CREW CENTRE OF EXPERTISE FOR WATERS

Policy Note

The impact of shadow flicker or pulsating shadow effect, caused by wind turbine blades, on Atlantic salmon (*Salmo salar*)

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As the need for onshore wind energy expands, such climate adaptation measures may have unintended and *potentially* significant influences on how fish respond when situated next to rivers or streams.

This CREW Policy Note examines evidence of potential impacts of shadow flicker, from wind turbine blades, on Atlantic salmon in the context of species conservation management and climate mitigation strategy in Scotland.

Overview

- There is no specific evidence available to support or refute any biological or ecological impact of shadow flicker from wind turbine blades on Atlantic salmon.
- The parr life stage of Atlantic salmon was identified as being most likely to be exposed to shadow flicker, but there is no evidence to suggest this would impact the biology or the ecology of the individual.
- There is no evidence available to support whether any habituation to the visual motion of wind turbine blades would impact on the response of an Atlantic salmon to potential predators.
- If an impact was identified, this would need to be interpreted in terms of the number of fish lost as a result of the effects of shadow flicker in comparison to any of the multiple stressors currently facing Atlantic salmon in our rivers.
- Should an impact be identified, various forms of mitigation were identified to prevent shadow flicker being cast on river surfaces.

The above key findings‡ are based on the authors' opinion following the review of the available literature and extrapolation applied to six life stages of Atlantic salmon in freshwaters **(Box 1)**.

BACKGROUND

Onshore wind farm developments have become a common sight within the Scottish landscape, and the installed capacity of onshore wind-generated electricity has expanded, to meet climate adaptation needs. Impacts from the installation and construction of wind turbines near rivers and streams may include changes to water quality or damage to vulnerable habitat (e.g., gravels used for spawning) that affect freshwater fish or by inadvertently creating barriers to their migration. However, the influence of wind turbine blade rotation on fish responses to artificial light patterns in freshwaters is not well understood.

One area of recent consideration is the impact shadow flicker† may have on the biology or ecology of Atlantic salmon (*Salmo salar*), a protected fish species undergoing significant decline across its natural range.

This CREW Policy Note summarises the evidence available on whether there is an impact from shadow flicker from wind turbine blades on Atlantic salmon and what mitigation options may be available to reduce any potential impact.

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† Shadow flicker has been defined as: *"Under certain combinations of geographical position, time of day and time of year, the sun may pass behind the rotor and cast a shadow over neighbouring properties. When the blades rotate, the shadow flicks on and off; the effect or impact is known as "shadow flicker"."* (ClimateXChange, 2017).

‡Authors' opinion has been formed based on a review of the literature and previous experience gained through a foundation of research in the freshwater environment. The opinions expressed have been formed with low confidence due to the level of extrapolation required resulting from to the lack of information and evidence available.

RENEWABLE ONSHORE WIND ENERGY IN SCOTLAND

In response to a changing climate and attempts to reduce emissions from the use of fossil fuels, renewable energy infrastructure continues to grow. For example, the Renewable Energy Directive in 2009 (2009/28/EC) and subsequent amendments has driven the increase in renewable energy production across Europe. Indeed, the target for Scotland is that 100% of energy production by 2050 will be delivered by the renewable energy sector[1].

Onshore wind farm developments have become a common sight within the Scottish landscape to meet climate adaptation needs. Scotland now has over 4,500 wind turbines, relating to schemes in excess of 100kW (i.e. not small wind turbines associated with domestic properties), in operation (Unpublished NatureScot data, up to December 2019). Onshore wind-generated electricity has expanded within a decade and provided approx. 70% of installed capacity of renewable energy since 2016[2]. This renewable energy picture is constantly evolving as more onshore wind farms become operational and the electricity generating capacity changes with improving technology, repowering assets as supply reaches lifespan end, and increasing proportion of offshore wind farms.

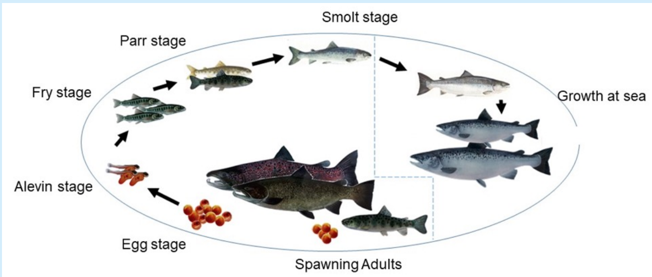
POTENTIAL WIND FARM IMPACTS ON RIVERS AND FISH

The impacts of wind farm installation, in proximity to Scottish inland waters (e.g., rivers, streams), on freshwater and diadromous fish and their associated fisheries has been highlighted by Marine Scotland Science[3]. These include changes to water quality and sediment loading caused during the construction phase through the release of, for example, fine sediments and runoff from drainage of land or pollution incidents. Damage may also occur to vulnerable freshwater habitats (such as gravels used by fish for spawning) in areas where stream and river crossings are constructed, or through habitat loss if barriers to fish migration are inadvertently created. Potential issues associated with shadow flicker effects on freshwater fish, regarding the placement of onshore wind farm installations, are a more recent consideration and have not been investigated previously.

The extent to which freshwater fish, specifically Atlantic salmon, may be exposed to and potentially impacted by shadow flicker (a flickering or pulsating light to shadow cast effect caused by the motion of the wind turbine blades as they pass in front of the sun) is not well understood.

