. It is possible to hypothesise impact pathways based on ecological principles and common sense but very few of these have been investigated in any detail, let alone enough to form definitive conclusions about the scale of the risks and impacts.

For this reason, investment in monitoring the impact on wildlife in general and migratory wildlife in particular of a selection of solar power plants located in or near migratory wildlife habitats or migration routes is needed to demonstrate which impact pathways are important and require mitigation through design and operational changes.

7.11 Conclusions

In conclusion, it appears likely that solar power plant impacts on migratory species, including terrestrial mammals, birds, fish and insects, are likely to be localised and technology-specific (Lovich & Ennen 2011, Turney & Fthenakis 2011, Northrup & Wittemeyer 2013). Overall, impacts are likely to be containable if projects are located away from key habitats and migration routes of migratory species (*e.g.*, Cameron *et al.* 2012).

There is some evidence that the reflective surfaces of solar power plants attract waterbirds and insects and that habitat changes may also attract additional species, including predators to project sites.

Some solar technologies use a large amount of water and this can increase aquatic habitat availability for some waterbirds and insects. However, the impacts of heavy water extraction, if required, on the hydrology and ecology of affected waterways and wetlands needs to be considered carefully as it could ultimately reduce habitat for migratory wildlife (*e.g.*, waterbirds and fish). This is a particular concern in arid regions where such habitats are already heavily constrained by low water availability.

Solar power plants should avoid protected and sensitive sites, manage surrounding land for the benefit of wildlife, and limit the ecological disturbance created by installation and maintenance operations, as well as associated infrastructure such as fencing and power lines.

Damerau *et al. (*2011) concluded that the sustainability of CSP plants in North Africa is dependent on regulation and governance to ensure that ecologically sound development proceeds, tailored to the location and particular biophysical setting of the plants.

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8 Wind energy

A. Gyimesi, J. van der Winden, A. Patterson & M. van der Valk

8.1 Introduction

Wind energy is the kinetic energy of moving air. The primary method of harnessing wind energy is through the production of electricity with turbines. The commercial production of electricity through wind energy has only been viable since the early 1970s following technological advances and the support of governments.

Modern wind turbines have evolved from smaller predecessors and utilise sophisticated technology aimed at improving efficiency while largely still following the same basic form. The commonest design for commercial wind turbines uses a horizontal axis generator housed within a nacelle located atop a vertical tower and driven by three blades that rotate on the vertical plane. The nacelle can rotate on the tower to ensure that the blades always face into the wind. Currently new types are being developed such as vertical axis turbines (www.windcraftdevelopment.com) and airborne turbines. As such turbines are not yet in commercial production, the current review focuses on the usual models.

Offshore wind is still small compared with global onshore capacity, but it's growing rapidly. Their rapid expansion continues across Europe in particular. Outside of Europe, China and the USA have the highest number of offshore wind farms in various stages of development. In total there are 1085 offshore wind farms covering a total area of 130,393 km^2 (James 2013). Appendix 1 of James 2013 shows the full details for each of these offshore wind farms.

As technologies have advanced so has the size and generating power of wind turbines. This has largely been driven by the scale of economics with fewer larger turbines being needed to generate the same amount of electricity than with smaller turbines. Typical wind turbines have increased from a having a rotor diameter of 17 m (75 kW) in the 1980s to 70 m (1.5 MW) in the 2000s and 125 m (5 MW) in 2010 with plans for future turbines of 250 m in diameter (15 MW) already in existence. As rotor diameter increases so too does the height of the tower with nacelle heights increasing from 25 m above the ground in the 1980s to 70 m in the 2000s and 125 m in 2010. Although nacelle heights have increased this is not always relative to rotor size and the rotors may reach closer to the ground on some modern turbines than in older designs.

Wind turbines can be located singularly or in groups, commonly known as wind farms. Wind farms follow a variety of designs and layouts, which are largely dictated by landscape and economic limitations, although a minimum required distance between turbines exists. Designs can be broadly categorised into single turbines, lines and groups.

Terrestrial wind farms can consist of single turbines up to many hundreds, although are typically smaller than offshore wind farms. Offshore wind energy technology is relatively new compared to terrestrial wind energy. The scale of economics, particularly in relation to construction and maintenance, results in planned offshore wind farms consisting of many hundreds of turbines. One advantage of offshore wind farms is the potential for larger turbines to be used and the generally higher quality wind resource, whereas one disadvantage is the distance to the market.

As with other renewable energy technologies, wind energy has the potential to decrease greenhouse gas emissions and is considered to have a relatively small environmental footprint. However, as the number of plans for new wind farms increases, along with their size, the potential effects on the environment and ecological systems may increase and new issues may arise. The potential impacts of wind farms on ecological systems include habitat loss through disturbance or displacement, barrier effects and collision-related mortality. Underwater sounds during wind farm construction and electromagnetic fields have been noted as potential negative factors for marine life, whereas benefits to wildlife include the use of underwater structures as artificial reefs and sheltered breeding grounds.

Planning wind farms and impacts on wildlife

In many countries wind energy is a fast growing renewable energy source. The increase in energy production by wind energy leads to an increase of wind farms onshore and offshore. Europe is the leading continent in developing onshore, as well as offshore wind farms. No commercial-scale offshore wind energy developments currently exist in North or South America, however North American generating capacity from onshore wind energy is more than 50,000 MW and expected to increase (Pagel *et al.* 2013). As the targets for renewable energy sources increase, national governments started to provide national wind energy plans, guidelines and research programmes. Apart from the aims in terms of megawatts, several countries have selected areas suitable for wind energy production, started monitoring pilots and formulated legislation or policy for the implementation of wind energy in relation to wildlife. Also non-governmental organisations have published overviews and guidelines. Some examples are presented in Table 8.1.

Table 8.1 Examples of international and national wind farm planning, guidelines, post construction monitoring and research overviews from governmental (GO), non-governmental (NGO) and pan-governmental organisations.

GO/NGO	type	source
Country	***Initiatives***	
Netherlands	National onshore wind farm planning	*1*
Netherlands	Offshore Wind Energy pilot results, post construction monitoring, guidelines	*2*
Germany	Offshore Wind energy review, guidelines and planning	*3*
Belgium	Offshore impacts and future monitoring	*4*
Canada	National onshore wind energy guidelines	*5*
United States	World Bank Group Environmental, Health, and Safety Guidelines for wind energy	*6*
Scotland	National guidance for wind farms, impacts on birds, onshore, offshore	*7*
NGO initiatives		
Birdlife International	Migratory soaring birds project: guidelines, projects, reviews	*8*
IUCN	Identification of biodiversity risks of offshore wind energy	*9*
Pan-governmental initiatives		
EU	Guidance for wind energy developments	*10*
Bern Convention	Reducing impacts on habitats	*11*

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8.2 Impact matrix

The (potential) impacts of wind energy deployment are summarized in Table 8.2. The migratory species groups where impacts are likely to occur include bats, terrestrial and marine mammals, birds, fish, crustaceans and squid, which are discussed in more detail below. No direct impact is expected in reptiles and insects and these are excluded from the analysis.

The impact matrix summarizes the impacts of wind energy production on the relevant species *groups* (see above). Impacts can be extrapolated to species level (Table 1.1) when wind energy development coincides with the habitat of these species.

Table 8.2 Impact matrix wind energy and migratory species. Assessment of the (potential) impact of the wind energy technology on migratory species.

Process phase	Species group	Impact	Description of ecological impact	Spatial extent impact	Duration of impact	Magnitude of impact
Construction & Decommissioning	**Birds, Bats, Terrestrial Mammals, Sea Turtles, Monarch Butterfly**	Habitat loss and fragmentation, Disturbance/ displacement, Habitat degradation,	see table 2.1			
	Marine Mammals, Fish and Squid, Crustaceans	Mortality, Physiological effects, Habitat loss and fragmentation, Disturbance/ displacement, Habitat degradation, Habitat gain	Noise, especially pile driving, may cause behavioural changes up to 50 km away, Underwater noise has potential to cause auditory injury within 1.8 km, Construction noise may impact the ability of fish to communicate or navigate, Artificial reefs around wind turbines possibly provide higher prey availability and habitat, increased shelter and protection from currents, Individuals near the construction zone likely displaced, vibrations from pile driving, Natural habitat around turbine foundations permanently altered, see table 2.1			
Operation	**Birds**	Mortality	Collisions with rotating blades.	Regional	Long-term	II
		Barrier effects	Migrating seabirds have been shown to avoid offshore wind farms, thereby increasing their migratory distance (this is often negligible compared to total migration distance).	Local	Long-term	I
		Disturbance/ displacement	From shallow feeding areas offshore.	Local	Long-term	I
	Bats	Mortality	Collisions with rotating blades.	Regional	Long-term	II
		Disturbance/ displacement	No studies have documented clear disturbance effects. On the contrary, bats may be attracted to wind turbines.	Local	Long-term	I
	Marine Mammals	Disturbance/ displacement	Turbine noise during high wind speeds (unlikely to be significant).	Local	Short-term	I
	Fish	Physiological effects	Noise may decrease the effective range of sound communication.	Local	Long-term	I
			Electromagnetic field (EMF) from submarine cables may impact ability to orientate or communicate. Currently little evidence of effects of underwater cables.	Local	Long-term	I
		Disturbance/ displacement	Noise levels during high wind speeds can cause fish to leave the area within 4 km of the wind turbine; barrier effects from EMF on elasmobranchs.	Local	Long-term	I
		Habitat alteration	Changes in community structure such as increased densities of piscivorous fish species close to offshore wind turbine foundations.	Local	Long-term	I

Process phase	Species group	Impact	Description of ecological impact	Spatial extent impact	Duration of impact	Magnitude of impact
	Crustaceans	Physiological effects	Noise can increase time to metamorphosis for estuarine crabs megalopae compared to natural sounds or silence. A delay in metamorphosis may prevent megalopae from settling into suitable habitats and will result in them spending more time in the plankton which is likely to increase the high risk of predation. This could lead to lower recruitment of crab species in the vicinity of coastal turbines.	Local	Short-term	I
			Crustaceans are known to have the ability to detect electromagnetic fields such as those generated by submarine cables. No studies found for migratory crustaceans and submarine cables associated with offshore wind energy.	N/A	N/A	N/A
		Habitat alteration	Artificial reef effect at bases of offshore wind turbines may alter community structure of crustaceans in the area.	Local	Long-term	I

Spatial extent (size of area) of the impact (local/project area, regional/beyond the project area); Magnitude (I = Effects reported, but no apparent threat to populations, II = High impact, but with no significant impact on the overall species population, III = High impact increasing the risk of species extinction). See §1.2.3.for explanation of terms used.

A delay in metamorphosis may prevent megalopae from settling into suitable habitats and will result in them spending more time in the plankton which is likely to increase the high risk of predation. This could lead to lower recruitment of crab species in the vicinity of coastal turbines.

8.3 Construction phase

Effects during wind farm construction generally reflect those for other similar construction projects and include mortality, habitat loss and disturbance. The level and duration of the effects witnessed vary depending on ecological and environmental factors as well as the location, timing, duration, intensity and size of the project and the construction techniques and any mitigation measures employed. Although the construction phase is generally much shorter and more local than the operation duration of a wind farm, activity may be more intensive during construction and acute responses may be evident. Through a multi-site, multi-species analysis, Pearce-Higgins *et al*. (2012) showed greater impacts of wind farms on birds during construction than with subsequent operation. Figures given by the European Wind Energy Association (EWEA) indicate that construction time for a terrestrial wind farm can be between two months for a 10 MW wind farm to six months for a 50 MW wind farm. Offshore wind farms, which are generally larger, can take up to several years to construct.

Although details between specific wind farms vary, construction generally involves the creation of a foundation on which the tower is positioned, usually in stages, before the rotors are lifted into position. Construction practices differ between terrestrial and offshore wind farms, mostly in relation to the construction of foundations and are largely due to differences in environment and substrate. On land, foundations are primarily built out of concrete on which the tower is fixed. At many offshore and some terrestrial wind farms, foundations consist of piles that are driven into the substrate. Alternatively, anchored, freestanding or floating foundations can be used offshore, which eliminates the need to pile driving. Associated structures, particularly roads, can fragment habitat and may necessitate draining land. The effects may be greatest on fragile habitats such as montane and peatlands.

8.3.1 Mortality and physiological effects

Mortality as a direct result of the construction of a wind farm is expected to be extremely localised and restricted to slow moving or immobile species. Other species noted as being at risk include marine mammal and fish, which can suffer injury or death as a result of shockwaves during marine pile driving operations (Haelters *et al.* 2013. Lindeboom *et al.* 2011). These effects can be mitigated by warning sounds in order to scare animals away from the area prior to driving activity (Lindeboom *et al.* 2011).

Underwater noise associated with construction of offshore wind energy facilities has the potential to result in physiological effects – namely auditory damage – to migratory marine mammals in the vicinity of the activity (Madsen *et al.* 2006, Bailey *et al.* 2010, Simmonds *et al.* 2014, Bundesministerium fur Umwelt, Naturschuts und Reaktionssicherheit in prep). Pile driving operations associated with the installation of turbine monopiles is potentially the most significant activity in this regard (Carstensen *et al.* 2006, Madsen *et al.* 2006, Bailey *et al.* 2010). Bottlenose dolphins spp. were susceptible to auditory damage from underwater construction noise when within 100 m of the source (Bailey *et al.* 2010).

The effects on fish are incompletely understood (Haelters *et al.* 2013) although for larvae of the common sole (*Solea solea*) the noise effects seem limited (Bolle *et al.* 2011).

8.3.2 Habitat loss

The construction of new onshore and offshore wind energy facilities may result in the loss of breeding, post-breeding, stopover, and non-breeding (northern wintering) habitat of migratory animals (Fox and Petersen 2006, Arnett *et al.* 2007, NRC 2007). This effect is local, but the cumulative impacts of multiple developments may cause more significant losses to important bird habitat.

Onshore wind farms are typically positioned in open habitats meaning that the loss of closed habitats is often limited. In some cases however, the site may have to be cleared of certain vegetation or areas levelled to facilitate access to the site and the construction processes (NRC 2007). Specific impacts to a habitat could include changes in vegetative structure and corresponding fauna, and thus the food availability of other animals (Arnett *et al*. 2007). However, changes to habitat that make an area unsuitable for a particular species may also improve the quality of the habitat for another (Fox and Petersen 2006). Apart from the loss of habitat directly due to the positioning of the wind farm structures (wind turbines, cables, associated buildings, etc.) wind farm can also involve a temporary loss of habitat through the presence of machinery or more long-term loss or fragmentation through the construction of roads or facilities (Langston and Pullan 2004, Arnett *et al*. 2007, NRC 2007). The scale and duration of the effects will depend largely on the type of habitat and its regeneration capacity as well as the sensitivity of the species in question.

Habitat loss during the construction of offshore wind farms can be considered to be less of an issue as much of the construction traffic and activity occurs on the water surface; however it remains unclear how avoidance behavior of some species may result in effective loss of habitat during the construction and operational phases of offshore wind farms (Furness *et al*. 2013). Loss of seabed habitat due to the positioning of wind turbine foundations, anchors and jack-up supports are limited in area, and the lack of requirement for access roads in offshore areas limits the effects of habitat loss further. Of potential concern is alteration to sedimentation patterns due to construction of offshore wind farms in such a way that the causes alteration to the base of the food web on which ocean-foraging birds rely (Langston and Pullan 2004).

8.3.3 Disturbance

The use of heavy machinery during the construction of wind farms and associated activity has the potential to cause disturbance to a range of animals. Local animals may leave the immediate area altogether as a result of increased activity, while some may only be reduced in number. The specific affects from disturbance will depend on scale and length of construction activity as well as the species involved, time of year and location.

The construction of offshore wind farms is likely to influence some species more than others. Many mobile species such as seabirds, seaducks and marine mammals can respond rapidly by leaving the area. For instance, pile driving and other noise-generating activities associated with the construction of offshore wind energy facilities may cause disruptions to migratory marine mammals, including individuals relatively far from the noise source (Carstensen *et al.* 2006, Madsen *et al.* 2006, Bailey *et al.* 2010, Thompson *et al.* 2010, Haelters *et al.* 2013). Dähne *et al*. 2013, observed the displacement of harbour porpoises up to 10.8 km from the sound source during pile driving for the construction of a wind farm in the German North Sea. Higher densities of harbour porpoises at distances up to 50 km suggest that they move far from the disturbance.

Habitat use of offshore wind facility construction areas by marine mammals has been shown to change substantially, with harbour porpoises and harbour seals largely leaving such areas following the commencement of construction activities (Carstensen *et al.* 2006, Brasseur *et al.* 2010, Brandt *et al.* 2011).

The size of the zone of impact of noise-generating activities is influenced by several factors, including the low-frequency hearing abilities of the species potentially affected, on sound-propagating conditions (including water depth and seafloor type), and the presence of other noises (Madsen *et al.* 2006). For instance, the negative effects of pile driving on harbour porpoises were detectable to a mean distance of 18 km at a Danish offshore wind farm in the North Sea (Brandt *et al.* 2011) and 15 km at another wind farm in the Baltic Sea (Carstensen *et al.* 2006). In contrast, undersea noise from construction activities may cause disturbance or displacement effects up to 40 – 50 km away to harbour seals, Minke whales, bottlenose dolphins and other mid- and low-frequency hearing cetaceans (Bailey *et al.* 2010, Lindeboom *et al.* 2011).

Although the effects may exist over the entire construction period (Brandt *et al.* 2011), they are likely to be relatively marginal on the population level, unless the wind farm is situated in a particularly important feeding area or close to a breeding colony (Lindeboom *et al.* 2011).

Wind farm construction in terrestrial habitats has the potential to influence animals. For instance, Rocky Mountain elk (*Cervus canadensis nelsoni*) were found to experience some degree of disturbance as a result of the construction activities associated with a new wind energy facility in the central United States (Walter *et al.* 2006). Despite this displacement, the authors concluded that the population was not adversely affected by the development as determined by home range size and dietary quality. However, effects may not only occur during foraging and resting but also during breeding. This may result in lowered breeding success or failure. Such effects can be alleviated by planning activity outside of the breeding season.

8.4 Fish

Migratory fish species may be affected by the operation of offshore wind energy facilities, as well as by the transmission of power from those facilities. Many studies found in the literature search related to fish and offshore wind energy referred to Europe, which hosts numerous offshore wind facilities. Negative effects, although mostly local, are thought to occur during both the construction and operation phases. These vary from disturbance and physiological effects from noise, habitat alteration and effects from electromagnetic fields (EMF).

8.4.1 Mortality and physiological effects

Fish are magneto-sensitive and are known to use the geomagnetic field information for orientation. While there is evidence that fish, particularly elasmobranchs can detect the EMF generated by undersea cables from wind energy facilities, there is no suggestion that these impacts could lead to increased mortality or long-term physiological impacts (CMACS 2003, Öhman *et al*. 2007, Gill *et al*. 2009, Normandeau *et al*. 2011).

Noise from offshore wind facilities does not have a destructive effect on the hearing abilities of fish, even within a few meters of the wind turbine (Wahlberg & Westerberg 2005). However, such noise may cause a disruption in communication between fish by decreasing the effective range of sound communication (Wahlberg & Westerberg 2005).

8.4.2 Habitat loss

No large-scale effects to fish biodiversity have been found following establishment of offshore wind facilities compared with reference areas (Wilhelmsson *et al.* 2006). Fish abundance near wind turbines is often higher than in surrounding areas, however species richness and diversity are typically similar (Wilhelmsson *et al.* 2006). The fish population itself can differ strongly before and after establishing offshore wind facilities, because of habitat loss and the development of new different habitats.

8.4.3 Disturbance and displacement: habitat degradation

Wilhelmsson *et al.* (2010) suggested that any impacts on fish due to avoidance of wind farms are likely to be very local. This is supported by Kikuchi (2010), who indicated that noise generated from construction and operation activities of offshore wind energy facilities may cause local disturbance to migratory fish species. The ability of fish to detect sound from wind farms depends on the size and number of wind turbines, the hearing abilities of the fish species, background noise level, wind speed, water depth, and sea bottom characteristics (Wahlberg & Westerberg 2005). The detection range between three species ranged from 0.4 to 25 km (Wahlberg & Westerberg 2005).

Although it has been shown that fish within 4 km systematically avoid offshore wind turbines during periods of high wind speeds (Wahlberg & Westerberg 2005), Reubens *et al*. (2013) showed substantial attraction of fish to the artificial reefs around turbine bases.

EMF emitted by submarine transmission cables associated with offshore wind farms may be detected by some fishes, particularly eels and elasmobranchs. The current knowledge indicates that behavioural responses to EMF are species-dependent and somewhat unpredictable (CMACS 2003, Gill *et al*. 2009, Olsson *et al*. 2010, Normandeau *et al.* 2011). For these reasons, inferences on how this detection of EMF may influence habitat value or behavioural changes are speculative. While EMF from undersea cables does not appear to pose a threat to species in these habitats, the long-term impacts of these cables is not well understood.

