# Appendix 16.3

# Bioacoustics Effects and Interim Sound Exposure Guidelines for Fish

**Table A16-3a: Documented effects of noise on relevant Freshwater Fish (from Mickle & Higgs 2018)**

| Species | Techniques Used | Reference / Title | Findings |
|---|---|---|---|
| Rainbow trout (*Oncorhynchus mykiss*) | Physiological: hearing threshold shift using three physiological markers to determine noise impact | Wysocki et al. 2007<br>Effects of aquaculture production noise on hearing, growth, and disease resistance of rainbow trout *Oncorhynchus mykiss* | When exposed to three increments of decibel levels (115, 130 and 150 dB re 1 µPa) rainbow trout hearing sensitivity, growth, survival, stress, and disease susceptibility were not negatively impacted by the increased noise levels. |
| Rainbow trout (*Oncorhynchus mykiss*) | Physiological: hearing threshold shift using three physiological markers to determine noise impact | Davidson et al. 2009<br>The effects of aquaculture production noise on the growth, condition factor, feed conversion, and survival of rainbow trout, *Oncorhynchus mykiss* | Rainbow trout habituated to chronic noise levels up to 150 db RMS with no negative impact on growth and survival over the long term |
| European eel (*Anguilla anguilla*) | Physiological: metabolic rate using increase in oxygen usage | Simpson et al. 2014<br>Anthropogenic noise compromises antipredator behaviour in European eels | Significant increase in oxygen usage in eels exposed to motorboat noise compared to fish in control conditions. 25-50% slower startle response to an 'ambush predator' leading to >2x greater predation rate. |
| Gudgeon (*Gobio gobio*), European perch (*Perca fluviatilis*) | Physiological: increase in cortisol | Wysocki et al. 2006.<br>Ship Noise and Cortisol Secretion in European Freshwater Fishes | Each exhibited increase in cortisol when exposed to ship noise but no increase in cortisol when exposed to Gaussian noise, indicating stress when exposed to anthropogenic noise |
| Eurasian perch (*Perca fluviatilis*), Roach (*Rutilus rutilus*) | Physiological: increase in cortisol | Johansson et al. 2016<br>Stress Response and Habituation to Motorboat Noise in Two Coastal Fish Species in the Bothnian Sea | Short-term noise exposure to both species exhibited an increase in cortisol, whereas the long-term exposure (11 days) fish no longer had elevated cortisol levels, suggesting noise habituation |
| Three-Spined Stickleback (*Gasterosteus aculeatus*) | Behavioural: attention shift, decreasing foraging efficiency | Purser & Radford 2011<br>Acoustic noise induces attention shifts and reduces foraging performance in three spine sticklebacks (*Gasterosteus aculeatus*) | Addition of brief white noise (10sec) to an acoustic habitat increased performance errors and ultimately decreased foraging efficiency in 3-spined sticklebacks |

The following tables are reproduced from Popper et al. (2014). They set out definitions of potential hydroacoustic effects on fishes (**Table A16-3b**) and the criteria for relative risk of an effect taking place in relation to continuous sound (**Table A16-3c**). Note that these criteria are still provisional and that substantially more data are required before firm criteria could be set (Popper & Hawkins 2019).

**Table A16-3b: Definition of Effects Used in Guidelines Tables (Popper et al. 2014)**

| Effect | Definition |
|---|---|
| Mortality and Mortal Injury | Immediate or delayed death. |
| Recoverable Injury | Injuries, including hair cell damage, minor internal or external hematoma, etc. None of these injuries are likely to result in mortality. |
| Temporary Threshold Shift - TTS (hearing loss) | Short- or long-term changes in hearing sensitivity that may or may not reduce fitness. TTS, for these Guidelines, is defined as any change in hearing of 6 dB or greater that persists. Levels less than 6 dB are generally difficult to differentiate and anything less than 6 dB will not be a significant effect from the standpoint of hearing. |
| Masking | Impairment of hearing sensitivity by greater than 6 dB, including all components of the auditory scene, in the presence of noise. |
| Behavioural Effects | Substantial change in behaviour for the animals exposed to a sound. This may include long-term changes in behaviour and distribution, such as moving from preferred sites for feeding and reproduction, or alteration of migration patterns. This behavioural criterion does not include effects on single animals, or where animals become habituated to the stimulus, or small changes in behaviour such as a startle response or small movements. |
| The relative risk of an effect taking place is indicated as being 'high', 'moderate' and 'low'. | |

**Table A16-3c: Continuous sounds – Guidelines for fish (Popper et al. 2014)**

| Type of Animal | Mortality & Potential Mortal Injury | Impairment - Recoverable Injury | Impairment - Temporary Hearing Loss (TTS) | Impairment - Masking | Behaviour |
|---|---|---|---|---|---|
| **Fish: no swim bladder (particle motion detection)** | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Low<br>(F) Low | (N) High<br>(I) High<br>(F) Moderate | (N) Moderate<br>(I) Moderate<br>(F) Low |
| **Fish: swim bladder is not involved in hearing (particle motion detection)** | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) Moderate<br>(I) Low<br>(F) Low | (N) High<br>(I) High<br>(F) Moderate | (N) Moderate<br>(I) Moderate<br>(F) Low |
| **Fish: swim bladder involved in hearing (pressure detection)** | (N) Low<br>(I) Low<br>(F) Low | 170 $dB_{rms}$<br>for 48 h | 158 $dB_{rms}$<br>for 12 h | (N) High<br>(I) High<br>(F) High | (N) High<br>(I) Moderate<br>(F) Low |
| **Eggs and Larvae** | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) Low<br>(I) Low<br>(F) Low | (N) High<br>(I) Moderate<br>(F) Low | (N) Moderate<br>(I) Moderate<br>(F) Low |
| Notes: Root mean square (rms) sound pressure levels dB re 1 µPa. All criteria are presented as sound pressure even for fish without swim bladders since no data for particle motion exist. Relative risk (high, moderate, low) is given for animals at three distances from the source defined in relative terms as near (N – 10's of metres), intermediate (I – 100's of metres), and far (F – 1000's of metres). | | | | | |

** For the most part, data in this table are based on knowing that fish will respond to sounds and their hearing sensitivity, but there are no data on exposure or received levels that enable guideline numbers to be provided.*

## References

Mickle, M.F. & Higgs, D.M. (2018) Integrating techniques: a review of the effects of anthropogenic noise on freshwater fish. Canadian Journal of Fisheries and Aquatic Sciences. 75(9): 1534-1541. https://doi.org/10.1139/cjfas-2017-0245

Popper, A.N. et al. (2014) Sound Exposure Guidelines. In: ASA S3/SC1.4 TR-2014 Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI. SpringerBriefs in Oceanography. Springer, Cham. https://doi.org/10.1007/978-3-319-06659-2_7

Popper, A.N. & Hawkins, A.D. (2019) An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. Journal of Fish Biology, 94, 692– 713. https://doi.org/10.1111/jfb.13948