Box 1: The life cycle of Atlantic salmon

Atlantic salmon are an anadromous fish species (reproduce in freshwater and migrate to the sea to take advantage of the better growing conditions). After spending one, two or three years maturing in the marine environment, mature ***adults*** *return, most often to their natal rivers, and lay* ***eggs*** *in a nest called a redd between November and January. Eggs incubate until March/April when the newly hatched animals (****alevin****) are dependent on their yolk sac for food and remain buried within the gravel. Young alevin are relatively immobile, but as they absorb their yolk sac they become more mobile and eventually emerge from the gravel as young fish, commonly referred to as* ***fry****. Fry generally inhabit the faster flowing parts of the river, usually the riffle sections, and start to feed on small prey items, usually macroinvertebrates from the water column. After a year of growth, the animals have reached a size of about 70 mm or larger and are referred to as* ***parr****. Atlantic salmon parr continue to grow in the river until they reach a certain size and thus attain energy reserves before they start the process of smolting. The process of smolting changes the animal's physiology, morphology and behaviour as an adaptation to life in the marine environment. When the animal starts to become silver and migrates towards the marine environment, the animal is referred to as a* ***smolt****. Smolts then feed at sea where they mature and return as adult fish.*



Note that six life stages to the left side of the dotted blue line occur in freshwater, and are the focus of this CREW Policy Note, whilst the right side of the dotted blue line involve life stages at sea. Colin Bean, 2021.

ATLANTIC SALMON CONSERVATION MANAGEMENT

Atlantic salmon are undergoing significant decline across their natural range and are a qualifying feature within 17 Special Areas of Conservation (SACs) in Scotland. In 2019, Scottish Government published a list of twelve high-level pressures affecting Atlantic salmon in freshwater and at sea[4], of these eleven relate to freshwater habitats **(Box 2)**.

Box 2: High-level pressures on Atlantic salmon

In 2019, the Scottish Government published a list of twelve high-level pressures affecting Atlantic salmon in freshwater and at sea. Of these, eleven relate to freshwater habitats; exploitation (the removal of individuals from the population by humans); predation/competition (the removal of individuals from the population by other animals); fish health (the effects from disease and parasites on individual survival); genetic introgression (the effect of altering the genetic integrity of a population through inter-breeding with intentionally stocked or escaped farm salmon); invasive non-native species (multiple effects at the individual and population level); water quality (the impacts of pollutants entering the watercourse); water quantity (the impacts from changes to the flow patterns in rivers from sources such as abstraction and large scale rainfall patterns); water temperature (impacts from changes to the temperature profiles of rivers through, for example, losses in riparian shading); instream habitat (impacts from changes to the cover provided in the river in the form of, for example, substrate and large woody debris); riparian habitat (impacts from losses of riparian vegetation and conifer plantations in areas already under pressure from acidification); migration barriers (loss of habitat through restriction of access via in-river structures). There is no current evidence that any of these eleven high-level pressures consider possible impacts of shadow flicker on Atlantic salmon.

There is a breadth of water policies relating to the conservation and management of Atlantic salmon in Scotland. Statutory obligations to protect Atlantic salmon are undertaken through SACs (via the EU Habitats Directive), through the maintenance and protection of freshwater biodiversity (via the EU Water Framework Directive), and through the management of Atlantic salmon populations (via various statutory commitments delivered by Marine Scotland Science and the District Salmon Fishery Boards). Atlantic salmon are also protected under Appendix III of the Bern Convention, listed as a UKBAP (UK Biodiversity Action Plan) Priority species and in the Scottish Biodiversity Plan (spring stock component only) which has succeeded the UKBAP under the Post-2010 Framework, the status of the stock is monitored by NASCO (North Atlantic Salmon Conservation Organisation), ICES (International Council for the Exploration of the Sea) and OSPAR (Oslo-Paris) Convention. Furthermore, the Scottish Government has been tasked with the delivery of the Wild Salmon Strategy, which is currently under development and is expected during 2021.

FUTURE PERSPECTIVES

The review has highlighted that our understanding of salmonid responses to light has focussed primarily on behavioural responses to acute changes in light intensity with emerging work in the last few decades on responses to strobe light, specifically on high frequency changes in light intensity.

Only since 2019 has evidence about fish behavioural response to more natural light patterns started to emerge. Furthermore, there is a lack of evidence to assess the cognitive abilities of Atlantic salmon to transfer information (i.e., habituation to the movement of wind turbine blades) to a novel setting within the river environment, with the principal concern being modifications of their response to predators. Further research is needed to bridge these knowledge gaps.

POLICY RECOMMENDATIONS

At present there is no evidence to support any change to related policy guidance. However, under the precautionary principle, some advice for best practice might be advised **(Box 3)**.

Box 3: Best practice advice following the precautionary principle

Mitigation can only be drawn up only when a significant impact is evident. Should this be found, then there are four possible measures available to mitigate the impact of shadow flicker cast from wind turbine blades on the water surface and fish populations:

- *For **existing** wind farms:*
  - a. *Changes to the operation of existing wind turbines.*
  - b. *The use of riparian screening to prevent shadow flicker reaching the water surface.*
- *For **proposed** wind farm developments:*
  - c. *Locating new wind turbines at far enough distances to prevent shadow flicker casting on the water surface.*
  - d. *Use appropriately sized wind turbine stem, such that wind turbine blades are not able to cast shadow flicker on the water surface.*

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