8.5 Reptiles

Sea turtles are a long-lived taxon known to migrate up to thousands of kilometres throughout the world's oceans. The literature search did not find any studies examining the potential effects specifically of offshore wind energy development on sea turtles.

As there are currently no commercial-scale offshore wind energy facilities in the waters off North or South America, impacts to sea turtles from this renewable energy technology in this region are speculative. Sea turtles are a relatively difficult taxon to study, given their longevity and the vast distances they travel. While sea turtles can be found in nearly all oceanic regions of the world, they typically are not highly concentrated in the waters off of northern Europe, or commonly found nesting in northern Europe, where the vast majority of operational offshore wind energy facilities worldwide are located. These factors may account for the lack of literature studying the relationship between wind energy and sea turtles. However, sea turtles are known to have the ability to detect EMF, which may interfere with their navigational abilities (Normandeau *et al.* 2011, Yalçın-Özdilek & Yalçın 2012). EMF generated by undersea transmission cables is likely the most significant potential impact to sea turtles from wind energy development, and should be considered when siting future offshore wind facilities in areas of high concentration of nesting or migrating sea turtles.

Effects of nesting habitat loss caused by placement at or near beaches during the construction phase are possible but no examples could be found. The use of lights on onshore turbines might affect orientation of hatchlings as found for other infrastructure (*e.g.* Witherington & Martin 2003).

8.6 Birds

The effects on birds can mainly be categorised into collisions, disturbance to resting, feeding and breeding birds, and barriers to flying birds (Winkelman 1992a, c, d; Spaans *et al.* 1998; Drewitt & Langston 2006). Flying birds may collide with the rotor or accidentally the tower, which usually leads to immediate death or at least serious injuries. Effects of disturbance on resting, feeding and breeding birds can be limited such as changes in behaviour or physiology. But this can ultimately lead to loss of habitat suitability for the individuals. Turbines can also disturb flying birds. Basically this can be regarded as avoidance of obstacles and but ultimately the avoidance behaviour might be so strong that that roosting or foraging sites become unavailable.

Disturbance effects can ultimately be regarded as habitat degradation affecting reproduction, survival or distribution of birds. As this is related to the size and design of wind farms in the following sections the key process factors have been used to describe effects. Much of the research conducted in Europe regarding the impacts of offshore wind on migratory birds can be applied to potential future developments elsewhere: for example Fox & Petersen (2006) suggest a method to assess habitat loss from offshore wind farms.

8.6.1 Mortality

a. Introduction

The most direct effect of wind farms is undoubtedly when birds collide with wind turbines. In addition to direct collisions, birds can be violently forced to the ground by the turbulence in the wake of a turbine (Spaans *et al.* 1998; Drewitt & Langston 2008). Collision casualties have been reported from virtually all bird species groups. Nevertheless, some species are more prone to collide with turbines than others. In addition, collision rates vary largely among wind farms, caused by location and design. This results in variation in the level of impact.

b. Contributing factors and causes

Collision of birds with wind turbines is the most commonly studied aspect of wind energy developments. Bird collisions with onshore wind turbines are easily documented using carcass-searching techniques. Determining mortality rates at offshore wind energy facilities is much more challenging. The mean number of reported collision fatalities varies from 3.7 to 58 victims / turbine / year (Winkelman 1992a; Everaert & Stienen 2007; Thelander & Smallwood 2007). A review of North American studies found that fatality rates of night-migrating birds at onshore wind energy facilities ranged from <1 – 7 birds per turbine per year, with the highest rates in the eastern United States (Kerlinger *et al.* 2010). The total number of collision mortality in the United States is estimated at 140,000 to 328,000 birds annually at turbines (Loss *et al*. 2013).

An estimated 2,700 birds, many of which are protected under the Migratory Birds Treaty Act (MBTA) and 40% of which are raptors (Falconiformes, Accipitriformes), are killed each year at Altamont Pass Wind Resource Area (California, United States) alone (Smallwood & Thelander 2008). At a 354-turbine wind energy facility in the northern United States, an estimated 613 avian collision fatalities occurred each year. Of those, 91% of species were migrants, and 20% of those were local breeders (Johnson *et al.* 2002). Analysis of radar data from the same area indicated that approximately 3.5 million birds migrate over the facility each year (Johnson *et al.* 2002).

The number of fatalities depends on the risk of a certain individual (and species) to collide with a wind turbine (*i.e. collision risk*) and on the *flight intensity* (flux) through the wind park. These aspects are related on the one hand to ecological characteristics (*e.g.* species and their preferred habitat), on the other hand to technical characteristics of the wind farm (*e.g.* configuration of the wind farm and turbine types; (Ontario Ministry of Natural Resources 2011)). Considering migratory birds, flight intensity may be temporarily and locally high, but each individual passes the wind farm only once or twice per year. In contrast, birds at breeding, staging and wintering sites may repeatedly (*e.g.* two times per day) pass wind turbines (with the corresponding chance of collision) during commuting flights (Krijgsveld *et al.* 2009). Therefore, many birds have a higher chance to collide with a wind turbine during local flight movements than during their seasonal migration (Hötker *et al.* 2006; Rydell *et al.* 2012).

- Ecological differences

  Large, slow-flying and less manoeuvrable species generally have a higher *collision risk (*de Lucas *et al. 2008)*. Typical examples are large soaring birds depending on thermal streams during their migratory journey (Strickland *et al.* 2011). They have difficulties to actively avoid wind turbines. An additional problem is put forward for species that have a good sight sideways but have a poor sight to obstacles in front of them (*e.g.* soaring raptors), leading to low avoidance rates and thus higher collision rates (Martin 2010). Avoidance rates further differ among species groups, resulting in varying collision risk levels. Moreover, less experienced juveniles seem to have a high collision risk compared with adults (Drewitt & Langston 2008).

  Finally, flight height, which commonly differs among species and situations, defines to a large extent the *flight intensity* at rotor height. Some species generally travel just above the ground or water surface during migration or daily flights, and thus below the rotor height of modern wind turbines. A review of effects of offshore wind energy in Europe on migratory bird species found that flight height may be the most important factor influencing collision mortality risk, and that gulls (Laridae), White-tailed eagles (*Haliaeetus albicilla*), Northern gannets (*Morus bassanus*), and skuas (Stercorariidae) are at particularly high risk in Scottish waters (Furness *et al.* 2013). On the other hand, a large number of species normally travel well-above turbine height (but see point 4 for weather effects).

During migration, most of the birds pass the rotor height only during take-off and arrival, as most species migrate at high altitudes. However, many species frequent lower heights during local foraging or display flights at a breeding-, stopover or wintering site compared with migration altitudes (Drewitt & Langston 2008).

- <u>Location</u>

  The location of a wind farm is the most important factor in shaping flux (flight intensity) and collision risk (Powlesland 2009). Wind farms situated in migratory bottlenecks, close to or within important staging sites, have to reckon with a high *flight intensity* and consequent high collision rates (Rydell *et al.* 2012). This effect is clearly illustrated by the higher collision rates along shorelines due to large bird aggregations (Richardson 2000), compared with wind farms in an open landscape without features that explicitly concentrate migrating birds (Percival 2005; Hötker *et al.* 2006; Rydell *et al.* 2012). Such landscapes are agricultural fields, grasslands, and forested areas, that generally show similar fatality rates (Strickland *et al.* 2011).

  Wetlands and coastal lagoons can form staging or stopover sites for a large number of waterbirds, shorebirds, gulls and terns. Wind farms placed adjacent to such sites can cause high collision rates among birds that frequently carry out foraging flights (Hötker *et al.* 2006). *Collision risk* can also be higher along mountain ridges where migratory soaring birds (*e.g.* raptors, cranes, storks, pelicans) make use of thermal streams (Hötker *et al.* 2006).

- <u>Configuration of the wind farm</u>

  The configuration of the wind farm can influence the *number of birds that fly through or avoid* a wind farm. For migratory birds, a line of turbines perpendicular to the main migration direction is relatively the most detrimental. Larger clusters of wind turbines seem to be more easily detected and avoided (Hötker *et al.* 2006). For this reason, the number of collisions is not linearly correlated with the number of turbines in a wind farm, although in general it holds that the more turbines a wind farm comprises of, the more casualties can be expected.

The *risk of collision* decreases with increasing distance between turbines (Drewitt & Langston 2006; Hötker *et al.* 2006). A similar effect occurs when a corridor is provided between clusters of turbines.

- <u>Turbine type</u>

  Early generation wind turbines were small with a relative high rotation speed. Modern, large wind turbines have a larger rotor diameter and hence cover a larger surface area where birds may fly through. However, these turbines are often also higher (*i.e.* providing more space for birds to fly below the rotors), and their rotor speed is lower. As *flight intensity* is the highest close to the ground, and lower rotor speed may reduce *collision risk*, higher turbines may generate a comparable number of casualties to small turbines (Everaert 2003; Barclay *et al.* 2007; Krijgsveld *et al.* 2009). , although Loss *et al.* (2013) found evidence for higher collision mortality as turnbien height increases.

  For safety reasons, various lights are placed on wind turbines. These lights can attract a large number of nocturnally migrating birds, and thus increase *collision risk* (Hötker *et al.* 2006; Drewitt & Langston 2008). The conclusions of different studies are not unambiguous, but mostly point towards white and red lights (especially continuous instead of intermittent) having a larger attracting effect, compared with blue and green light (Drewitt & Langston 2008; Poot *et al.* 2008). However, in North-America no difference in fatality rates was found between turbines with and without aviation obstruction lighting (Kerlinger *et al.* 2010).

- <u>Visual and weather conditions</u>

  The most casualties are reported during circumstances with low visibility, such as night, fog or a low cloud ceiling (Langston & Pullan 2003; Powlesland 2009). This affects local birds just as birds on migration. During migratory flights, birds commonly travel well-above turbine height, but under such visual conditions they lower their flight height and may end up at wind turbine altitude (Langston & Pullan 2003; Drewitt & Langston 2008). A comparable effect is caused by headwinds. Migrating birds tend to fly lower in headwinds than in tail winds. Nevertheless, the *flight intensity* of migrating birds is both during poor visual conditions and headwinds relatively low (Rydell *et al.* 2012).

c. Species involved and magnitude of problem

The observed mortality effects of wind farm development on bird abundance and diversity are mixed, and may change dramatically, even between closely related species (Leddy *et al.* 1999, Garvin *et al.* 2011, Furness *et al.* 2013). Swans, geese and shorebirds collide relatively rarely with wind turbines, likely due to their strong avoidance reaction (Pettersson 2005; Larsen & Guillemette 2007; Winkelman *et al.* 2008; Fijn *et al.* 2012). High collision rates are reported for gulls, terns and some raptor species (Thelander *et al.* 2003; Hötker *et al.* 2006; Everaert & Stienen 2007). Raptors may be especially vulnerable to blade strikes by rotating turbines, possibly due to their specific foraging and flight behaviours (Hoover & Morrison 2005). Collision mortality of Bald Eagles and Golden Eagles is widespread in the United States (Pagel *et al.* 2013). Turkey Vultures, old world vultures and Red-tailed Hawks may also be disproportionally at risk of collision with rotating blades due to their specific flight behaviours (Garvin *et al.* 2011). For instance, Red-tailed hawks were the only one of 12 potential raptor species found during carcasses searches at a wind farm in Wisconsin, United States (Garvin *et al.* 2011).

One of the likely reasons put forward was that these birds, in search of food, concentrate more on the ground below them than the space in front of them (Krijgsveld *et al.* 2009; Martin 2010). In addition, hawks are more likely to perch during periods of low wind speeds and take flight during strong winds, when turbine blades are rotating faster (Hoover and Morrison 2005). Hawks also tend to glide along hillsides that face into the wind during periods of increased wind speeds, increasing the risk of colliding with turbines situated on the tops of such ridges (Hoover & Morrision 2005). These are also the bird species that show the smallest avoidance reaction to wind farms. Crows form an exception from this rule as having low avoidance rates and often flying within the rotor swept area, but also having a low collision rate (Hötker *et al.* 2006; Strickland *et al.* 2011).

Although the actual number of collisions may not be high, raptor fatality rates are relatively high compared to the number of individuals exposed to collisions (Strickland *et al.* 2011). In combination with their long life expectancy and a low reproductive rate, such large-bodied birds may experience population-level effects (*e.g.* vultures in Spain, White-tailed Eagles in Norway, Red Kites in Germany, Bald Eagles and Golden Eagles in the USA; Janss 2000; Lekuona 2001; Hötker *et al.* 2006; Carrete *et al.* 2009; Dahl *et al.* 2012; Bellebaum *et al.* 2013). Nevertheless, the highest collision rates among these birds are found outside the migration period: collision fatalities mostly take place during local flight movements (Hötker *et al.* 2006). During migration, due to their high flight intensity, songbirds suffer the highest number of collisions (Kunz *et al.* 2007). However, the number of casualties among these birds is usually relatively small compared with the magnitude of migrants passing the wind farm (Rydell *et al.* 2012).

d. Regional aspects

In general, the most crucial places for collisions are coastal and mountainous areas with intensive bird movements (Hötker *et al.* 2006). In Europe, two of the most critical sites seem to be Navarre and Tarifa in Spain, where large numbers of Griffon Vultures collide with wind turbines every year (Barrios & Rodriguez 2004; Lekuona & Ursua 2007; Ferrer *et al.* 2012). Many of the casualties occurred among resident birds. Nevertheless, these Spanish sites lie on one of the most important migratory routes for a large number of migrants crossing from Europe to Africa and are passed by high numbers of diurnally migrating raptors (Barrios & Rodriguez 2004). As well as their location at a key migration bottleneck the Tarifa wind farms are sited on slopes used by vultures to gain lift (Barrios & Rodriguez 2004). In North America, the Altamount Pass is a comparably well-known site for high mortality among raptors (Smallwood & Thelander 2008).

Wind farms placed in territories of raptors during the breeding season may lead to effects on the local population. For example, local Red Kite populations in Germany suffer from wind farm developments (Hötker *et al.* 2006). Also in Germany, but more so in Norway, White-tailed Eagles showed large mortality at some sites, with possible effects on the local population (Hötker *et al.* 2006; Dahl *et al.* 2012). But species differences are substantial as many raptor species are hardly affected by wind farms such as Hen Harriers (Erickson *et al.* 2002; Whitfield & Madders 2006). Comparably, wind farms close to or in wetlands, especially those nearby colonies of breeding birds (*e.g.* of terns and gulls) may cause high collision rates (Everaert & Stienen 2007).

8.6.2 Habitat loss: disturbance of resting, feeding and breeding birds

a. Introduction

Disturbance of birds by wind energy developments is less thoroughly studied than collisions. Likely also due to the less obvious effects that disturbance may cause, although these can have at least the same impact size on a population as collisions (Powlesland 2009). Moreover, effects can on the one hand occur directly due to the physical presence of the turbines, ranging from simply being a strange object in the landscape, to the movement or noise of the rotors (Birdlife Europe 2011). For instance, migratory birds were found to perch less often on the towers of operating wind turbines (1% of observed perch time) than non-operating wind turbines (22% of observed perch time), suggesting that the noise and/or movement of operating wind turbines causes disturbance and displacement of bird species (Smallwood *et al.* 2009).

Among direct effects disturbance caused by maintenance workers needs to be mentioned. In offshore situations this comprises also higher shipping traffic and in remote sites eventually helicopter traffic. On the other hand, indirect effects may also occur: due to the development of maintenance roads previously remote areas may become more accessible. Consequently, not only the infrequent visits by technicians may cause disturbance but also recreational activities may increase (Birdlife Europe 2011). All in all, disturbance effects may lead to a part of the habitat being lost for birds or at least used less intensively (Pearce-Higgins *et al.* 2009).

b. Contributing factors and causes

Disturbance effects may play a different role for migratory species on their breeding grounds and on their stopover or non-breeding sites, affecting foraging and resting behaviour. However birds can be affected during active (migratory) flights by avoiding wind farms. This will be discussed under barrier effects of wind farms later in this report. Therefore, in the following section the effects of disturbance mainly regard breeding, staging and non-breeding sites.

1. Ecological differences

   Breeding birds are less affected in their selection of territories by wind turbines, compared with feeding or resting birds at wintering or staging sites (Hötker *et al.* 2006). Avoidance distances are often used to measure the level of disturbance. These indicate small avoidance distances (maximally a few tens of meters up to 200 m) and slight decrease in breeding densities close to wind farms (Hötker *et al.* 2006; Pearce-Higgins *et al.* 2009). However, most of the studies on breeding birds were conducted on small songbirds or meadow birds. Generally, larger effects could occur by larger-bodied bird species (*e.g.* swans and geese) during the breeding period, but disturbance studies on such species are largely lacking (Hötker *et al.* 2006).

   In contrast, such larger species were more commonly investigated on wintering or staging grounds. These studies indicate an increasing avoidance distance with increasing body size (Hötker *et al.* 2006). Geese, ducks and waders have lower densities near wind turbines up to several hundred meters during the winter season (Hötker *et al.* 2006), but 600 m is widely accepted as the maximum disturbance distance (Langston & Pullan 2003; Drewitt & Langston 2006). Exceptions are Grey Heron (*Ardea cinerea*), birds of prey (*Falconiformes*), Eurasian Oystercatcher (*Haematopus ostralegus*), gulls, Common Starling (*Sturnus vulgaris*) and crows (*Corvidae*), which have comparable densities nearby wind farms (Hötker *et al.* 2006).

2. Location

   Species living in environments with few vertical structures (wetlands, grassland areas and offshore habitats) have the highest avoidance distances (such as geese, Common Scoter, Red-throated Diver, Gannet) (Percival 2005; Drewitt & Langston 2006, Krijgsveld *et al.* 2011). For instance, grassland areas >180 m from operating wind turbines were found to support a greater diversity of grassland birds than areas <80 m from wind turbines (Leddy *et al.* 1999). This effect may not be consistent among different species, however. Some grassland birds show no evidence of disturbance or displacement from operating wind turbines, while others, such as the Le Conte’s sparrow (*Ammodramus leconteii*), are found in significantly lower densities near wind turbines (Stevens *et al.* 2012).

3. Configuration of the wind farm

   Obviously, the size of the wind farm defines the area that is potentially disturbed. Just as with collisions, a larger distance between turbines seemed to have a smaller disturbing effect on birds (Hötker *et al.* 2006; Reichenbach & Steinborn 2006).

4. Turbine type

   In case of birds at their breeding sites, the disturbing effect of early-generation, small wind turbines seems to be comparable or even larger compared with modern, large wind turbines (Hötker *et al.* 2006). The reason is likely that the moving rotor blades of modern turbines are positioned higher and move slower. In contrast, due to their size, large turbines seemed to have a more disturbing effect on birds on their wintering or staging sites (Hötker *et al.* 2006).

c. Species involved and magnitude of disturbance

Large disturbance effects were found among birds that live in remote offshore areas (Leopold *et al.* 2011, Krijgsveld *et al.* 2011, Rydell *et al.* 2012, Vanermen *et al.* 2013). Either at their breeding or wintering sites, these birds are not accustomed to large vertical objects in their habitat and avoid turbines at relative large distances. Behavioural effects on divers, Northern Gannets, Common Scoters, Common Guillemots and Razorbills was shown to take place up to 2 – 4 km from the wind farm (Leopold *et al.* 2011, Krijgsveld *et al.* 2011, Petersen *et al.* 2006). Similarly, birds of open habitats, such as waterbirds (*e.g.* geese *Anserini* and Eurasian Wigeon *Anas penelope*) and meadow birds (*e.g.* Common Golden Plover *Pluvialis apricaria*, Lapwing *Vanellus vanellus*, Meadow Pipit *Anthus pratensis* and Wheatear *Oenanthe oenanthe*), show relatively substantial behavioural reactions to turbines (Hötker *et al.* 2006; Pearce-Higgins *et al.* 2009).

Whether birds can habituate to the presence of wind farms remains to be determined (Hötker *et al.* 2006; Madsen & Boertmann 2008). Some studies reported decreasing avoidance distance with increasing time since operation (a sign of habituation; Petersen *et al.* 2006), while others showed declines in bird numbers with time (*i.e.* more and more birds leaving the area and low immigration rates; Stewart *et al.* 2005; Hötker *et al.* 2006; Stewart *et al.* 2007).

d. Regional aspects

The largest disturbance effects are found in open landscapes (Hötker *et al.* 2006; Reichenbach & Steinborn 2006). Therefore, these effects are not restricted to certain areas in Europe but can occur virtually anywhere. Currently, documented incidents of loss of habitat due to disturbance occurred at offshore sites in the North Sea. Here foraging and resting sites of *e.g.* seaducks were lost due to wind farm development (Guillemette *et al.* 1998).

8.6.3 Barrier effects

a. Introduction

Disturbance of flying birds is likely the least systematically studied effect of wind farms on flying birds (Langston & Pullan 2003; Fox *et al.* 2006). Disturbance may cause birds avoiding the whole wind farm (*i.e.* macro-avoidance) or individual wind turbines (*i.e.* micro-avoidance). In extreme situations, such disturbance may lead to loss of roosting or foraging sites as they become completely unavailable to birds, in which case wind farms become a real barrier to bird movements (Drewitt & Langston 2006; Rydell *et al.* 2012).

There are currently only a few examples of such extreme cases (Gove *et al.* 2013). More commonly, due to the adjustment of the flight route, birds have to count with longer flight distances and a consequent increase in flight costs and travel time (Birdlife Europe 2011; Rydell *et al.* 2012). Regarding migratory birds, this is considered with the current smaller scale generation of wind farms, to be negligible compared to the generally high costs of the total journey. Nevertheless, in areas where numerous large-scale wind farms are situated in intensively used migration routes, this can lead to considerably higher energetic costs to birds (Masden *et al.* 2009).

b. Contributing factors and causes

Disturbance of flying birds all depends on the avoidance rate of bird species, but may play a different role for migratory species during the journey and on the breeding, stopover or wintering sites. During active migratory flights, wind farms may be situated at locations previously being part of the migration route. When avoiding these sites, birds may have to considerably adjust their migration route (Masden *et al.* 2009). Wind farms at breeding, stopover or wintering sites of migratory birds may cause avoidance reactions during commuting flights but may also form a barrier so that roosting or foraging sites become unavailable.

- Ecological differences

  There is a large difference in avoidance rate among species (Hötker *et al.* 2006). Birds of open habitats (marine areas, wetlands and shorelines) show the largest reaction. In contrast, other (commonly smaller-bodied) species seem to have less fear of a wind farm and take more risk by flying between turbines (Garthe & Hüppop 2004; Desholm & Kahlert 2005; Drewitt & Langston 2006).

- Location

  The most considerable disturbance effect of birds during migratory flights may take place at large wind farms in intensively used migratory corridors. For example, in offshore situations birds initiated avoidance reactions sometimes kilometres from the wind farm (Desholm & Kahlert 2005; Larsen & Guillemette 2007). Such avoidance reactions can increase travel costs or in extreme cases can lead to the adjustment of the migration route.

- Configuration of the wind farm

  Barrier effects are expected mainly at wind farms of large clusters or long lines. Nevertheless, for birds with a strong avoidance rate even smaller clusters or shorter lines can have a strong disturbance effect.

- Turbine type

  Flying birds seem to show stronger avoidance reactions to modern, large wind turbines (Hötker *et al.* 2006). Therefore, the chance that such turbines cause disturbance effects or form a barrier is higher, compared with small turbines. Often, these latter are also avoided more easily by slightly raising the flight height, which leads to only marginal additional travel costs.

- Visual and weather conditions

  Avoidance reactions of the same species may be different during daylight and night-time. During daytime and in good visual conditions birds may initiate an avoidance reaction farther from the wind farm (Allison *et al.* 2008). Therefore, often a slight correction of the course is adequate to avoid the wind farm. In case reactions take place just before the wind farm, avoidance may be more abrupt and lead to stronger corrections of the flight course (Masden *et al.* 2009).

c. Species involved and magnitude of problem

Species with the strongest avoidance reaction are among waterbirds and seabirds (Hötker *et al.* 2006; Rydell *et al.* 2012). These birds prefer open habitats and are less habituated to vertical structures. Swans, geese, ducks and shorebirds are commonly reported to adjust their flight routes to avoid wind farms (Pettersson 2005; Drewitt & Langston 2006; Dirksen *et al.* 2007). For instance, Common Eiders showed avoidance reactions already at 1 – 2 km distance from a wind farm (Larsen & Guillemette 2007).

In addition, some large birds also show strong avoidance reaction to wind farms. For example, Common Cranes adjusted flight course at a distance of 0.7 – 1 km from a wind farm. The flight formations that fell apart during avoidance were recovered only 1.5 km behind the wind farm (Von Brauneis 2000). However, other larger-bodied birds (*e.g.* Common Cormorant, Grey Heron, raptors and gulls) were less sensitive or less willing to change their migration direction (Hötker *et al.* 2006).

d. Regional aspects

The largest avoidance reactions are reported from offshore habitats, in Europe mostly from the North Sea (Rydell *et al.* 2012). Currently, wind farms in Europe are commonly limited to a size of a few dozens of wind turbines. Therefore, barrier effects are not considered to be detrimental yet (Drewitt & Langston 2006).

2. Summary

The effects of onshore and offshore wind energy developments differ between species groups (Table 8.3).

Table 8.3. Effect on species groups of wind turbines based on the reviews of Hötker et al. (2006), Garthe & Hüppop (2004), Furness et al. (2013). Krijgsveld et al. (2011) and Powlesland (2009), supplemented with information from this review and expert judgement, the effect sizes are categorized as follows:

0 = no effects reported or likely to take place;

I = effects reported or are likely, without threat to the population;

II = regionally or locally high effects known, possible impact on a population.

Bird families in Europe vulnerable to wind farm development	**Collisions**	**Disturbance**	**Barrier effects**	**Key areas in Europe**
Loons (*Gaviidae*) and Grebes (*Podicipedidae*)	I	II	I	North Sea
Shearwaters, Petrels (*Procellariidae*)	I	0	0	
Boobies, Gannets (*Sulidae*)	0	II	I	North Sea
Pelicans (*Pelicanidae*)	I	0	0	
Cormorants (*Phalacrocoracidae*)	I	0	0	
Herons, Bitterns (*Ardeidae*)	I	0	0	
Storks (*Ciconidae*)	II	0	I	Germany
Ibisses (*Threskiornithidae*)	I	0	0	
Flamingos (*Phoenicopteridae*)	I	0	0	
Ducks, Geese, Swans, Mergansers (*Anatidae*)	I	II	II	German, Danish & Dutch wetlands
Raptors (*Accipitriformes and Falconiformes*)	II	0	II	Spain, Portugal, Germany, Norway
Partridges, Quails, Grouse (*Galliformes*)	I	II	0	Germany
Rails, Gallinules, Coots (*Rallidae*)	I	I	0	
Cranes (*Gruidae*)	I	I	II	Germany
Bustards (*Otidae*)	I	I	I	
Shorebirds / Waders (*Charadriidae* + *Scolopacidae*)	I	II	II	North Sea coast
Skuas (*Stercorariidae*) and Gulls (*Laridae*)	II	I	II	North Sea coast
Terns (*Sternidae*)	II	I	II	North Sea coast
Auks (*Alcidae*)	I	II	II	North Sea
Sandgrouse (*Pteroclididae*)	0	I	0	
Pigeons, Doves (*Columbidae*)	I	0	I	
Cuckoos (*Cuculidae*)	I	0	0	
Owls (*Strigiformes*)	I	0	II	
Nightjars (*Caprimulgidae*) and Swifts (*Apodidae*)	I	0	I	
Hoopoes (*Upudidae*) and Kingfishers (*Alcedinidae*)	I	0	I	
Bee-eaters (*Meropidae*)	I	0	I	
Rollers (*Coraciidae*)	I	0	I	
Woodpeckers (*Picidae*)	I	0	I	
Ravens, Crows, Jays (*Corvidae*)	I	0	0	
Medium-sized and small songbirds (*Passeriformes*)	I	II	I	Meadows and grasslands

8.7 Bats

The impacts to migratory bat species from wind energy developments are similar to the impacts to birds. Direct mortality of bats at North American and European onshore wind energy facilities has been widely documented.

The effects of the increasing number of onshore wind facilities in North America on bats are compounded by widespread mortality in the eastern half of the continent as a result of white-nose syndrome (WNS), a highly-contagious fungal infection that has caused sharp declines in bat populations throughout the region.

Future offshore wind energy development in the Northern Hemisphere may also cause negative impacts to migratory bat species, which are known to fly offshore during part of their migration. Little work has been done to study the impacts of existing offshore wind energy facilities in other parts of the world on migratory bat species.

8.7.1 Mortality

Mortality of migratory bat species at onshore wind energy facilities may occur during the operational phase (due to collisions with, or barometric trauma from, rotating blades or collisions with towers) and during the transmission phase (due to collisions with electrical lines) of wind energy development. Barotrauma is a phenomenon in which abrupt and extreme changes in atmospheric pressure cause tissue damage to air-containing structures (such as lungs) in the bodies of bats that causes internal bleeding and, potentially, death. Impact trauma from direct collision and barotrauma are the two leading theories to explain the high fatality rates of migratory bats around operating wind turbines. While some studies (Baerwald *et al*. 2008, Grodsky *et al*. 2011) suggested that barotrauma was responsible for a significant fraction of turbine-related deaths, more recent research that used advanced forensic pathology (Rollins *et al*. 2012) and computational fluid dynamics simulations (Houck 2012) indicate that impact trauma might not be responsible for the vast majority of turbine-related bat deaths and

Maple Ridge Wind Farm, Lewis County, New York, United States. Photo credit: Argonne National Laboratory, US Dept. Of Energy.

that barotrauma is likely a minor etiology (National Renewable Energy Laboratory, 2013).

Bat fatalities at onshore wind energy facilities are widespread and often extensive, but are also highly variable and intermittent (Kunz *et al.* 2007, Arnett *et al.* 2008, Rydell *et al.* 2010a, Niermann *et al.* 2011, EUROBATS 2013). A study of bat collision at an 89-turbine facility in the central United States estimated 400 - 650 bat fatalities per year, most of which were migratory tree bats (Jain *et al.* 2011).

Facilities along forested ridges in eastern North America experience higher fatality rates than facilities in the grasslands of the western part of the continent (Kunz *et al.* 2007). In Europe, fatality rates of up to 20-40 bats per turbine per year have been recorded although 1-3 is more common (Rydell *et al.* 2010a). Most casualties are migratory species (Dürr, 2013, EUROBATS 2013).

Time of year and meteorological conditions appear to be significant predictors of bat fatality rates at onshore wind energy facilities. Bat fatalities rise as bat activity increases during late summer and early autumn, the migratory period for many bat species (Arnett *et al.* 2008, Baerwald & Barclay 2011, Jain *et al.* 2011, Behr *et al.* 2011a, b, Rydell *et al.* 2010a). Bat activity increases during periods of low wind speed and warm ambient temperature (Horn *et al.* 2008, Baerwald & Barclay 2011, Behr *et al.* 2011a, b, Rydell *et al.* 2010a), making these weather conditions more dangerous in terms of bat collision with wind turbines.

Increased moon illumination and falling barometric pressure are also positive predictors of bat fatalities (Baerwald & Barclay 2011). Fatality rates have also been documented to increase immediately before and after the passage of storm fronts (Arnett *et al.* 2008). Bat mortality may be linked to large-scale nocturnal insect migration (Rydell *et al.* 2011b).

In North America as well as Europe, most of the dead bats belong to a small number of species that belong to the suite of fast-flying aerial hawkers (lasiurine, nyctaloid, pipistrelloid species) (Arnett *et al.* 2008, Dürr 2013, EUROBATS 2013, Kunz *et al* 2007, Rydell *et al.* 2010a).

Specific behaviours of bats may increase risk of collision mortality. Bats may approach rotating and non-rotating wind turbines with repeated fly-bys. At operational turbines, bats may follow or become trapped in blade-tip vortices, often resulting in collision (Horn *et al.* 2008). Turbine lighting, or the lack thereof, has not been shown to influence bat mortality (Arnett *et al.* 2008, Jain *et al.* 2011), however the presence of lights at a wind energy facility may attract insects, and in turn, insectivorous bat species.

Barclay *et al.* (2007) conclude that proportionally more bats get killed at higher towers. Rotor diameter was not found to be of importance. Rydell *et al.* (2010a) found that both tower height and rotor size were contributing to higher bat mortality. In both reviews, data from different sources were used. In a large study in Germany however, in which all wind farms were researched using the same protocols and turbine types were the same, no clear effect of tower height could be found (Niermann *et al.* 2011).

Barclay *et al.* (2007) and Rydell *et al.* (2010a) found no relation between fatality rate and minimum distance between the tip of the rotor and the ground. This is surprising, as several reports show that bat activity is consistently lower when measured at higher altitudes (*e.g.* Albrecht & Grünfelder 2011, Bach *et al.* 2012, Behr *et al.* 2011a).

Rydell *et al.* 2011b suggest that bat mortality is related to large-scale nocturnal insect migration, which may take place in air layers within the rotor-swept area of larger turbines.

Wind turbines in large wind farms do not kill more bats than those operating in smaller units or solitarily (Rydell *et al.* 2010).

8.7.2 Habitat loss and degradation

Migratory bat habitat loss and degradation has not been documented in the literature as an impact of the construction or operation of wind energy facilities. However the effect is likely at most cases negligible. Some degree of habitat degradation and fragmentation may occur due to changes in vegetation structure as a result of land clearing for the installation of turbines and associated infrastructure, but the effect is likely negligible. These are mainly effects during the construction phase.

8.7.3 Habitat degradation through disturbance

Bat activity has been shown to be relatively equal between sites with and without operating wind turbines (Jain *et al.* 2011), suggesting that the presence of wind energy facilities do not cause significant disturbance or displace of bat species. In fact, it is hypothesized widely that bat mortality is relatively high because bats are attracted to rather than disturbed by wind turbines (Cryan & Barclay 2009).

8.8 Other species

8.8.1 Insects

The primary migratory insect species considered for this report was the monarch butterfly (*Danaus plexippus*). Monarch butterflies are known to migrate several thousands of miles over multiple generations from the breeding grounds, primarily in eastern and central United States and Canada, to the wintering grounds in Mexico (Meitner *et al.* 2004). However, very few studies exist that examine the potential effects of onshore or offshore wind energy development on migrating monarch butterflies.

One study postulated that wind currents created by rotating turbine blades may be sufficient to sweep away approaching butterflies before collision with the turbine (Grealey & Stephenson 2007). The authors found no evidence that butterfly mortality or other potential impacts to butterflies, including monarchs, are of concern at commissioned wind energy facilities. The presence of rare butterfly habitat is nevertheless identified in the study as an important consideration during the siting phase of wind farm development.

8.8.2 Crustaceans

Potential impacts to migratory crustacean species from wind energy development are wholly restricted to the offshore environment. As there are currently no operational commercial-scale offshore wind energy facilities in the waters of North or South America, little information is available regarding potential effects to this taxon from offshore wind in this geographic region. Very few studies were found that examine the relationship between offshore wind energy development and migratory crustacean species in general.

No studies were found that specifically addressed direct mortality of migratory crustacean (Crustacea, in part) species as a result of offshore wind energy development. However, some work has been done to test the effects of electromagnetic fields (EMF) generated from undersea cables on crustaceans and other taxa. Namely, the effects of EMF generated by undersea transmission cables may impact magneto-sensitive migratory crustacean species, however no direct evidence of such impacts exists (Normandeau *et al.* 2011).

Migratory crustaceans such as lobsters (Nephropidae) may experience reduced orientation and navigational capabilities in the immediate vicinity of undersea cables, which could impact migration (Normandeau *et al.* 2011). In addition, one study documented potential physiological effects of offshore wind turbine noise on crustaceans (Pine *et al.* 2012). In a laboratory experiment, the time to metamorphosis of the megalopae of two estuarine crab species (non-migratory) was significantly increased when exposed to offshore wind turbine noise, compared to silence or natural sounds.

Degradation of migratory crustacean habitat may be an impact of offshore wind energy development, although it is likely a negligible one, and the literature review did not result in the discovery of any studies quantifying this impact.

8.8.3 Terrestrial and marine mammals

Marine mammals

Migratory marine mammals may be affected by the operation of offshore wind energy facilities. While no such facilities currently exist in the waters off of North and South America, some work has been done studying the effects of offshore wind energy on marine mammals in Europe. Many species of marine mammals found in European waters are also found in the Western North Atlantic off of North America; it is likely that the documented impacts of offshore energy on European marine mammals can be applied to potential future offshore wind developments in North America.

Three main classes of effects of offshore renewable energy generation have been repeatedly identified in reviews of their potential impacts on marine mammals. These are noise, risks of collision, and changes in the availability of the animals' habitats (Thompson *et al.* 2013).

1. Noise

Noise will be generated during construction, operation and decommissioning of the wind farms.

The noise levels arising from pile driving varies depending on the type and diameter of the pile, the ground conditions and the method of pile driving, which may be 'impact' or 'vibro' (vibration). Studies undertaken during the construction of existing wind farms have recorded noise source levels of between 243 dB re 1 Pa@1 m and 257 dB re 1 Pa@1 m depending on the pile diameter (Nedwell *et al.* 2007a) and cover a bandwidth from 20 Hz to 20 kHz with a major amplitude of 100 – 500 Hz (OSPAR, 2009). Noise from piling can be detected above ambient noise levels up to 25 km from source and for larger diameter turbines up to 100 km from source (Nedwell *et al.* 2007a).

Measurements from operating wind farms have reported levels of sound of 125 dB re 1µPa at around 180 Hz and between 100 and 110 dB at frequencies up to 1 kHz for mid to high frequency pinnipeds at a range of 83 m (Mainstream Renewable Power, 2013). Temporary Threshold Shift (TTS) may potentially occur within about 5 m of the turbine (SMRU, 2012). Predicted zones of audibility for odontocetes are predicted to be very localised and less than 1 km or even less than 100 m due to low source levels and restricted range of frequencies (Thomsen *et al.* 2006; SMRU, 2012). For species with better low frequency hearing, *i.e.*, seals and baleen whales then they may be able to detect operating wind turbines between 60 m and 6.4 km (SMRU, 2012).

The range at which marine mammals may be able to detect sound arising from offshore activities depends on the hearing ability of the species and the frequency of the sound. Pinnipeds (seals) are likely to be more sensitive to sounds below 1 kHz than harbour porpoises, which are in turn, more sensitive than bottlenose dolphin or baleen whales to low frequency sound. Other factors which may affect the potential impact sound may have on marine mammals includes ambient background noise, the effect of which can vary depending on water depth, seabed topography and sediment type. Natural conditions such as weather and sea state and other existing sources of human produced sound, such as shipping, can reduce the auditory range (Mainstream Renewable Power, 2013).

Several studies to assess the effects of noise related to offshore wind farms on marine mammals have been summarised in James (2013) and Thompson *et al.* (2013) including:

- McConnell *et al.* (2012) used high-resolution Global positioning system (GPS) telemetry tags to study movements of harbour and grey seals in southern Denmark. Seals were tagged at haul-out sites (where seals come to land) within 10 km of two wind farms: Nysted and Rødsand II. The results were compared with similar data collected in 2009. Both species frequently transited from the haul-out sites through the two nearby wind farms. Visually, there was no obvious interruption of travel at the wind farms' boundaries. Interactions with wind farms were assessed using residence times within wind farm zones, comparison of path speed and movements inside and outside the wind farms and the proximity of individual locations to individual turbines. No significant effect of the wind farms on seal behaviour was detected. This is in accord with another local study (Edren *et al.* 2010) of haul-out counts that concluded that the wind farms had no long-term effect on the local seal population trends.

- A study conducted in the Dutch Egmond aan Zee offshore wind farm entailed two periods of monitoring acoustic activity at the wind farm site and at two reference sites (Scheidat *et al.* 2011). The study covered the preconstruction/baseline period (2003-2004) and an operational period (2007-2009). Porpoise acoustic activity increased during the operational period when compared to the pre-construction baseline. However, there was an overall increase in porpoise abundance in Dutch waters over the last decade. Porpoise activity was significantly higher inside the wind farm than in the reference site. The authors suggest that this apparent increase in porpoise activity within the operating wind farm may indicate an attraction effect due to increased food availability inside the wind farm (reef effect) and/or a sheltering effect with reduced levels of disturbance from vessels within the wind farm compared to the heavy ship traffic in adjacent areas of the southern North Sea.

- Bailey *et al.* (2010) related the sound levels from installation of 5MW turbines to noise exposure criteria for marine mammals to assess possible effects. They estimated that bottlenose dolphins could suffer auditory injury but only within 100 m of the pile driving. They also estimated that behavioural disturbance, defined as any modifications in behaviour, could have occurred up to 50 km away. For Harbour porpoise the distance at which injury was perceived was 1.8 km (Thomsen *et al*. 2006).

- Tougaard *et al.* (2009) estimated that during piling operations at Horns Reef, porpoises were significantly disturbed and may have been excluded from the construction area for up to 17% of the time over a five-month period during which 80 foundations were installed. In a follow up study Brandt *et al.* (2011) monitored porpoise vocalisations during construction of the Horns Rev II offshore wind farm in summer 2008. Porpoise acoustic activity dropped to zero for 1hr after pile driving and stayed below normal levels for up to 72 hours at a distance of 2.6 km from the construction site. A negative effect was detectable out to a mean distance of 17.8 km and within 4.7 km the recovery time exceeded the interval between pile driving bouts. The longer recovery periods meant that porpoise activity was reduced over the entire five-month construction period, which has the potential to encroach into the breeding season.

- At Nysted, the main noise generating activities during construction were dredging and backfilling of gravity foundations. However some piling activity (1.5 to 10 hours per day over a 25 day period) occurred for installation of sheet piles around one turbine foundation (Carstensen *et al*. 2006). Harbour porpoise acoustic activity was monitored by acoustic data loggers (T-PODs) in a structured Before-After-Control-Impact (BACI) experiment. A significant decrease in detection of porpoise clicks relative to the pre-exposure baseline period was seen in response to general construction noise (Henriksen, *et al*. 2003; Carstensen *et al*. 2006; Tougaard *et al.* 2005). Mean waiting times, defined as the period between two consecutive encounters of echolocation activity, increased from 6 hr in the baseline period to three days in the wind farm area during the construction period with an apparently greater increase in waiting times (4 hr to 41 hr greater) during piling operations compared to general construction activities. The effect was apparently widespread although the increase within the wind farm was six times larger than changes observed in a reference area 10 km away (Carstensen *et al*. 2006; Tougaard *et al.* 2005). Activity apparently returned to normal levels compared with the overall construction period some days after the pile driving ceased.

- Thomsen *et al.* (2006) estimated that both harbour porpoises and harbour seals are likely to be able to hear pile driving blows at ranges of more than 80 km. They concluded that behavioural responses are possible over many kilometres, perhaps up to ranges of 20 km and that masking might occur in harbour seals at least up to 80 km. Using potential hearing damage criteria of 180 dBrms re 1 μPa for cetaceans and 190 dBrms re 1 μPa for seals they estimated that hearing loss might be a concern, at 1.8 km in porpoises and 400 m in seals. Thomsen *et al.* (2006) also concluded that severe injuries in the immediate vicinity of piling activities cannot be ruled out.

- David (2006) estimated that pile-driving sound would be capable of masking vocalisations by bottlenose dolphins within 10-15 km and weak vocalisations up to 40 km. For operational installations, Lucke *et al.* (2007) have suggested that there is potential masking of low frequency hearing. Conversely Tougaard *et al.* (2008) state that it is unlikely that the low frequency tonal noise would mask the high frequency signals of porpoises at any range. There is insufficient information on the extent to which pile-driving or seismic pulses mask biologically significant sounds for marine mammals (Bailey *et al.* 2010). The better low frequency hearing of seals could mean that noise from operational installations would be able to mask biologically significant sounds.

In 2013 Mainstream Energy Power carried out an extensive assessment (using a great number of scientific publications) of potential effects of offshore wind farms in Scottish and UK waters including:

- pile noise during installation of jacket foundations;
- drilling during installation of jacket foundations;
- vessel noise during construction;
- vessel presence during construction;
- turbine noise during operational phase;
- vessel noise during operation and maintenance;
- vessel presence during operation and maintenance;
- electromagnetic field of inter-array and export cables;
- sediment disturbance of inter-array and export cables;
- vessel noise of inter-array and export cables.

The only impacts of any significance included effects of piling noise during installation of jacket foundations on bottlenose dolphins, harbour porpoises, grey seals and harbour seals (lethal effects, displacement, change in behaviour, temporary hearing threshold shifts). A summary of the complete assessment is found at the end of chapter 13 of Mainstream Energy Power (2013).

2. Risk of collision

During construction, maintenance and decommissioning there will be an increase in vessel movements increasing the risk of collisions. Vessel collisions with marine mammals are known to occur and may account for a large proportion of deaths. The majority of recorded mortalities are of large baleen whales, particularly fin and northern right whales although injuries to smaller marine mammals may go unnoticed (Wilson *et al.* 2007 in Mainstream Energy Power, 2013). Collisions with seals have been reported, but pinnipeds are recognised as being agile swimmers and predicted to be able to avoid the relatively slow moving vessels used during the construction and operational phases of the project.

Larger vessels of at least 80 m or longer are thought to cause most injuries and deaths, particularly those travelling at 14 knots or faster. Slower moving or smaller vessels are not thought to have such a significant effect (Laist *et al.* 2001 in Mainstream Energy Power, 2013).

3. Changes of the availability of habitat

The original habitat is changed by the construction an offshore wind farm. The introduction of turbines can have an effect on benthic communities, which in turn may have an effect on prey species for marine mammals.

The noise generated by operating offshore wind turbines is less likely than construction-related noises to cause disturbance of migratory marine mammals. Noise levels from operating wind turbines are unlikely to result in hearing impairment of migratory marine mammals at any distance (Madsen *et al.* 2006), but may hamper communication among cetaceans (Tougaard *et al.* 2008).

The operational noise of wind farms is audible to harbour porpoises at 100 m and to harbour seals over 1 km (Thomsen *et al.* 2006). However, simulated noise from a 2 MW offshore wind turbine increased the closest approach distances of harbour seals and harbour porpoises to the sound source (Koschinski *et al.* 2003).

At a Danish wind farm in the Baltic Sea, harbour porpoises left the wind farm area after construction and did not return during the operational phase (Tougaard *et al.* 2009). In contrast, harbour porpoises and harbour seals in other wind farms regularly occurred in the vicinity of operating turbines (Thompson *et al.* 2010, Lindeboom *et al.* 2011). For instance, at another Danish study, no difference was found in harbour porpoise activity inside and outside a wind farm (Diederichs *et al.* 2008). Even more, Scheidet *et al.* (2011) found relatively more harbour porpoises in a Dutch wind farm area in the North Sea, compared with two reference areas. The increased food availability (see §7.3 and 7.4) and reduced vessel traffic in the wind farm area were provided as likely explanations. Therefore, results of one wind farm seem not to be directly applicable to another one.

In addition to generated noise, electromagnetic fields of underwater cables may also negatively affect cetaceans. These fields may alter migration, feeding behaviour, reproduction or susceptibility to predation (U.S. Department of Energy 2009).

Terrestrial mammals
Little information exists documenting the effects of onshore wind energy on migratory terrestrial mammals in North and South America. One study documented the effects of an onshore wind energy development comprised of 45 wind turbines on a migratory terrestrial mammal species (Walter *et al.* 2006). In this study, a population of Rocky Mountain elk were tracked during and after the construction of a wind power facility in the central United States. They found that the tracked population of elk experienced some loss of grassland habitat, however the authors' assessment was that the loss of habitat was negligible to the population and did not result in any adverse effects. Furthermore, roads and power lines associated with the transmission phase of onshore wind energy are potential sources of habitat fragmentation for migratory terrestrial mammals (Forman & Alexander 1998, Dyer *et al.* 2002, Kuvlesky *et al.* 2007, Lovich & Ennen 2013). While vehicle collisions on roadways do not typically limit population size, the barrier effect of roads due to habitat fragmentation and vehicle noise may have demographic and genetic consequences (Forman & Alexander 1998). However, Walter *et al.* (2006) found that elk freely crossed the gravel access roads associated with a new wind energy facility.

8.9 Mitigation measures

8.9.1 General

The review document has been prepared in conjunction with a guideline document in which guidelines for siting, planning and mitigation are presented and prioritised. Within this review chapter, basic background information is presented. Although siting and mitigation can overlap they are as much as possible separated. The presented information is as much as possible based on literature unless stated otherwise, e.g. in case of mitigation suggestions.

Siting wind energy developments away from rare species habitats and main migration routes is the most important step in mitigating the conflicts between wind energy facilities and migratory species of all taxa.

Strategic Environment Assessment and research

In wind farm planning it is highly important and proved successful to use current knowledge of species and site-specific risks and plan wind farms accordingly. For instance in the Netherlands this is the policy since the early start of wind farm development. The Netherlands is important for millions of migratory bird species distributed over many fresh and marine wetlands yearly making billions of risky movements. Currently, a total number of ca. 2,000 wind turbines, and covering an area of 41,000 km^2, are present, which overlap substantially with bird-rich lowland landscapes. However, to date no serious impacts on regional or national populations of migratory species have been identified. The tools to achieve and safeguard this are implementation of sound research combined with Strategic Environmental Assessments and followed up with site specific Environmental Impact Assessments. (http://ec.europa.eu/environment/nature/natura2000/management/docs/Wind_farms.pdf). The Critical Site Network Tool developed for the African-Eurasian region identifies critically important sites for migratory birds that can inform strategic impact assessment and site planning.
See http://csntool.wingsoverwetlands.org/csn/down.html

8.9.2 Fish

a. Mitigation of EMF impacts

The strength of the EMF emitted into the environment may be reduced through proper cable design, burial depth, layout (in the case of multiple cables), magnetic permeability of cable sheathing, ampere loading. EMF should be minimized to avoid potential impacts to migratory fishes, especially elasmobranchs.

8.9.3 Birds

a. Mitigation of bird collisions

Siting and planning

- The most important measure to minimize the risk of collisions on birds is careful selection of site and number of turbines (Hötker *et al.* 2006; http://ec.europa.eu/environment/nature/natura2000/management/docs/Wind_farms.pdf, Leddy *et al.* 1999). By avoiding the placement of wind farms close to areas with considerable numbers of birds and migratory bottlenecks (achieving low fluxes), the collision risk can be largely reduced (U.S. Fish and Wildlife Service 2012). In addition to migratory bottlenecks, critical sites include wetlands, coastal areas and mountain ridges (Hötker *et al.* 2006).
- Increasing the space between and underneath rotors can reduce collision risk for birds in a wind farm as they can more easily avoid collision with individual turbines (Hötker *et al.* 2006). On the other hand, spacing wind turbines was proposed to make wind farms more detectable, and hence easier to avoid (Birdlife Europe 2011).
- Avoiding placing lines of turbines perpendicular to the main migration/flight route, or plan corridors in between large clusters of turbines (Everaert 2003; Birdlife Europe 2011). Large areas within wind farms that are free of wind turbines also provide safe foraging space (Smallwood *et al.* 2009).

Mitigation

- The effect of increasing the visibility of wind turbines has been a matter discussion. Contrast patterns on the blades, or ultraviolet paint may help birds to recognize wind turbines as a danger (Drewitt & Langston 2008). A single, controlled ex situ experiment found that thick black stripes running across a wind turbine's blades made them more conspicuous to an American kestrel *Falco sparverius* than control (unpatterned) blades. Other designs were less visible or indistinguishable from controls (McIsaac, 2001).
- Dummy turbines at the end of lines or edges may reduce collision victims under birds that try to avoid wind farms (Smallwood 2007).
- Temporary shutdown of turbines in high-risk periods, such as peaks in migratory activity or foraging flights has also been proposed (Hötker *et al.* 2006; Everaert & Stienen 2007; Smallwood 2007), as stationary blades may form less of a risk.
    - -Power down wind turbines when winds are strong (Hoover and Morrison 2005, Smallwood *et al.* 2009).
    - -Power down wind turbines at tops of slopes when winds are strong and perpendicular to the slope (Hoover & Morrison 2005).
- Scaring devices are used as deterrents, to reduce flight intensity in a wind farm (Drewitt & Langston 2008).
- If possible, install transmission cables underground (U.S. Fish and Wildlife Service 2012). If this is not possible, mark overhead cables using deflectors (Birdlife Europe 2011).

b. Mitigation and prevention of disturbance effects on birds

Siting and planning

- Replacing smaller turbines by large turbines seems to reduce the effects on small ground-breeding birds (Reichenbach & Steinborn 2006). Similarly, a larger space in between turbines may be experienced as less threatening by birds (Reichenbach & Steinborn 2006). On the other hand, positioning turbines closer together reduces the total size of affected habitat (Birdlife Europe 2011).
- Minimizing the extension of the maintenance road network can reduce the accompanying human disturbance (Hötker *et al*. 2006).
- In offshore environments, floating turbine technology may remove the need of wind farm development in ecologically valuable shallow water habitats (Wilhelmsson *et al*. 2010; Gove *et al*. 2013).

c. Mitigation and prevention of disturbance of flying birds

Minimizing the barrier effect of large-scale wind farms is possible by planning corridors in between clusters of wind turbines and preventing the realization of long lines of turbines. Creating more space (> 200m) in between turbines may enable flight through the wind farm (Percival 2005). Lines of turbines perpendicular to the main migration route may help to prevent large avoidance reactions (Winkelman 1992b).

8.9.4 Bats

Mitigation

A critical mitigation technique may be to raise the cut-in speed (the lowest wind speed at which the blades of a turbine will begin rotating) and change the blade angles of turbines to reduce operations during periods of low wind speeds. This change has been shown to reduce bat mortality by 44 – 93%, with ≤1% loss in total annual power output in this situation (Arnett *et al.* 2011, Baerwald *et al.* 2009, Behr *et al*, 2011c, EUROBATS 2013, Lagrange *et al.* 2012).

8.9.5 Other mammals

Siting and planning

In case of marine mammals, presumed seasonal migratory patterns should be used to determine timing of construction activities or monitoring/mitigation efforts (Whitt *et al.* 2013).

No specific mitigation measure were identified in the literature for terrestrial mammals, however siting onshore wind energy facilities (including associated roads and power line) away from major terrestrial mammal migratory routes would likely help alleviate the impacts to migratory terrestrial mammals from wind energy developments.

Mitigation

Noise mitigation may be applied to reduce noise levels below 160 dB Sound Exposure Level or 190 dB Sound Pressure Level at distances greater than 750 of the piling site (An *et al.* 2012).

For each of the potential effects assessed by Mainstream Energy Power mitigation measures were identified. Mitigation measures included the use of different types of foundations, drilling pipes rather that piling, using smaller hammer sizes to reduce the energy input, soft start, providing a barrier between the pile and the environment using bubble curtains and/or a piling sleeve, using certified Marine Mammal Observers and/or passive acoustic monitoring to detect marine mammals, using acoustic deterrents, and timing activities avoiding sensitive periods of the year (Mainstream Energy Power, 2013).

8.10 Positive effects

Few direct positive effects of onshore or offshore wind energy development were identified in the literature. Indirect effects can be caused by the lack of human disturbance or for instance less commercial fishing activities in offshore wind farms (Vandendriessche *et al.* 2013).

8.10.1 Fish and crustaceans

Fish and crustaceans may benefit from the creation of artificial reef habitat around the bases of offshore wind turbines, however community structure of these taxa post-construction may be entirely different from what existed in the area before wind turbine installation (Wilhelmsson *et al.* 2006, Langhammer 2012, Reubens *et al.* 2013a, Reubens *et al.* 2013b). Namely, the installation of turbine monopiles, scour protection, and artificial reefs have often been shown to increase fish attraction by increasing habitat heterogeneity, prey availability, cover from predators and by providing havens for commercially harvested species and shelter from currents (Wilhelmsson *et al.* 2006, Langhammer 2012, Reubens *et al.* 2013b).

Fish abundance near wind turbines is often greater than in surrounding areas, however species richness and diversity are typically similar (Wilhelmsson *et al.* 2006). For instance, Atlantic cod, a migratory fish species that occurs throughout the North Atlantic, show aggregation behaviour near artificial hard substrates of wind turbines (Reubens *et al.* 2013a). This effect was seasonal, however, with many fish present near artificial reefs during the summer and autumn and very low densities during winter. When present at artificial reefs, cod displayed a high degree of site fidelity (Reubens *et al.* 2013a).

8.10.2 Birds

A positive side effect of wind farm developments on birds may be the creation of new habitat for prey species. This may take place at breeding as well as wintering sites of birds. For instance, commercial fishing is prohibited at offshore wind farms, and hence these sites serve as refuge for fish, while the fundaments of the turbines may serve as substrate for benthic organisms (Wilhelmsson *et al.* 2010). Such developments increase the prey availability of piscivorous and benthivorous birds. Consequently, bird species with a low avoidance reaction to wind turbines, such as cormorants, gulls and terns may show a positive numeric response to wind farm developments (Lindeboom *et al.* 2011, Vanermen 2013b). Comparably, rodents may thrive at onshore wind farms, attracting a large number of raptors. Nevertheless, such developments may increase the flight intensity, and hence potentially the number of collisions, of these species. Moreover, these effects may be location-specific, as in the central United States raptor abundance was found to have reduced by 47% following the construction of a wind energy facility (Garvin *et al.* 2011).

8.10.3 Mammals

The presence of additional food sources due to the lack of fisheries and the created new hard substratum can create an attractive habitat for marine mammals. Moreover, due to the low vessel traffic intensity, wind farm areas are relatively quiet compared to the surrounding waters (Lindeboom *et al.* 2011).

8.11 Gaps in knowledge

While the electrical generating capacity of wind energy in Latin America, Asia and Africa is a small fraction of North American and European capacity, the technology is expected to grow worldwide, lending the need for more research into the impacts of wind energy development on migratory species of all taxa. Many habitats in the southern hemisphere are fragile and already extensively impacted by agriculture, urbanization, and other renewable and non-renewable energy development. Extensive study will be needed to assess the compounding impacts of new wind facilities in these areas.

Especially important will be to assess the (future) impacts on species groups at a **population level** as the scale and number of wind farms will increase.

Additional work is also needed to assess collision rates of migratory birds and bats at offshore wind energy facilities in Europe, as this will likely be a good predictor of impacts to those taxa from potential future offshore wind development in the waters of North and South America.

Simmonds and Brown (2010) state for cetacean conservation: “the available information, including inferences drawn from the impact of other human activities in the marine environment, indicate a significant risk of negative consequences, with the noise from pile driving highlighted as a major concern. The marine renewable-energy industry will also deploy some novel technologies, such as large submerged turbines, with unknown consequences for marine wildlife. Further research is urgently required, including distributional and behavioural studies, to establish baselines against which any changes may be measured."

More study is needed to identify potential impacts to migratory fish and crustaceans from EMF generated by undersea cables. This is likely the most significant potential impact to fish and crustaceans from wind energy development, but little direct evidence of impacts to these taxa from EMF generated by undersea cables exists.

The effects of EMF and habitat alteration on sea turtles also requires further study, as potential offshore wind energy developments in North and South America may have the potential to impact these species near major nesting beaches.

In view of the rapid extension of offshore wind farms in the North Sea, there is a need to acquire more knowledge on the effect of noise caused by pile driving, of fish and fish larvae. However for larvae of the common sole (*Solea solea*) the noise effects seem limited (Bolle *et al.* 2011). How fish larvae are affected by the EMF generated by undersea cables from wind energy facilities is unknown. Besides that more knowledge is needed of the function of spawning area and the nursery function of off shore wind farms.

8.12 Conclusions

Wind farms can have impacts on many migratory species as well in the construction phase in terms of habitat loss, disturbance or habitat degradation as well as in the operational phase in terms of mortality and disturbance (habitat degradation). The migratory species groups where impacts are likely to occur include bats, terrestrial and marine mammals, birds, fish, crustaceans and squid, which are discussed in more detail below. he potential and significance of the impacts of wind energy development and deployment on migratory species depends upon a number of factors including site specific factors, the species involved and the design of wind farms (number, type and size of turbines, the configuration of the wind farm, etc.).This makes it is difficult to make generalization about the impacts.

To date, examples of serious impacts at local, regional or international population levels are scarce. Most striking are the impacts on vultures and there are indications for population effects on Red Kites in Germany all due to collisions. But this is all related to the current scale and number of wind farms. If the numbers of farms and turbines increases the impacts at a population level of certain migratory species might be substantial. Currently this is a major international responsibility to get better understanding of this issue especially for collision rates for birds and bats and impacts on population levels. The first steps have been taken to model and assess effects at a flyway or population level for offshore wind farms at the North Sea, which are situated at an important flyway for many birds.

Another main concern of wind energy developments is the impact of underwater noise on cetaceans and fish; especially with novel technologies, such as large submerged turbines. Besides that, EMF generated by undersea cables may also have significant potential impact to fish. Little evidence of these impacts to these taxa exist and findings of studies undertaken are ambiguous.

Wind energy developments can potentially have positive effects on migratory species, especially offshore wind farms. Fish may benefit from the creation of artificial reef and habitat around the bases of offshore wind turbines. Positive effects can also result from the lack of human disturbance or less commercial fishing activities in offshore wind farms. In turn, piscivorous birds may profit from this local increase in prey.

8.13 Literature

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9 Discussion and conclusions

9.1 Renewable energy

Renewable energy use has increased substantially over the years. Some types, such as hydropower, already have been used for decades while other technologies are currently under development, leading to progressive growth in the extent of the renewables sector as well as in information on the impacts on wildlife.

It is recognized that the production of energy from renewable sources can contribute significantly to climate change mitigation. Nevertheless, all these renewable energy deployments can be regarded as power plants with their corresponding infrastructure potential affecting migratory species (table 9.1). As migratory species by definition have a breeding area geographically separated from non-breeding habitats, individuals and populations can be affected at several points and locations during their life cycle: at breeding areas, during migration or at migratory stopover sites, or at non-breeding areas. Impacts can be cumulative and result from combinations of comparable or different renewable energy deployments, as well as other factors. An overview of the species-groups covered in this review are given in table 9.2.

This review shows that relatively few well-documented scientific studies on effects are available. Most reviews speculate as to the theoretical impacts and are based on little evidence. This has implications for the current review, which focussed on scientific papers, although other materials and expert opinion have been used in the absence of published information.

Table 9.1. Overview of main impacts of renewable energy technologies deployment on migratory species. Due to differences in scale and distribution world-wide effects differ substantially. '–' means 'not known' / ' not likely'.

Energy	**Regionally or locally high impact, but with no significant impact on the overall species population**	**impacts on population level known**	**impacts on population level likely**
Biomass	habitat loss for all species groups	-	- / small scale
Geothermal	few bird, mammal and fish species	-	-
Hydropower	Many fish species and some bird species	several fish species one extinction	fish, fresh water cetaceans
Ocean energy	Fish, sea turtles, birds crustaceans and squid	-	-
Solar power	habitat loss for all species groups	-	- / small scale
Wind energy	many species of birds, bats	few bird species	birds and bats

9.2 Scale and cumulative effects

Some renewable energy deployments still have a small or local scale (ocean energy, geothermal) while others are widespread and abundant (*e.g.* hydropower and wind energy). Most production remains in northern Europe and North Africa, other than hydropower, which is more globally widespread. This means in general that effects of widely used deployments are larger and more widespread, significant and also better studied. However, renewable energy deployments need not always be large enough to have significant impacts. Small-scale deployments can affect species even at a population level. Examples have been provided for fish or cetacean species depending on a single river ecosystem or wind farms affecting soaring birds at strategic migration bottlenecks (see annex 1 Examples of potential impact hotspots for migratory species).

In general scale is an important, yet hardly studied, subject. As the size or the total number of power plants increases the effects can be expected to grow. This is especially the case if mitigation is not applicable or insufficiently applied. To date, very few attempts have been made to model or study effects at larger scales such as population level, or effects throughout the entire migration route or for birds “flyway”. The long migratory paths hamper sound studies of effects at an international level and different types of effects (not only from the construction and operation of renewable energy) can also accumulate.

As the numbers of renewable energy deployments has increased so has the attention on cumulative effects. Few published studies have attempted to quantify the cumulative effects of wind farms, although several studies mention its importance (Drewitt & Langston 2006; Masden *et al.* 2010). These studies mostly focus on the effects on birds. In most cases, the cumulative effects of multiple wind farms are unlikely to be equivalent to the sum of the effects of component wind farms (additive); these may also be either more or less (multiplicative). Furthermore, cumulative effect studies should also consider other developments and pressures of differing types, such as other forms of habitat loss or degradation and obstacles to migration.

A number of studies consider cumulative effects in relation to assessing the effects of wind farms although provide no quantitative assessment (Exo *et al.* 2003; Desholm & Kahlert 2005). Poot *et al.* (2011) made one of the first attempts to assess the effects of multiple wind farms in the North Sea on the population levels of birds. To ensure a realistic scenario actual data from bird populations and existing wind farms were used, however, a number of other variables had to be estimated, as no data were available. These assumptions followed a realistic worst-case scenario and as such the effects of the ten wind farms were taken as additive. Even so, few effects were noted at the population level for the species assessed, despite this worst-case scenario that was adopted in the modelling.

Bellebaum *et al.* (2013) suggested that cumulative effects of the current number of terrestrial wind farms could soon influence the German population of Red Kites.
The level at which cumulative effects are detectable may depend on the type of impact. For example, barrier effects on birds are generally small compared to collisions; however, barrier effects of multiple wind farms may play an important role in increasing energy expenditure and ultimately survival of migratory birds (Masden *et al.* 2009). In the future, potential barrier effects to migratory fish and marine mammals may develop, as more offshore wind energy projects become operational.

Wind farms also result in cumulative impacts for non-avian species groups. Carstensen *et al.* (2006) suggested that cumulative effects might occur for harbour porpoises, particularly where multiple developments occur within their population range. The assessment of the cumulative effects of wind farms, particularly in combination with other forms of developments, remains difficult to assess quantitatively. In the absence of empirical data, modelling is likely to remain an important tool.

Bare *et al.* (2009) used models to assess the possible long-term effects of habitat fragmentation on the movements and gene flow of short-distance migrant and resident tortoises. Their results indicated that impacts to the species' connectivity could be compounded by renewable energy developments, which decreased core and highly suitable habitat and can act as major obstacles to migration and gene flow.

Habitat fragmentation has the potential to have a major effect on migratory species. Tsoutsos *et al.* (2005) reported that if very large areas are being used for industrial scale solar plants there is potential for a regional or flyway level impact on migratory soaring bird populations. Instances where solar arrays occupied habitat at known resting sites for migratory species or if the cumulative impact on a population has not been appropriately evaluated, could result in the risk of abandonment of an area, leading to disruption of links within the landscape. In addition, solar power and biomass generation technologies often need additional transmission lines (Turney and Fthenakis 2011), which can add to cumulative effects on migratory pathways.

The assessment of population-level effects is one of the current key major conservation challenges.

9.3 Diversity in impacts

Impacts vary in their magnitude. Impacts can include adult mortality, loss of breeding habitat and disturbance effects. Simple summarisation is difficult given the highly variable ecological characteristics of the species involved and the diverse settings in which impacts occur. Moreover, even amongst closely related species substantial differences in impacts could occur, making predictions difficult. Behaviour is also an important factor with migrating individuals sometimes showing different behaviour to local or breeding individuals, this can sometimes be a result of local knowledge of an area or different activity. Demography and life history are also important, as short-lived species with higher reproduction rates have a higher recovery potential than long-lived and slow reproducing species.

For example, mortality arising from wind turbine strikes is typically much greater for vultures in Asia, Africa and Europe than for many other bird species. This makes impact assessments difficult if new species or sites are involved without existing knowledge, although broad knowledge of the ecological and morphological characteristics of the species concerned are always helpful as a guide.

In many countries with new developments, existing knowledge is not always used and effects may be at times exaggerated or overlooked. Furthermore, the focus of research may often be directed towards popular or affordable studies and away from the most important ecological and conservation questions. For example, in some countries it seems to be more common to study the effects of wind turbines on migratory birds whereas other developments may be more straightforward and cost-effective to assess and have similar impacts on migratory species: for example, riverine hydropower dams are likely to impact multiple species of migratory fish.

9.4 Strategic planning and research to avoid conflicts

Proper planning and research is essential to minimise the effects of RET on migratory species. This means planning at the international and national levels as well as site-specific. In many cases the effects can be substantially lower if planned well or if mitigation is included. For instance in the Netherlands this is the policy since the early start of wind farm development. The Netherlands is important for millions of migratory bird species distributed over many fresh and marine wetlands making billions of movements annually bringing about collision risk with such developments. Currently a total number of ca. 2,000 wind turbines are present and cover 41,000 km^2, with a substantial overlap with bird-rich lowland landscapes. But to date no serious impacts on regional or national populations of migratory bird species have been identified. The policy to achieve and safeguard this, are the implementation of sound research combined with Strategic Environmental Assessments and followed up with site specific Environmental Impact Assessments. In North America, government sponsored environmental studies such as those being undertaken by the US Bureau of Ocean Energy Management, are expanding the knowledge base for examining regional or cumulative effects that may result from ocean-based renewable energy deployments. Similar government supported research within Europe includes flyway-level tracking of Bewick's swans (*Cygnus bewickii*) in relation to proposed wind farms.

Connectivity information is essential to understand and minimize impacts to threatened populations. Currently, we know year-round ranges for many species (see also annex 1), but information about migratory routes is generally scarce. Research to date has focused heavily on temperate regions and often covers only one period of the annual cycle (http://www.migratoryconnectivityproject.org). Information on migratory routes is essential in the planning phase of renewable energy developments. Modelling can be a helpful instrument for this (*e.g.* Roever *et al.* 2013).

Studies can lead to practical mitigation measures at existing at future developments. For example, research into the behaviour of bats around wind turbines has shown that a reduction in the cut-in speeds of wind turbines can significantly reduce the collision-related mortality of bats while having a negligible effect on energy production.

The current study summarizes impacts on migratory species and can be used as a reference in Environmental Impact Assessments at a local scale. In addition to this review document, a guideline document is presented addressing relevant issues for impact assessment studies.

9.5 Positive impacts

The review lists at least some positive effects for migratory species. Although generally the negative effects are larger, some distinct positive effects have been found, such as the creation of new water bodies behind dams for migratory waterbirds or new habitat for certain species as a result of biomass crops.

9.6 Post construction monitoring

It is not usual to monitoring impacts on wildlife after construction of RET. So many aspects of impacts are poorly assessed and documented. There are two motivations for post-construction impact assessments. The first is to provide information that will allow better input into planning decisions regarding further energy developments, and so reduce future impacts. The second is to understand the nature of impacts so as to provide information of use in provision of mitigation measures, either locally at the site concerned, or elsewhere.

Post-construction monitoring and studies on the effectiveness of mitigation should always be published (for example in the journal *Conservation Evidence*) to have the information widely available.

9.7 Gaps in knowledge

Shortcomings in knowledge for the specific energy types are described in the relevant chapters of this report. These gaps range from site-specific, where the impacts on individuals are insufficiently known, to the population-level, where information as to the effects along the migratory pathways and at the population is insufficient. Many of these gaps in the knowledge can be addressed through post-construction monitoring together with studies of behaviour and demography in the vicinity of the power plants. For the large-scale impacts, connectivity studies, migration studies, hotspot identification, site assessments and population models are needed to assess any potential effects at the population or flyway level.

In the absence of data many studies have taken a theoretical approach in assessing the potential impacts of developments on migratory species. Alternatively, models or comparisons can be carried out using the precautionary approach. This approach assumes worst-case scenarios for assessing the potential impacts on species and can provide a useful approach, particularly for initial assessments and for situations where the effects are expected to be low.

9.8 Conclusions

- All types of renewable energy deployments have the potential to have impacts on migratory species.

- The extent of current knowledge differs between energy types and species groups. For instance, far more studies are available on the effects of wind energy than for ocean energy or solar energy. Similarly, birds have been studied far more widely than bats or insects.

- The examination of potential barrier effects on bird migrations should be expanded to migratory fish and marine mammals for ocean-based energy developments.

- Studies need to be both site- and species-specific. The value of general statements as to the potential effects of different energy types and on different species-groups is limited.

- Relatively few impacts have been well documented. Most papers and reviews include speculations on impacts. This is partly caused by the lack of proper pre- and post-construction monitoring, which can lead to the exaggeration or underestimation of effects.

- The current study summarises impacts on migratory species and can be used as a reference in Environmental Impact Assessments at the local scale. In addition to this review, a guideline document will be presented addressing relevant issues for impact assessment studies.

- So far, very few large-scale impacts have been documented: only a few examples are available that indicate population impacts. This is partly due by the lack of cumulative studies, but mainly by the relative small scale of current renewable energy developments.

Table 9.2 Taxonomic group levels considered for migratory species in this review (simplified according to table 1.1) with a summary of current and possible short-term impacts. M= mortality, H = habitat impacts, B = barrier effects, 0 = zero or negligible effects, ? = effects completely unknown, + = positive effects

Annex I/II species (groups)	**Biomass**	**Geo-thermal**	**Hydro-power**	**Ocean Energy**	**Solar Energy**	**Wind Energy**
Bats	H	?	+	0	H	M,H
Whales and dolphins	0	0	H	H,B	0	H
Gorillas	H	?	0	0	0	0
Dugongs	0	0	?	H	0	H
Seals	0	0	H	H,B	0	H
Elephants	H	?	0	0	?	0
Ungulates	H	?	0	0	H	H
Carnivores	H	?	0	0	H	H
Penguins	0?	0	0	H	H	0
Flamingos	0	?	0	0	H	M,H
Pelicans	H	?	+	?	H	M,H
Ducks, swans and geese	H	?	+	?	H	M,H
Herons	H	?	+	0	H	M,H
Ibises	H	?	+	0	H	M,H
Storks	H	?	+	0	H	M,H
New World vultures	H	?	0	0	H	M,H
Other raptors	H	?	0	0	H	M,H
Rails	H	?	+	0	H	M,H
Cranes	H	?	+	0	H	M,H
Bustards	H	?	0	0	H	M,H
Waders	H	?	+	0	H	M,H
Gulls and terns	H	?	+	?	H	M,H
Warblers	H	?	0	0	H	M,H
Albatrosses and petrels	H	0	0	H?	H	M,H
Sea turtles	H	0	0	H,B?	0	H,B
Crocodiles	H	?	H/+	0	0	H
Sturgeons	0	?	B,H	?	H	0
Catfish	0	?	B,H	0	H	0
Sharks	0	0	B,H	B,H	0	0?
Rays	0	0	B,H	B,H	0	0?
Salmon and Eel	0	?	B,H	?	H	0
Monarch butterfly	H	?	0	0	H	H

9.9 Literature

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Species lists

Annex I/II species	Order	taxonomic group	nr species	habitat
Bats	1. Mammalia		40	terrestrial
Whales and dolphins	1. Mammalia	Cetacea	50	marine
Gorillas	1. Mammalia	Primates	1	terrestrial
Dugongs	1. Mammalia	Sirenia	4	marine
Seals	1. Mammalia	Pinnipedia	4	marine
Elephants	1. Mammalia	Loxodonta	2	terrestrial
Ungulates	1. Mammalia	Ungulata	24	terrestrial
Carnivora	1. Mammalia	Carnivora	4	terrestrial
Gorrilas	1. Mammalia		2	terrestrial
Penguins	2. Aves	Spheniscidae	2	marine
Flamingos	2. Aves	Phoenicopteridae	5	water
Pelicans	2. Aves	Pelicanidae	2	water
Ducks and geese	2. Aves	Anatidae	52	water
Herons	2. Aves	Ardeidae	8	water
Ibises	2. Aves	Threskiornitidae	5	water
Storks	2. Aves	Ciconidae	5	terrestrial
New World vultures	2. Aves	Cathartidae	1	terrestrial
Hawks, eagles, kites, harriers and Old World vultures	2. Aves	Accipitridae	47	terrestrial
Falcons and caracaras	2. Aves	Falconidae	16	terrestrial
Owls	2. Aves	Strigidae	12	terrestrial
Rails	2. Aves	Rallidae	6	water
Cranes	2. Aves	Grus	9	terrestrial
Bustards	2. Aves	Otidae	2	terrestrial
Avocets, stilts	2. Aves	Recurvirostridae	3	water
Plovers, dotterels and lapwings	2. Aves	Charadriidae	26	water
Pratincoles	2. Aves	Glareolidae	3	water
Sandpipers, curlews and sub-family Phalaropodina	2. Aves	Scolopacidae	35	water
Gulls and terns	2. Aves	Laridae	31	water
Old World warblers and sub-family Sylviinae	2. Aves	Muscicapidae	8	terrestrial
New World warblers	2. Aves		5	terrestrial
Albatrosses and petrels	2. Aves	Procellariformes	38	marine
South American birds	2. Aves		5	terrestrial
rest, different families	2. Aves		20	
Sea turtles	3. Reptilia	Cheloniidae	8	marine
Leatherback sea turtle	3. Reptilia	Dermochelyidae	1	marine
Crocodiles	3. Reptilia	Crocodiles	2	river/marine
Sturgeons	4. Pisces	Acipenseridae	19	river
Catfish	4. Pisces	Siluridae	1	river
Sharks	4. Pisces	Selachimorpha	7	marine
Rays	4. Pisces		1	marine
Salmon and Eel	4. Pisces		2	marine/fresh
Insects	5. Insecta	Butterfly	1	terrestrial

Annex II groups

Annex I/II species	**Order**	**taxonomic group**	**nr species**	**habitat**
Evening bats	1. Mammalia	Vespertilionidae		terrestrial
Flamingos	2. Aves	Phoenicopteridae	5	water
Ducks and geese	2. Aves	Anatidae	52	water
New World vultures	2. Aves	Cathartidae	1	terrestrial
Hawks, eagles, kites, harriers and Old World vultures	2. Aves	Accipitridae	47	terrestrial
Falcons and caracaras	2. Aves	Falconidae	16	terrestrial
Cranes	2. Aves	Grus	9	terrestrial
Avocets, stilts	2. Aves	Recurvirostridae	3	water
Plovers, dotterels and lapwings	2. Aves	Charadriidae	26	water
Sandpipers, curlews and sub-family Phalaropodina	2. Aves	Scolopacidae	35	water
Old World Flycatchers and sub-family Sylviinae	2. Aves	Muscicapidae	8	terrestrial
Sea turtles	3. Reptilia	Cheloniidae	8	marine
Leatherback sea turtle	3. Reptilia	Dermochelyidae	1	marine

Additional groups agreements	Order	**Nr species**
ACAP (Albatrosses and Petrels)	Aves	28
AEWA (African-Eurasian Migratory Waterbirds)	Aves	255
ACCOBAMS (Mediterranean and Black Sea Cetaceans)	Mammalia	
ASCOBANS (Small Cetaceans of the North Sea)	Mammalia	
EUROBATS (European Bats)	Mammalia	52
GORILLAS	Mammalia	2
WADDEN SEA SEALS	Mammalia	2
WAAM (West African Aquatic Mammals)	Mammalia	32
Additional species groups		
Salmon Salmo salar	Pisces	1
Eel Anguilla anguilla	Pisces	1

For information on the species lists:
- CMS species lists (Annex I and II): http://www.cms.int/documents/index.htm
- Species lists of the CMS instruments: http://www.cms.int/species/

Annex 1 Examples of potential impact hotspots for migratory species

1.1 Introduction

This annex presents some worldwide examples where renewable energy technology deployments might have impact on migratory species. At sites with concentrations of certain species impacts of Renewable Energy Developments (RET) developments might theoretically be more serious and in such case these sites can be defined as potential impact hotspots.. In this annex some, partly theoretical examples, are presented of such potential impact hotspots. Of course sites with high concentrations of migratory species might not be interesting for RET development and in such cases the potential impact is low or zero.

The available data do not allow for an exhaustive overview of hotspot areas of migratory species. Above this, there is no complete and detailed spatial overview of future renewable energy technologies deployment. The presented examples from the Americas, Asia, Australia, Europe and Africa give an idea in which way renewable energy technologies might affect migrating species. The purpose of this chapter is to show some theoretical examples which can give an idea of the aspects of possible conflict areas and species related issues. It shows that impacts can be regional but also international and the examples show that in most cases different types of technologies can affect different stages of the life cycle of migratory species at a different spatial and temporal scale. On the other hand the examples also show that impacts can be very local so that strategic planning and siting easily can avoid serious impacts. Within Impacts assessments species distribution maps, as presented in the examples, should be an essential step in the planning and siting phase.

Identification of potential impact hotspots or in other words vulnerable crux-points, both spatial bottlenecks and core spatial resources, along frequently used movement paths is a critical step towards conservation of migratory routes (Wall *et al.* 2013). This annex presents a number of examples of some vulnerable species and areas on a global scale. The focus is especially on species of the CMS Family instruments lists (e.g. CMS annex I and II) that are particularly susceptible on population level to fatalities, disturbance, displacement, habitat loss, migration route interruption and other negative impacts potentially caused by each type of renewable energy technologies deployment.

To give insight in ‘potential impact hotspots’ the hotpots identified should be overlaid with maps of future renewable energy technologies deployment (e.g. the distribution of renewable energy potential in Africa, see figure A.1).

The information provided could be used to further assess potential impacts, including cumulative impacts and to assess if measures can be taken to avoid, mitigate or compensate impacts.

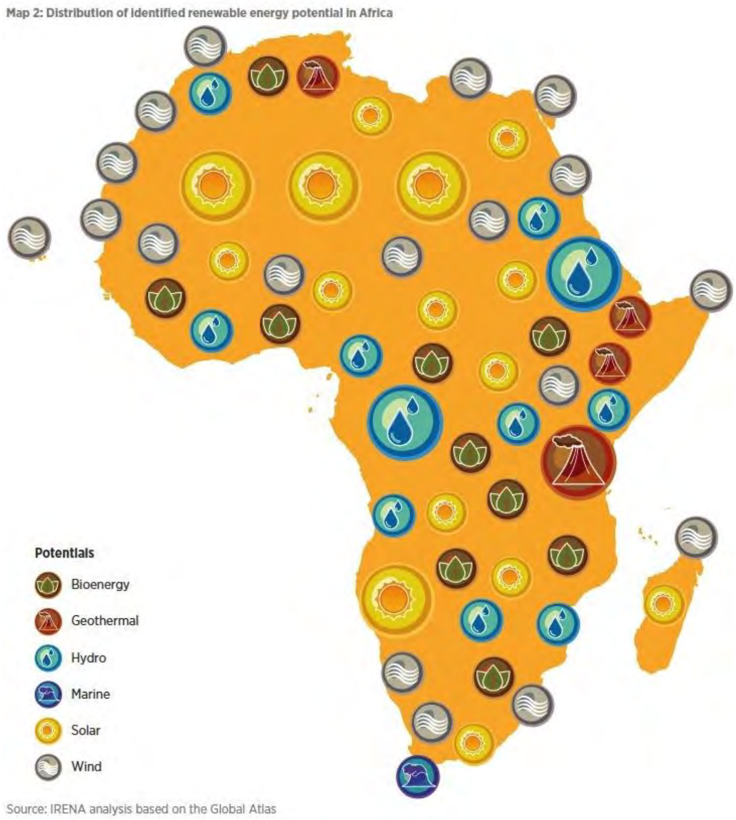

Figure A.1 Distribution of renewable energy potential in Africa (Source: Irena 2013).

1.2 The Americas

1.2.1 Monarch butterfly, biomass and wind energy

The monarch butterfly (*Danaus plexippus*) migrates several thousands of miles over multiple generations from their reproduction grounds, primarily in eastern and central United States and Canada, to the wintering grounds in Mexico (Figure A.2).

Of the six renewable energy technologies researched as part of this report, wind energy was the only one having a possibility of impacting migratory insect species in the North-western Hemisphere. It has been postulated that wind currents created by rotating turbine blades may be sufficient to sweep away approaching butterflies before collision with the turbine (Grealey & Stephenson 2007). The authors of this study found currently no evidence that butterfly mortality or other potential impacts to butterflies, including monarchs, are of concern at commissioned wind energy facilities. And above this, it is yet unknown if areas with high butterfly densities might be interesting for the development of wind energy so the presented example is theoretical. However, this theoretical example provides some information of the p[potential impacts on a CMS lists insect species throughout its life cycle. RET deployments like, wind energy or biomass production might affect the insects at their migration routes or staging sites and assessments should might need to address this issue.

During winter the insects can concentrate (http://monarchwatch.org) in huge numbers in small areas. This might imply serious impacts if such places are diverted into crops for biomass production, especially if pesticides or herbicides are used. Within the reproduction areas the habitat degradation and decline of milkweed due to development of infrastructure might add to negative effects on this migratory species.

Figure A.2 North American monarch butterfly migration routes (Source: US Forest Service).

1.2.2 Hydropower development and fish within the Andean Amazon

Hydropower offers a reliable alternative source of domestically produced electricity to Neotropical countries; this is especially true in the Andean Amazon, where regional governments are prioritizing new hydroelectric dams as the centrepiece of long-term energy plans (Finer & Jenkins 2012). The six major Andean tributaries of the Amazon River (Caqueta, Madeira, Napo, Maranon, Putumayo, and Ucayali) span five countries including Bolivia, Brazil, Colombia, Ecuador, and Peru. There are currently 48 dams greater than 2 MW capacity in the Andean Amazon, with plans for an additional 151 such dams encompassing five of the six major tributaries over the next 20 years (Finer & Jenkins 2012, see Figure A.2). The majority of the planned dams would cause the first major break in connectivity between Andean headwaters and the lowland Amazon.

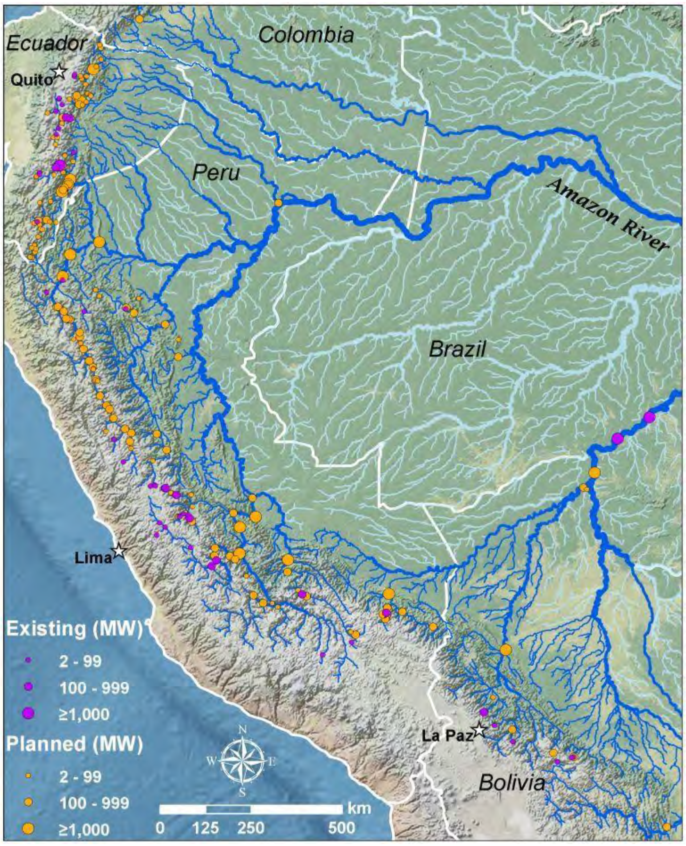

Figure A.3 Hydroelectric dams of the Andean Amazon sorted by status and capacity (Source: Finer & Jenkins 2012).

Carrying one-sixth of all freshwater transported by rivers, the Amazon River and its tributaries represent the largest river system in the world and contain the most diverse assemblage of fish fauna with over 940 described species (WWF & TNC 2013). Many fish migrate to spawn and feed in the resource-rich white-water channels and flood-plains of the Andean tributaries from other low-fertility black-water and clear-water tributaries in the Amazon basin. These annual movements are the most common form of migration among Amazon fishes and are critical to maintaining the region's fisheries, because all commercially important species appear to spawn only in white waters (Goulding *et al.* 1997). Many fish species use the main stem and its Andean tributaries as migration corridors, most notably large predatory **catfish** (*Pimelodidae*) moving from brackish water upriver to Andean clear-water spawning areas. Unlike their relatives from other tropical systems, Amazonian migratory catfish cover long distances and exploit a great variety of habitats. During the low-water period (June-October), as seawater invades the estuary, a great number of catfish schools leave the brackish waters to move up the Amazon River and its tributaries (Barthem *et al.* 1991). The most remarkable of these migrations is that of the dorado, or dourada, catfish (*Brachyplatystoma* spp.), which travels as far as 5000 km from the Amazon estuary to the headwaters in Columbia, Bolivia and Peru (McClain & Naiman 2008).

The prioritization of new hydroelectric dams as the centrepiece of long-term energy plans within the Andean Amazon has the potential to disrupt the intimate link between the Andes and the main stem Amazon including the migratory patterns of many resident fish species. The loss of connectivity could lead to the obstruction of the upstream migrations and interruption of the downstream movements of eggs or young. The life strategies of migratory fishes could also be impacted by hydrological changes within the tributaries and floodplains.

The loss of fluvial connectivity in river systems due to the construction and operation of hydropower facilities impact species that rely on spawning migrations and restrict movement of these species to important migratory, spawning, and nursery habitat. Artificial fish passage ways designed to reconnect fragmented rivers and restore fish movement potential have not always been successful due to installation with unclear objectives, lack of species-specific studies before installation, and lack of monitoring (for more details and references, see chapter 4 of this review).

1.2.3 Leatherback seaturtle and ocean energy along the northeastern Pacific coast

Sea turtles may theoretically be impacted by the deployment of ocean energy or offshore wind energy facilities. As neither of these technologies is currently in use in the Western Hemisphere, any hotspots of impacts between sea turtles and renewable energy technology are speculative and would only exist in the Western Hemisphere if those technologies are ultimately deployed there.

Sea turtles are found in all warm and temperate waters throughout the world with most species undergoing long migrations between their feeding grounds and the beaches where they nest. The largest sea turtle is the leatherback (*Dermochelys coriacea*). It is the sole remaining member of the taxonomic family *Dermochelyidae*. Leatherbacks have the most extensive range of any living reptile (Figure A.4).

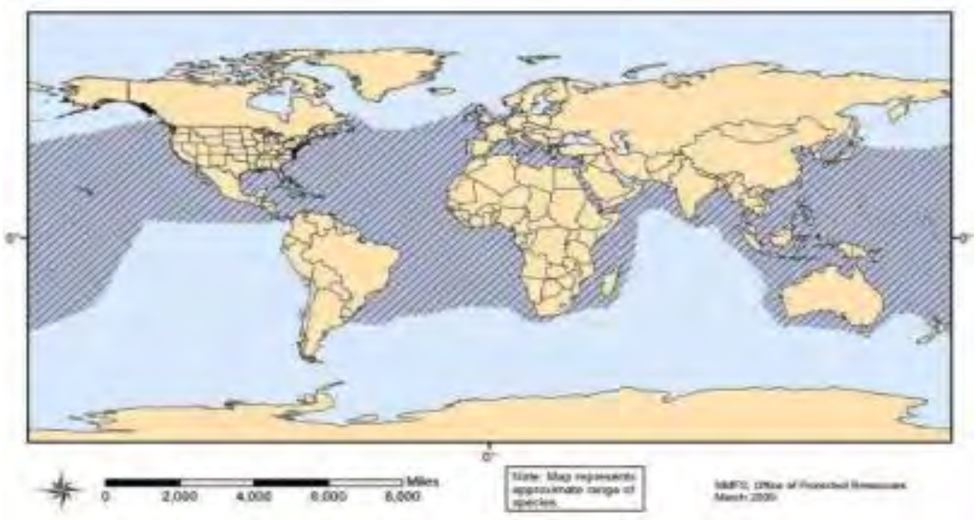

Figure A.4 *Leatherback seaturtle distribution range hatched grey (Source: NMFS 2012).*

Unlike all other sea turtles, leatherbacks have several unique physiological traits that enable them to extend their geographic range further into cold ocean waters (latitudes as high a 71^{o} N and 47^{o} S) to forage (Figure A.4). Nesting, however, is confined to tropical and subtropical beaches.

Migratory routes are not entirely known, however, recent satellite telemetry studies have documented transoceanic migrations between nesting beaches and foliage areas in both the Atlantic and Pacific Oceans (Benson *et al*. 2011). Despite conservation efforts, leatherback turtles are still experiencing population declines particularly in the Pacific, caused by long-term egg and adult harvest and incidental capture in fishing gear. The critically endangered Pacific leatherback population travels more than 12,000 miles roundtrip across the ocean from Indonesian nesting beaches to feed on seasonal aggregations of jellyfish along the northern Pacific coast (Benson *et al*. 2011, Tapilatu *et al*. 2013). Wind-driven coastal upwelling of nutrient-rich waters drives primary productivity within the waters off the United States west coast (NMFS 2012). The peak time of leatherback sightings along the west coast occur between July and September which corresponds to a relaxation of in the upwelling and sea surface temperatures increase to their warmest levels near the coast (Benson *et al*. 2011). Under Section 4 of the Endangered Species Act, the National Marine Fisheries Service has designated critical habitat areas along the California, Washington and Oregon coast in an effort to protect the essential foraging habitat (Figure A.5).

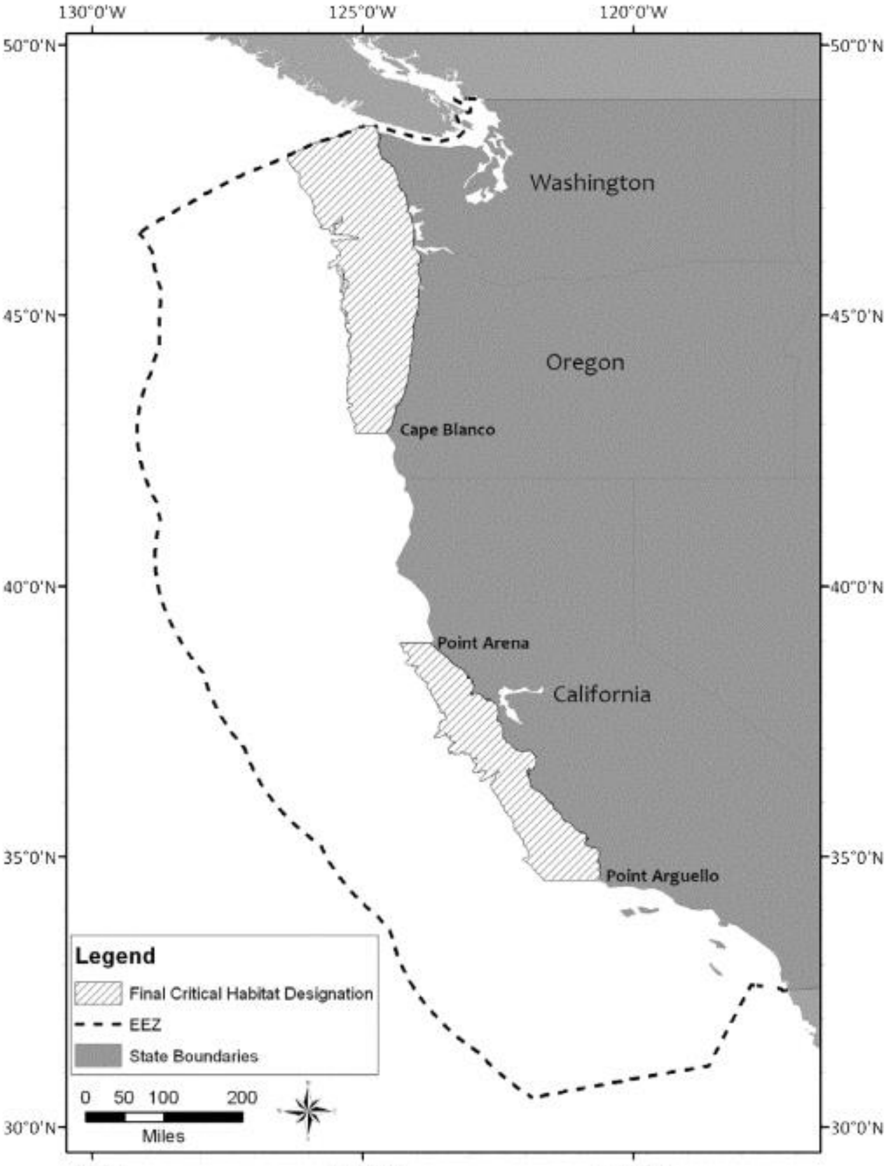

Figure A.5 Leatherback seaturtle west coast critical habitat (Source: NMFS 2012).

Without thoughtful planning, the deployment of offshore renewable energy sources along the northeastern Pacific coast (ocean energy and offshore wind) could add further treats to this endangered population especially within the critical habitat areas identified by NMFS. While technologies to capture ocean energy sources have been implemented or planned in several European and Asian locations, the potential for ocean energy in the western hemisphere is still in early stages of development (IHS EER 2013). The northwestern coast of the United States has especially high potential for ocean wave energy development and is one of only a few areas in the world with abundant, available wave power resources; the Bureau of Ocean Energy Management (BOEM) is currently seeking public comment on the hydrokinetic facility proposal off the coast of Oregon (BOEM 2014). Ocean currents such as the California contain an enormous amount of energy. Submerged water turbines, similar to traditional wind turbines, may be deployed in the coming years to extract this form of energy (BOEM 2014). Water depths off the northwestern coast of the United States limit technologies available to deploy wind turbines.

Impacts on the Pacific leatherback turtle population from the development and deployment of offshore renewable energy technologies along the northwestern coast of the United States may include mortality (through entanglement with offshore and coastal structures or direct collision with structures and/or service vessels), habitat degradation due to increase noise and light disturbance as well as electromagnetic fields (see chapter 5 of this review for more details and references).

1.2.4 Raptors and wind energy in California

Due to the relative mobility of migratory birds compared to other taxa of migratory wildlife and the fact that birds use virtually every habitat type in all biomes, birds may be impacted by more of the renewable energy technologies included in this report than any other migratory species group. A well-studied impact hotspot between migratory bird species and renewable energy technology exists in the southwestern United States. This region hosts extensive onshore wind and solar energy facilities and has a high potential for additional future development of these two renewable energy technologies.

The high avian mortality rates through collisions with turbines and electrocution on power lines at the Altamont Pass Wind Resource Area (APWRA) in central California have been widely reported (Figure A.6). For example, Smallwood & Thelander (2008) estimated the annual wind turbine–caused bird fatalities to number 67 golden eagles *Aquila chrysaetos*, 188 red-tailed hawks *Buteo jamaicensis*, 348 American kestrels (*Falco sparverius*), 440 burrowing owls *Athene cunicularia hypugaea*, 1,127 raptors, and 2,710 birds.

Figure A.6 *The Altamont Pass Wind Resource Area in Central California is currently the largest wind energy facility in the world covering approximately 50,000 acres.*

The high mortality rates at Altamont Pass have been attributed to the geographical location of the site and the antiquated turbine designs. The APWRA in west-central California includes over 5,400 wind turbines, each rated to generate between 40 kW and 400 kW of electric power, or 580 MW total (Smallwood & Thelander 2005). APWRA is located on a major bird migratory route in an area with large concentrations of raptors, including a high density of breeding golden eagles. Fast-spinning blades with small surface area have long since been abandoned for larger more efficient (and safer) blades. Lattice towers, verses tubular designs, were thought to increase mortality rates by providing perch sites and drawing raptors to the blades. However, Smallwood & Thelander (2005) believe this is likely not the problem that it was portrayed to be in the past as they found birds are disproportionately killed by wind turbines mounted on tubular towers, which provide fewer perch sites than do lattice towers.

The California Energy Commission and researchers have recommended replacement of thousands of outdated turbines with fewer, larger turbines, relocating or retiring particularly lethal turbines; siting and configuring turbines to avoid bird flight paths; increasing; discontinuing the rodent poisoning program due to ineffectiveness; and moving managing grazing away from turbines as shorter grasses make rodent prey more accessible, retrofitting power poles to prevent bird electrocutions, and protecting habitat by purchasing land or conservation easements off-site for raptor nesting to compensate for ongoing losses.

1.2.5 Bats and wind energy facilities in northeastern North America

Northeastern and north-central North America hosts a variety of migratory bat species, including rare and endangered species such as the Indiana bat *Myotis sodalis*, gray bat *Myotis grisescens* and the northern long-eared bat *Myotis septentrionalis*. Several studies have documented widespread and extensive bat mortality at onshore wind farms in the eastern and central US (Kunz *et al*. 2007, Arnett *et al*. 2008, Jain *et al*. 2011). The practice of placing wind turbines along forested ridges in eastern North America may contribute to the higher fatality rates at facilities in that region than in the western part of the continent (Kunz *et al*. 2007). The foraging behaviours of bats, which includes multiple fly-bys of rotating and non-rotating wind turbines likely also contributes to higher risk of collision mortality.

Research on bat migration in the marine environment is very limited, but bats are thought to migrate offshore, at least to some extent (Johnson *et al*. 2011). More research will likely come forth as interest in offshore wind energy in North America continues to grow. At present there are several proposed offshore wind farms in North America, including off the coasts of New England and the Mid-Atlantic states. Offshore-migrating bats likely use these same areas in high numbers during spring and fall movements (figure A.7), so the potential for negative interaction in the offshore environment must be considered during siting and operations of marine wind energy facilities.

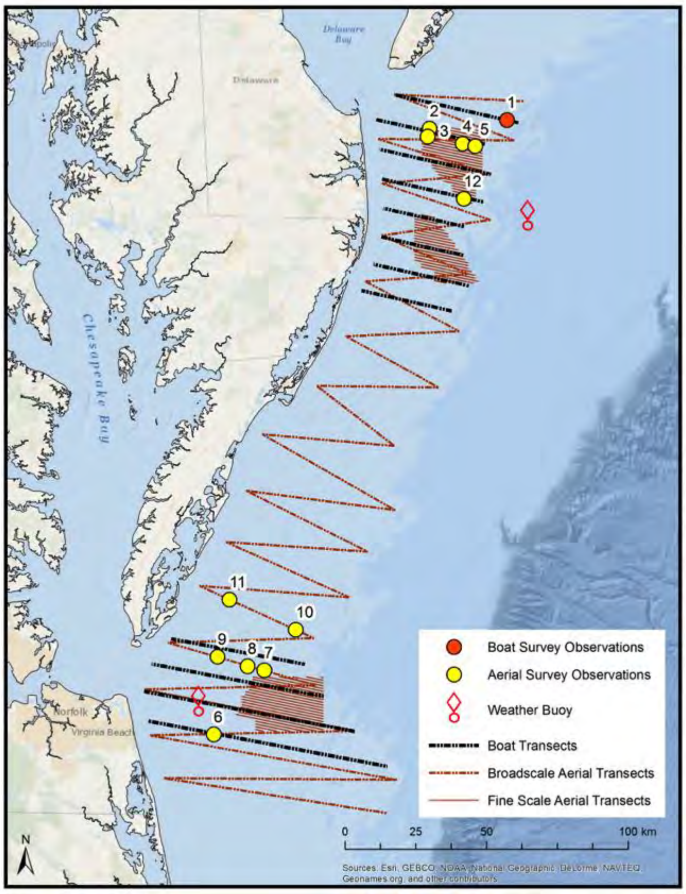

Figure A.7 Observations of eastern red bats during offshore migration off US Mid-Atlantic coast (source: Hatch et al. 2013).

1.2.6 North Atlantic right whale and ocean energy and offshore wind energy

Marine mammals may be impacted by the deployment of ocean energy or offshore wind energy facilities. As neither of these technologies are currently in use in the Western Hemisphere, any impact hotspots between marine mammals and renewable energy technology are speculative and would only exist in the Western Hemisphere if those technologies are ultimately deployed there.

Many species of whales including humpback, finback, right, and minke whales inhabit the western North Atlantic. The North Atlantic right whale *Eubalaena glacialis* is considered by the National Marine Fisheries Service (NMFS) to be the rarest of all large whale species. Census data from 2010 reported fewer than 400 recognized individuals known to be alive in the western North Atlantic (NMFS 2012). More recent analysis of sightings data suggests a slight growth in population size, however, the whales remain critically endangered (NMFS 2014).

The species is typically found near the coast between 20° and 60° latitude. The majority of the western North Atlantic population range from wintering and calving areas in shallow coastal waters off the coast of Florida and Georgia to the summer feeding and nursery grounds in New England waters and north to the Bay of Fundy and Scotian Shelf (North Atlantic Right Whale Consortium 2012, see Figure A.8).

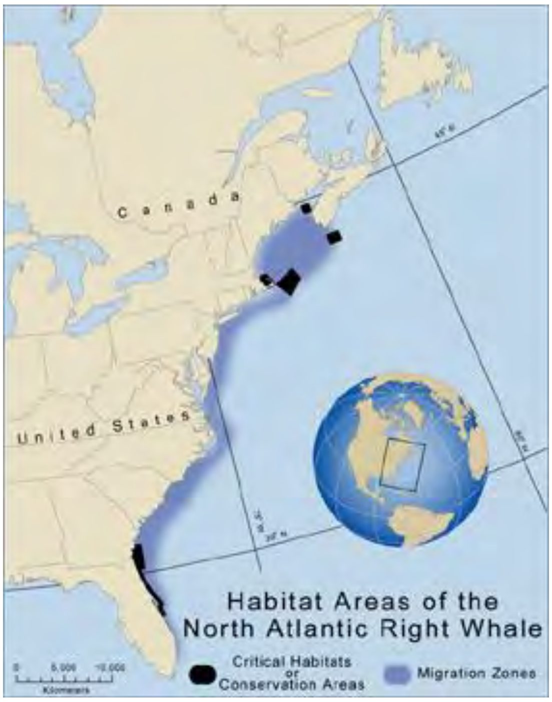

Figure A.8 *Migration zones and critical habitat areas of the North Atlantic right whale (Eubalaena glacialis).*

NMFS identified five "areas of high use" that are key habitat areas for right whales including coastal Florida and Georgia, Great South Channel, Massachusetts Bay and Cape Cod Bay, Bay of Fundy, and the Scotian Shelf (NMFS 2014). During winter months a small number of whales also congregate in Cape Cod Bay and move into the Great South Channel east of Cape Cod in the early spring. The remainder of the population disappears to unknown locations during the winter. By mid-summer and into the fall months, large numbers of right whales migrate to Canadian waters, where they are frequently observed in the Bay of Fundy and sometimes on the western Scotian Shelf. Most of the population can be found in Canadian waters during the summer and early fall months. According to NOAA researchers, about 83% of right whale sightings in the mid-Atlantic region occur within 20 nautical miles of shore (NMFS 2012).

Deployment of offshore renewable energy sources (ocean energy and offshore wind) should avoid the five areas of high use identified by NMFS. While technologies to capture ocean energy sources have been implemented or planned in several European and Asian locations, the potential for ocean energy in the western hemisphere is still in early stages of development (IHS EER 2013). Potential for tidal energy generation is high in areas with high tidal amplitude, including the northeast Atlantic off of the United States and Canada (Boehlert *et al*. 2008, Lewis *et al*. 2011, USEPA 2013). According to a report by the US Department of Energy (USDOE 2010), wind speeds offshore of the western North Atlantic coast from about Long Island, New York to the Atlantic Provinces of Canada are higher than in any other location along the Atlantic coast of North America. This report demonstrates the high potential for offshore wind resource development in the area, which as stated above is also critical for the survival of the North Atlantic right whale. Development and deployment of offshore renewable energy technologies along the western North Atlantic can conflict with the right whale population in a number of ways:

- Conflicts between ocean energy developments and migratory right whales include the potential of such developments to obstruct migratory pathways and introduce acoustical disturbances during both construction and operational phases. Degradation to marine mammal migratory habitat is most likely to occur through acoustical impacts due to noises coming from construction, maintenance, and decommissioning activities as well as operational buoys and cables (Dolman & Simmonds 2010). Acoustical communication between individuals may also be obscured by noise generated by the ocean energy development (Boehlert *et al*. 2008). Mortality during construction is also a significant risk to right whales that may be present within the area of the project site;
- Migratory right whales may also be affected by the construction and operation of offshore wind energy facilities based on the findings of limited studies on marine mammals in Europe. Underwater noise associated with construction of offshore wind energy facilities (especially pile driving operations) has the potential to result in physiological effects and may cause disruptions to migratory marine mammals (Madsen *et al*. 2006). Noise levels from operating wind turbines are unlikely to result in hearing impairment or displacement of migratory marine mammals at any distance (Madsen *et al*. 2006).

1.2.7 Pronghorn and renewable energy (onshore wind, solar and geothermal) deployment in Arizona

Western North America hosts several species of large, migratory terrestrial mammals of the Order *Artiodactyla* including bison (*Bison bison*), elk [wapiti] (*Cervus canadensis*), caribou [reindeer] (*Ranifer tarandus*), and pronghorn antelope (*Antilocapra americana*). Over-exploitation resulting in habitat loss and habitat fragmentation has significantly reduced populations of migratory Artiodactylids in North America, especially bison and pronghorn.

Pronghorns in general are relatively numerous and the species as a whole is listed as Least Concern by the IUCN. However, the Sonoran Desert population in parts of Arizona and New Mexico is protected under the US Endangered Species Act, and populations in Mexico are listed under CITES Appendix I (BLM 2013). Pronghorns have a highly complex social structure. Small family units travel together throughout the year and aggregate into large herds during the winter. Migration distances are determined mainly by the availability of food resources, with wide-ranging migrations occurring during sub-optimal foraging conditions, including drought. In the south-western US state of Arizona, pronghorn range in the north-central flatlands, which are characterized by low amounts of precipitation, extreme seasonal temperature fluctuations, and high wind speeds. Vegetative cover in this area is sparse and low growing and cacti are abundant (BLM 2013).

In Arizona, pronghorn may be impacted by the development and deployment of onshore wind, solar, and geothermal energy technologies. Arizona has a high potential for development of all three of these technologies. Average annual wind speeds in Arizona are similar to other western US states, and are typically higher than in the eastern part of the continent and lower than in the central plains (USDOE 2012). Solar power potential in Arizona and its neighbour states in the US and Mexico is the highest on the continent (USDOE 2009a). Additionally, Arizona and other southwestern and western US states have a relatively high potential for geothermal energy development (USDOE 2009b).

Construction began on Arizona's first utility-scale wind energy facility in 2009. Development of the facility raised concerns that local pronghorn populations could be impacted through disruption of movement patterns, degradation of fawning areas, habitat fragmentation, and avoidance of areas under active construction (AGFD 2011). A radio-tracking study was started in 2010 in an attempt to determine the effects of wind energy development on pronghorn. Several other wind energy facilities are currently being planned in Arizona, the ultimate effects of which on pronghorn are not currently fully understood.

Solar energy developments also have the potential to impact pronghorn in Arizona. Pronghorn habitat at the Sanders Mesa, which is used by pronghorn when adverse weather makes access to other areas too difficult, was reduced by approximately 130 hectares or 50% following the development of solar energy facility there (AGFD 2011). The US Bureau of Land Management (BLM), which holds and administers approximately one third of the total land area of Arizona, has designated over 77,000 hectares of land in Arizona as potentially available for renewable energy development, primarily solar. The BLM has approved two utility-scale solar energy projects within these areas and several other proposals are pending.

The BLM has also approved several geothermal energy projects in neighbouring states, however none are currently approved on BLM land in Arizona. The increase in geothermal development in the region has led to impacts related to most infrastructural developments such as additional vehicular traffic, which can cause habitat fragmentation, avoidance behaviour, and injury or death by collision with vehicles.

1.2 Europe

1.2.1 White stork and renewable energy

Over 90 million birds annually, pass Europe from their breeding areas in the northern United States, Canada, Greenland, Iceland, Siberia or northern Europe to wintering areas in western Europe and on to southern Africa. The migration takes place in spring and autumn and the birds can use one or more stops en route towards their destination.

The white stork (*Ciconia ciconia*) is a good example of a long distance migrant. It breeds mainly in Eastern and Southern Europe (Figure A.9). In the breeding regions, the species inhabits open areas, generally avoiding regions with persistent cold, wet weather or large tracts of tall, dense vegetation such as reedbeds or forests, shallow marshes, lakesides, lagoons, flood-plains, rice-fields and arable land especially where there are scattered trees for roosting (BirdLife International 2014).

Migration after the breeding season starts in August. Birds travel in small and large flocks up to many thousands of individuals to sub-Saharan Africa. Storks migrate with the assistance of thermal updrafts, restricting the migratory routes the species can take. As a result of the lack of thermals, the species must avoid long stretches of open water, such as the Mediterranean Sea. This concentrates the rous along the western Mediterranean (i.e. Straits of Gibraltar) or the east (i.e. Bosphorus in Turkey). The eastern route continues through the Middle East and the Rift Valley / Red Sea Flyway along East Africa, which is the second most important flyway in the world for migratory soaring birds.

Storks generally arrive to their wintering grounds in sub-Saharan Africa by early-October. At the wintering grounds they may gather in large numbers (hundreds or thousands of individuals) concentrating at abundant food sources. During the winter the species shows a preference for habitats such as grasslands, steppe, savannah and cultivated fields, often gathering near lakes, ponds, pools, slow-flowing streams, ditches or rivers (BirdLife International 2014).

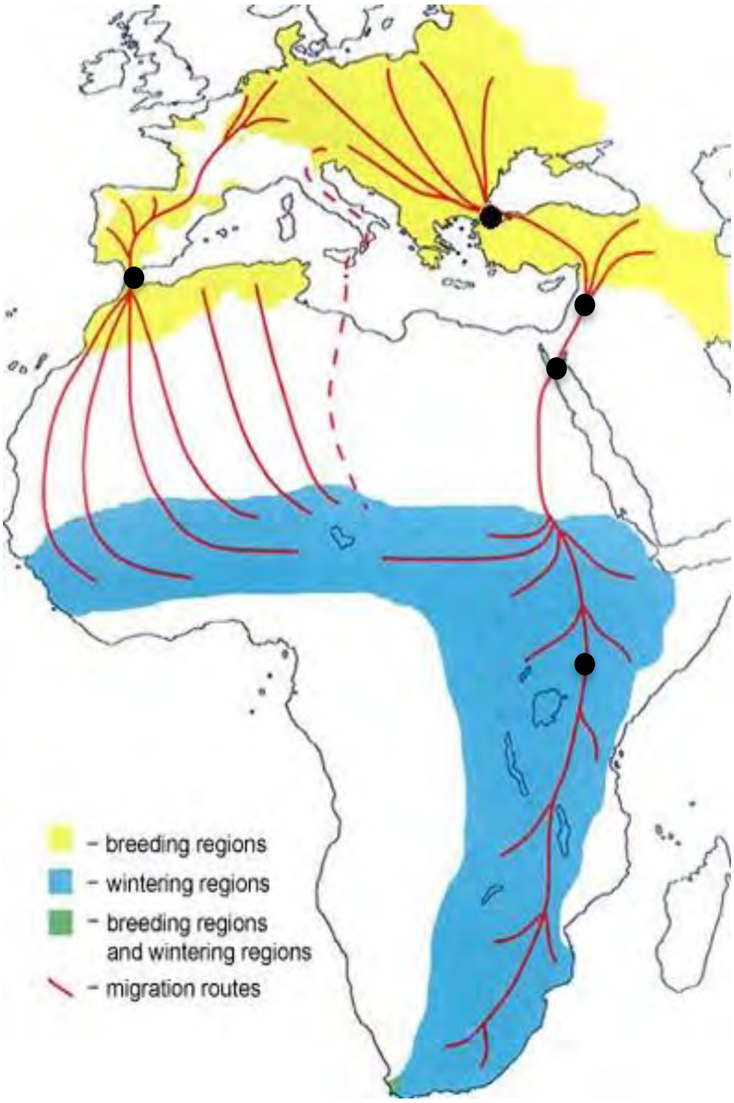

Figure A.9 *Distribution of the white stork in Europe and Africa. Black dots along the migration routes depict examples of migratory bottlenecks where renewable energy developments may potentially result in conflict hotspots.*

Power lines form a very serious threat for white storks during migration, especially because of the risk of electrocution and to a lesser extent collisions with aboveground wires (Prinsen *et al*. 2011). Development of any renewable energy deployment should take this into consideration when planning new power plants and associated infrastructure. Comparably, collisions with wind turbines are not a widespread phenomenon, but examples do exist (Hötker *et al.* 2006; Zielinski *et al.* 2009). In case of migration bottlenecks, such as by Gibraltar, the Bosphorus, and the northern edge of the Red Sea and the Rift Valley (Figure A.9), with very high numbers of migrating white storks, wind farm developments may potentially result in high numbers of casualties.

Once arrived to the wintering grounds in Africa, the major threat to the species by renewable energy developments may be habitat alteration for the production of biofuel crops. This may result in the drainage of wet meadows, conversion of foraging areas and intensification of agriculture. Moreover, the creation of dams and river canalisation schemes for the sake of hydropower stations may result in drought, maybe even the desertification of foraging sites.

As this species has a long migratory pathway, RET development can have impacts on a large scale. This stresses the need for migratory pathway assessments, mortality criteria and international agreements.

1.2.2 Bats and renewable energy

Several bat species are migratory with reproduction areas distinctly different from wintering areas. Some species migrate over long distances. Long distance migratory bat species in Europe fly in a south or south-western direction in autumn (Hutterer *et al.* 2005). Species with a known long distance migration are: Nathusius' pipistrelle, noctule bat, Leisler's bat, greater noctule bat and parti coloured bat (Dietz *et al.* 2007). Most of these species are tree roosting bats, migrating to areas with milder winters where they can safely hibernate. Bats are expected to follow rivers (Furmankiewicz & Kucharska 2009) or coastlines during migration (Petersons 2004, McGuire *et al.* 2012). However, large lakes and the North Sea and Baltic Sea are crossed (Petersons 2004) so observer effects might be important in this respect. Compared to birds, bats migrate relatively slow, generally not covering more than 30-50 km per day (Dietz *et al.* 2007). This, combined with their reluctance to fly during daytime restricts bats to flyways that contain sufficient potential roost sites. This might explain why bats do not seem to cross the Sahara during migration. In North America migrating bats follow mountain chains such as the Rocky Mountains and the Appalachian chain. In Europe most mountain chains are situated east-west and are thus not efficient routes for long distance north-south migration.

Impacts along migration routes
Most migratory bat species can collide with wind turbines (Durr 2013) and can thus be considered as risk species with regards to wind energy development, especially at forested ridges (Arnett *et al.* 2008; Bearwald & Barclay 2009, Brinkmann *et al* 2006). They can collide during migration or at stopover sites.

Within the bats' preferred flyways, suitable stopover sites are particularly high-risk areas. During migration bats use stopover sites to refuel (Dzal *et al.* 2009; McGuire *et al.* 2012). These areas contain both food and potential roost sites within the bats' flyway. They can be islands and peninsula's located along/near the coastline or in big lakes. Forests and wetlands are also high-risk areas, particularly if they can offer roost sites or food that is scarce in the surrounding area. Wind farms in these areas have a particularly high fatality risk. This is exemplified by Bouin, a marsh along the Atlantic coastline in France with one of the largest fatality rates in Europe (mostly noctule bat and Nathusius' pipistrelle; Dulac 2008).

Summarizing, the following areas have a high risk for bats to collide with a wind turbine: coastlines, forested mountain chains, river valleys and the shores of big lakes that run in the bat's preferred direction of travel. Within these structures, suitable stopover sites are particularly high-risk areas: islands, peninsula's, forests and wetlands.

Hotspots near important bat roosts

The most important bat roosts, containing more than thousand individuals are located in caves, mines or other man-made underground structures. In northern Europe the temperature deep inside these underground structures is suitable for hibernation but generally too low for maternity roosts. The number of hibernating bats in northern Europe can be impressive. In Nietoperek, Poland for instance between 20,000 and 30,000 bats are present in winter. Most species are non-migratory or regional migrants, long distance migrants are rarely present here.

In southern Europe, underground structures are also used as maternity roosts. Since it is important to avoid intraspecific competition for food, large groups are only formed by fast flying species that can utilize a large feeding area outside the caves or in areas with an exceptionally high supply of food resources. Typical species that form large roosts are: Schreiber's bat, greater mouse eared bat, and long-fingered bat. These species can be considered as regional migrants. In northern Bulgaria significant roosts of the noctule bat (long distance migrant) occur in the entrance zone of caves.

Potential effects of renewable energy development are flooding of caves, or change of cave climate downstream resulting from the development of hydroelectric plants or habitat degradation/loss (i.e. deforestation) of karst areas, which are generally rich in caves and form important feeding area, by various forms of renewable energy technology deployment.

Obviously a multitude of other important bat roost sites exist: e.g. attics of old buildings such as churches, castles and monasteries, hollow bridge segments, etc. Because of the very small scale of these sites, and often the presence of alternative roost sites in the neighbourhood, the effect of renewable energy development on such roost sites is less likely or easy avoided by proper siting.

1.2.3 Fin whales and offshore renewable energy deployment in the Corso-Liguran basin

Each summer high numbers of fin whales *Balaenoptera physales* migrate towards the Corso-Liguran basin, roughly between Northwestern Italy and Corsica (Figure A.10), mainly from elsewhere in the Mediterranean (Panigada *et al.* 2005; Laran & Gannier 2008) and possibly the Eastern Atlantic Ocean (although this is subject to debate as sighting rates of this species at Gibraltar are relatively scarce). The seas in the Northwestern Mediterranean are characterised by enhanced productivity in summer (Astraldi *et al.* 1994), hence they attract large numbers of seabirds, whales and dolphins. The high numbers of marine top-predators formed the basis to declare the

Pelagos Mediterranean Marine Mammals Sanctuary in this area to draw the attention to this hotspot and to ensure and facilitate the conservation of its inhabitants (http://www.cetaceanhabitat.org/ pelagos.php). In winter numbers of fin whales are substantially lower in this area (Panigada *et al.* 2011), as the whales disperse mainly to other parts of the Mediterranean.

Figure A.10 Location of the Pelagos Sanctuary for Mediterranean Marine Mammals.

Also migratory bottlenecks for marine mammals should be taken into account. An example of such in the Mediterranean is the Strait of Gibraltar, but also many fjords in Scotland and particularly in Iceland and Norway can have a similar function. These areas are often characterised by strong oceanic currents, and would thus provide an ideal situation to develop tidal energy turbines. However, marine mammals often use these corridors to migrate through, often driven by the migration of their prey. Disruption of these migration routes could be caused by renewable energy deployments.

1.3 Africa

1.3.1 Bottlenecks for migratory soaring birds and wind energy

The highest migratory bird diversity is found in the Northern Hemisphere, as many birds breeding in Africa are non-migratory (Somveille *et al.* 2013). Most of the migratory bird species occurring in Africa breed in Europe although short and long distance movements enhanced by the monsoon are common throughout. A typical example of a long distance migrant which can also react on the monsoon is illustrated by the white stork, described in section 1.2.1. The migratory bottlenecks mainly described for that species hold true for a large number of migrants crossing from Europe to Africa and are thus critically important for many diurnally migrating soaring birds (Barrios & Rodriguez 2004).

Within Africa the most important migratory bottlenecks are found at the northern end of the Red Sea between Egypt and Saudi-Arabia, at the southern end of the Red Sea at the most southern point of Yemen and the Rift Valley in East-Africa (Figure A.11). At these points a vast number of migratory soaring birds cross through a very small corridor. At these locations, especially the foreseen wind energy developments may create critical impact hotspots.

The Critical Site Network Tool (http://csntool.wingsoverwetlands.org/csn/down.html) developed for the African-Eurasian region identifies critically important sites for migratory birds that can inform strategic impact assessment and site planning. Recently, BirdLife International has developed a Sensitivity Tool (http://maps.birdlife.org/MSBtool) explicitly for the Migratory Soaring Birds Project, focusing on the Rift Valley / Red Sea Flyway. Both tools incorporate a major amount of bird data from the region, also providing the locations of Important Bird Areas (IBAs).

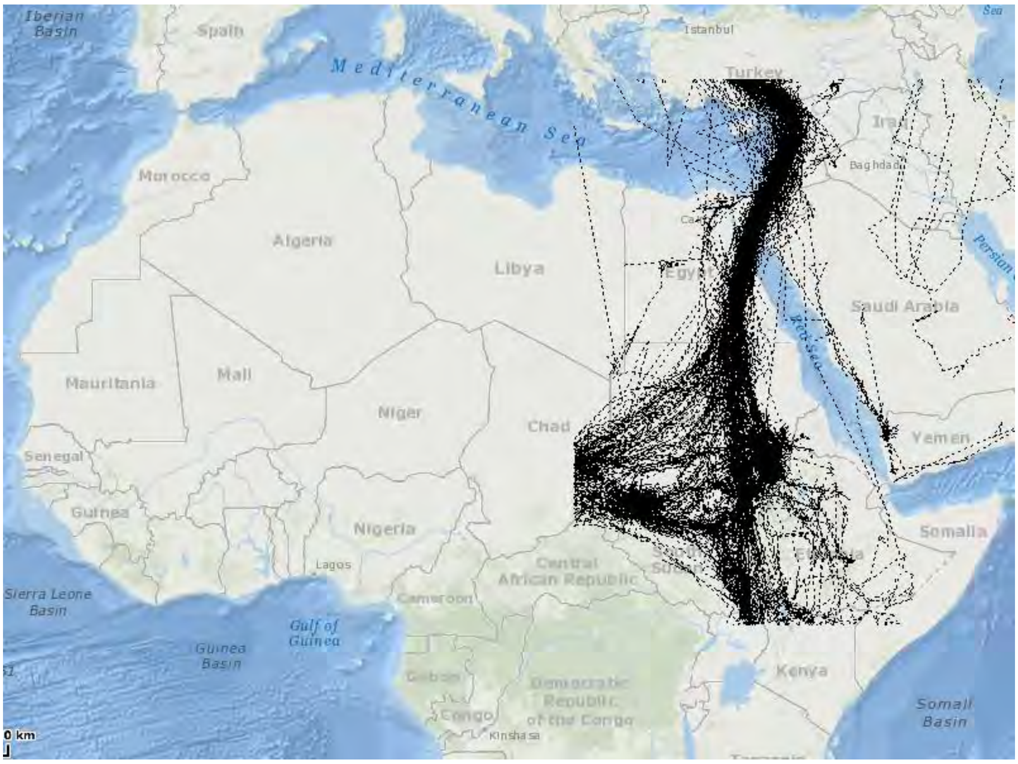

Figure A.11 Soaring bird satellite tracks (black dots) included in the Sensitivity Tool of BirdLife International focusing on the Rift Valley / Red Sea Flyway. The map clearly illustrates the migratory bottlenecks at the northern end of the Red Sea and in the Rift Valley where renewable energy developments may potentially result in conflict hotspots.

1.3.2 Fruit bats and renewable energy deployment

Migration routes

Long distance bat migration from Eurasia to sub-Saharan Africa is yet unkown. There is a clear difference between the Mediterranean and the desert bat species diversity. This difference can be seen between Spain and Morocco as well as between Lebanon and southern Israel (Dietz *et al.* 2007). Long distance migrants from Europe have never been recorded south of the Sahara. In areas where extreme cold winters do not occur, hibernation or torpor is probably a safer strategy to survive a period with low food supply than migrating further. Bats are forced to follow routes that regularly contain potential roost sites. Consequently, the coastline of the Western Sahara seems unsuitable as an important flyway for bats.

However bats such as the straw-coloured fruit bat can migrate long distances south of the Sahara. On an annual basis thousands of kilometres are covered by this species to take advantage of the fruit pulse in northern Zambia (Richter & Cumming 2008). The onset and duration of the rainy season changes with latitude. Therefore, peak availability of fruit, nectar and insects gradually shifts from north to south. This must be a major driving force of bat migration in Africa.

The exact migration routes that bats follow in Africa are unknown. Satellite tracked straw-coloured fruit bats (Richter & Cumming 2008) present the only source of information. Based on this study, little can be deduced about the landscape features that bats follow during migration. Generally, the same ecological principles apply as discussed in 1.2.2. An estimated 5–10 million straw-coloured fruit bats (*Eidolon helvum)* congregate between October and December each year at Kasanka National Park in north-central Zambia (Richter & Cumming 2008). The Kasanka colony is one of the largest known aggregations of fruit bats in the world.

Potential impacts from renewable energy deployment on such a hotspot might be habitat loss due to deforestation when power plants and infrastructure is constructed, but also mortality due to collisions with wind turbines and electrocution at power lines.

1.3.3 Southern right whales and nearshore renewable energy deployment in South Africa

Southern right whales *Eubalaena australis* migrate after the austral summer from Antarctic waters north to spend the austral winter in warmer waters off southern Africa (Best *et al.* 1993, Best & Shell 1996). They use this period to mate and calve. The reason to give birth in temperate waters is possibly to benefit from calmer waters and avoid predation of calves by for example killer whales (Corkeron & Connor 1999). The whales, and especially cow-calf pairs, in South Africa are often distributed very close inshore away from ocean swells and often near sandy beaches (Elwen & Best 2004). This strongly contrasts to other marine mammal hotspots in the world, where congregations of animals are mainly related to food availability. The areas where large numbers of animals congregate are very stable over the years (Elwen & Best 2004).

Due to the inshore distribution of these southern right whales, the possibility for interactions between these animals and renewable energy developments is potentially large. Additionally, most of these animals are in a critical part of their life cycle (either giving birth (cows), or very young (calves)), and possibly more vulnerable than during other parts of the year. Yet, the occurrence and spatial distribution of these animals is very stable over the years and highly predictable. Marine spatial planning of renewables should carefully take into account these micro-sites with higher abundance of whales to minimize interactions and possible adverse effects.

1.3.4 African elephant in the Gourma region of Mali

Africa is home to a number of migrating terrestrial mammals like the African elephant (*Loxodonta africana*) and a number of Artiodactyla (mostly Bovidae).

Over thousands of years Savannah elephants in Africa have evolved migratory patterns to find water and good-quality forage. The desert-adapted African elephants living in Gourma region in Mali, which is situated in the northern part of the Sahel, has one of the planet's widest-ranging terrestrial movement systems. The Gourma elephants are the northernmost population in Africa (Blake *et al.* 2003) and a critical population with respect to the conservation status of the endangered elephants of north-west Africa (Blanc *et al.* 2007; Bouché *et al.* 2011). The population numbers approximately 500 elephants, representing around 10% of all West African elephants. The Gourma elephants inhabit an ecological extreme for the species where the environment is harsh and highly variable, spanning a wide ecological gradient. Water availability and forage abundance and quality are factors known to affect the movements and distribution of elephants in arid and savannah ecosystems (Wall *et al.* 2013).

Research conducted using GPS elephant collars mapped the Gourma elephant ranges and revealed a unique pattern of migration (Wall *et al.* 2013). It was found that the elephants use approximately 38,000 square kilometres of the Gourma region in their quest for food and water. It is the largest range ever recorded for the species and the longest known elephant migration circuit in the world. This population of elephants makes an annual migration circuit to cope with the widely dispersed and variable nature of the Gourma's resource, finding water in the north during the dry season and abundant good-quality forage in the south during the wet season. Their circular migration route is thought to be unique to this population. Throughout the dry season the elephants move from lake to lake, which dry as the season progresses, and eventually converge on Lake Banzena. This lake is the only place with water that Gourma elephants can access at the end of the dry season (Canney *et al.* 2007).

Figure A.12 shows the circular migration route of the Gourma elephant population. Wall *et al.* (2013) found the elephants spend a large amount of time in relatively few areas ('hot-spots' or 'high-use regions). These hotspots, e.g. Lake Banzen, are critical to the spatial integrity of this recorded movement system. These elephant hotspots should be considered conservation priorities (Wall *et al.*, 2013). The study also highlighted possible bottlenecks to the movements of the Mali elephants. The most prominent example is the one mile-wide gateway in a sandstone ridge known locally in French as 'la Porte des Elephants' (Translation: 'Elephant Doorway').

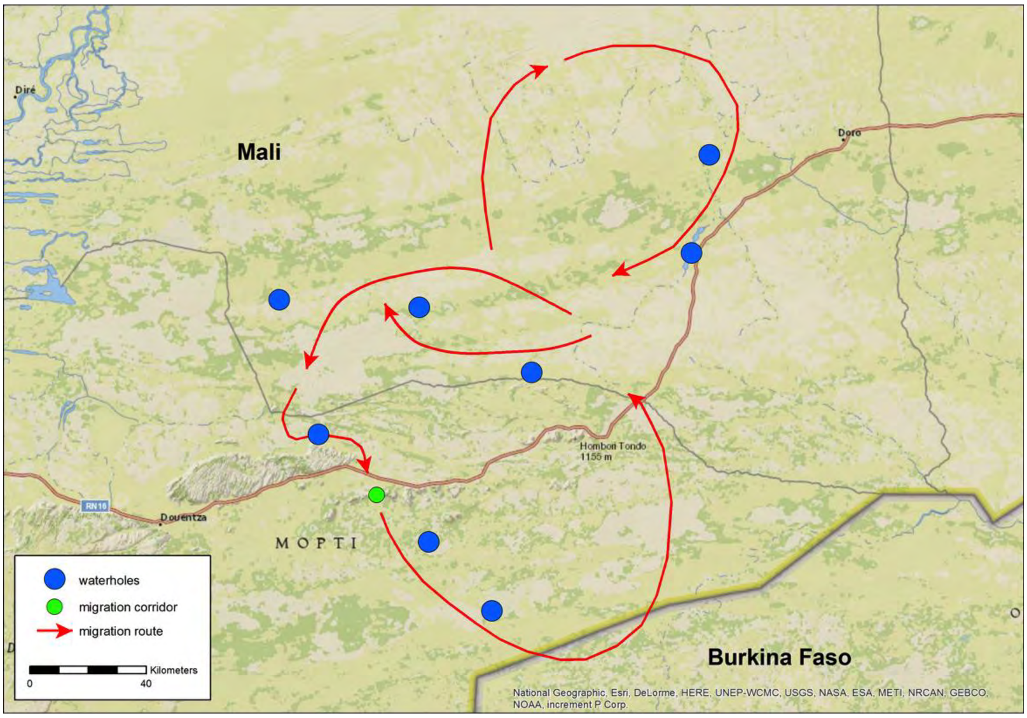

Figure A.12 *Migration routes of elephants in the Gourma region, Mali (adapted from* http://www.wild.org/where-we-work/the-desert-elephants-of-mali*). Permanent and semi-permanent waterholes are vulnerable areas as well as the narrow migration corridor 'la Porte des Elephants'. Mali has significant renewable energy potential, especially solar, hydro and biomass/biofuels. Development of these RETs could all have an impact on the Gourma elephant migration routes. Large-scale solar energy and biomass deployment could form barriers to elephant migration. Hydropower deployment can lead to hydrological alterations, which can lead to the degradation or loss off drinking places on which the elephants depend.*

The Porte des Elephants, through which all migrating elephants must pass. Source: Blake et al. 2013. http://savetheelephants.org/wp-content/uploads/ 2014/03/2003Sahelianelephants.pdf.

Deployment of renewable energy sources should take into account the high-use regions and bottlenecks of the African elephant migration routes as described above. Mali has significant renewable energy potential, especially solar, hydro and biomass/biofuels (IRENA 2013, Ministry of Energy and Water Resources 2012). The potential for solar energy in Mali is well distributed over the national territory. Biomass potential comes from several sources distributed over the country (for example fuel wood, about 33 million ha). An inventory of hydropower sites identified about 20 potential sites nationwide. Of these, only few sites are developed, representing about 22% of the potential capacity. Development and deployment of renewable energy technologies in Mali can conflict with the Gourma elephant population in a number of ways:

a) Hydropower deployment leads to hydrological alterations, which can lead to the degradation or loss off drinking places on which they depend.
b) Biomass deployment can lead to loss of habitat or disruption of migration routes. There also is a risk of secondary effects (disturbance and death) because of conflicts between farmers and elephants, when biomass fields are within the migratory pathways of elephants.
c) Large scale solar energy deployment can lead to disruption of migration routes and to loss of drinking places if important drinking places are used for cooling.

1.4 Asia - Pacific

1.4.1 Terrestrial Mammals

The central Asian region harbours the largest intact and still interconnected grasslands in the world. It is of global importance for many migratory mammals, which rely on large steppe, desert and mountain ecosystems that still provide habitat, space and food resources for long-distance migration. The Central Asian region is home to at least 11 species of terrestrial mammals, most of which are listed as threatened on various threatened species lists such as CMS (Convention on Migratory species). These species depend on moving freely over long distances, including across international borders. The region is one of the world’s last remaining hotspots of large ungulate migrations,

Listed among these species is the Saiga antelope (Saiga tatarica), with its range including Kazakhstan, Mongolia, the Russian Federation, Turkmenistan and Uzbekistan.

The Saiga antelope is a critically endangered migratory ungulate of the steppes and semi-deserts of Eurasia. Until the late 1980s more than a million saigas used to roam the arid regions of Eurasia. After the collapse of the Soviet Union in 1991, saiga populations declined by more than 95%, primarily due to poaching for the species' meat and horn. This population collapse was one of the fastest observed in a large mammal in recent decades. While individual populations are starting to recover, especially the trans-boundary ones continue to be in a perilous state.

Conservation efforts for this species are critically dependent on international collaboration between the range states. Several populations are trans-boundary and the length of the species migratory journeys between summer and winter ranges can exceed 1000 km north to south.

International collaborative work has designed a program for the protection of this species with and associated Action Plan. The work program has been drafted in consideration of biological, economic and social research, as well as practical information provided by a range of stakeholders. Activities focus on monitoring, distribution and variation in breeding grounds along migration routes, reduction of poaching and other measures.

Not much is known on future plans for the use of renewable energy sources in the region, particularly solar and wind energy and therefore the effects of such developments on migratory mammals is difficult to predict. Poaching, habitat degradation from overgrazing by livestock and conversion to agriculture, overhunting, illegal trade and potentially climate change put further pressure on the animals. Because many populations are already small, the impact of these various threats could be further exacerbated by poorly sited renewable energy developments, such as hydropower dams and solar energy plants, particularly those that occupy large areas.

Solar farms don't just represent a possible barrier to land mammal migration in this region but, given the semi-arid nature of much of the region, it could end up a solar energy production hot spot, particularly as the human population of the region expands into the range of these mammals. There is a need to investigate in greater detail the requirements of the Saiga Antelope and other migratory land mammals in the central Asian grasslands and plan for the development of land-hungry solar farms in a way that does not compromise the key habitats and migration routes of this species.

1.4.2 Birds

The Yellow Sea Region lies between North and South Korea to the east and China to the west, and covers an area of 458 000 sq km. Biodiversity in the inter-tidal zone of the Yellow Sea Region is high: excellent feeding and roosting areas accommodate many different species of waterbirds, and preliminary records indicate that the coastal zone of the Yellow Sea eco-region supports about 200 breeding, staging and wintering waterbird and seabird species. The Yellow Sea eco-region is a very important component of the East Asian-Australasian migratory waterbird flyway(Barter 2002).

The Yellow Sea support very large numbers of migratory shorebirds. It is estimated that at least 2,000,000 shorebirds use the region during northward migration, and 1,000,000 during southward migration. This number constitutes approximately 40% of all the migratory shorebirds in the East Asian-Australasian Flyway (Barter 2002, Kelin,& Qiang, 2006).

A total of 36 shorebird species have been found to occur in internationally important numbers at one or more sites in the Yellow Sea, representing 60% of the migratory shorebird species occurring in the Flyway. Several of these species are internationally threatened species.

Whilst the majority of birds use the region’s wetlands as migration staging areas, seven species also occur in internationally important concentrations during the non-breeding season and five species breed in internationally important numbers.

The importance of the Yellow Sea is demonstrated by the fact that it supports more than 30% of the estimated flyway breeding populations of 18 shorebird species during northward migration; for six of the species the region carries almost the whole flyway breeding population at this time.

Twenty seven sites have been identified around the Yellow Sea coastline at which at least one shorebird species has been recorded in internationally important numbers. Ten of these sites are located in China, one in North Korea and sixteen in South Korea.

The rapid growth of the human populations and economies of China and South Korea is causing serious loss and degradation of coastal habitats.

Thirteen rivers empty into the Yellow sea, the largest of which is the Huang He (Yellow River) and Chang Jiang (Yangtze River). The latter two rivers are undergoing significant changes that will greatly reduce the amount of sediment input and it is predicted that future loss of intertidal areas will occur at an increasing rate due to the combined effects of reclamation and reduced accretion.

The Chinees government is now engaged in a new expansion of dams. By 2020, China aims to generate 120,000 megawatts of renewable energy, most of it from hydroelectric power. The hydropower projects built on rivers within the Yellow River basin are predicted to reduce sediment delivery to the sea coast and consequently reduce available feeding grounds for migratory shorebirds. Numerous smaller rivers flowing into the Yellow Sea are also being affected in similar ways leading to reduced sediment input to coastal areas, which often results in erosion of estuaries and intertidal areas.

China and South Korea are both accelerating the development of wind energy. On the south west coast of South Korea, in Jeollabuk-do, the country's largest wind farm (offshore) will shortly commence construction in the shallow seas off this area. Stage 1 will total 100 MW of installed capacity, due for construction in 2015, while stage 2 involves a further 400 MW of capacity. Using turbines ranging from 3MW to 7 MW, this represents the development of several hundred turbines. The shallow seas of the west Korean coast, together with the country's strong maritime and shipbuilding capability provide a basis for the rapid expansion of offshore wind energy development in the nearby shallow waters of the Yellow Sea, close to the key migratory staging grounds of a very significant proportion of the Asian – Australasian flyway populations of shorebirds.

The potential for interaction between migrating shorebirds and wind turbines is considered very high and an understanding of shorebird habitat choice and behaviour should be an essential piece of information to inform the ultimate location and layout of wind farms in this globally important bird migration hub. The Yellow Sea is an excellent candidate for a strategic environmental assessment for the future development of its offshore and coastal wind energy resource.

1.4.3 Bats

Very little is understood about bat migration in Asia and Australia. Small numbers of bats are affected by wind farms in Australia but the impacts are not considered significant at a population level and no migratory species are known to be affected.

Further research is needed on the status and migratory habits and routes of bats in northern Asia before it is possible to identify hot spots that may be vulnerable to renewable energy development, such as wind energy.

1.4.4 Marine mammals

The Southern Right Whale (Eubalaena australis) is a species which was brought to the brink of extinction early in the 20th century. It has a circumpolar distribution in the Southern Hemisphere, occurring between latitudes of approx. 30 to 60 degrees south. It is known to occur in the coastal waters of South America, South Africa, New Zealand and some oceanic islands. In Australia it is recorded along the southern coastline from Perth to Sydney, including Tasmania. The population which spans across the Southern Hemisphere is estimated to be 7,500 with up to 2,100 frequenting Australian waters (DEWHA 2007, IUCN 08). It is thought that many of the populations across the Southern Hemisphere have had a general overall increase of about 7% per year but the populations frequenting south-eastern Australia (Victoria, South Australia, Tasmania and New South Wales) appear not to have exhibited the same rate of increase, placing them in a more vulnerable situation.

In Australia Southern Right Whales have an annual migration between summer feeding grounds in the sub-antarctic waters of the Southern Ocean to more temperate inshore waters off the coast of southern Western Australia, South Australia, Tasmania, Victoria and occasionally New South Wales.
During what is termed the over-wintering months (May to November) they have a tendency to frequent certain coastal areas where localised aggregations occur and during this time breeding, calving and rearing of young takes place. Warrnambool (Logan's Beach), Victor Harbour (in South Australia) and Bunda Cliffs at the Head of the Bight (near Ceduna) seem to be the main calving grounds for Southern Right whales in Australia. In Victoria's South West, the waters east of Warrnambool have proved to be a regular site where calving and rearing takes place. It could be considered the only true nursery area in Australian waters and therefore an important hot spot for this whale.

Several specific management actions has been implemented in southern Australian waters to protect these whales, none of which address the development of renewable energy along ocean shores and its effects on the whales.

Southern Right whales, appear to seek out areas which are close to high wave energy coastlines (beaches with high swells and breaking waves), such beaches suitable for the development of renewable energy produced from the ocean wave energy.

Whales seems to be effected through behavioural reactions to the acoustic output of wave energy buoys during installation and operation. Ocean Power Technologies (Australasia) Pty Ltd is developing a 19 megawatt wave power station connected to the power grid near Portland, Victoria. This would be the nearest project to the Warrnambool hotspot. However, if this form of energy generation expands in south western Victoria and eastern South Australia, there could be scope for interaction with Southern Right Whales at a sensitive stage in their annual life cycle. Consideration should be given to further investigating the possible impacts of wave energy facilities in this part of the world on this important whale hotspot.
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1.4.5 Other mammals

The Chinese River Dolphin (Lipotes vexillifer) is a fresh water dolphin endemic to the Yangtze River of China. Once a thriving population this species is now unfortunately considered extremely rare to the point that it might soon become extinct. The World Conservation Union (IUCN) has now classified this dolphin as Critically Endangered (Possibly Extinct). These dolphins are also known as “the Baiji dolphin”.
The Chinese river dolphin was found in the mouth of the Yangtze River to a point about 1900 kilometres up the river, as well as in the middle and lower regions of the Quintangjiang River and in the Dongting and Poyang lakes.
The Yangtze River is one of the world's busiest waterways, and is subject to a great range of human pressures that have had a serious, detrimental effect on the Baiji. There are four major factors that threaten Baiji survival: Dams and floodgates that block fish migration in the river's tributaries and lakes; fishery exploitation; water pollution; and boat propellers. These stresses, as well as lack of fish food, can inhibit reproduction and consequently lead to extinction.
China currently plans building more dams including one upstream of the Three Gorges Dam in the Yangtze River.
Under the 12th Five Year Plan (2011-2015) being implemented by the Chinese government, about 100 dams are in various stages of construction or planning on the Yangtze and its tributaries — the Yalong, Dadu, and Min. Many of these dams will generate hydroelectricity.
The impacts of dam construction and operation have contributed along with other factors, such as pollution, to degradation of the river environment. This has already depleted food sources, habitat and water quality, leading to mounting pressures on this critically endangered species. Further hydro power development may, in concert with other impacts from the river catchment and adjacent, rapidly developing urban centres, lead to the eventual extinction of this unique species.

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