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Water quality limits for Atlantic salmon (*Salmo salar* L.) exposed to short term reductions in pH and increased aluminum simulating episodes

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Abstract. Acidification has caused the loss or reduction of numerous Atlantic salmon (*Salmo salar* L.) populations on both sides of the North Atlantic. Acid deposition peaked in the 1980's and resulted in both chronically and episodically acidified rivers. At present, water quality is improving in all affected rivers due to reduced acid deposition. However, spring snow melt, heavy rainfall and sea salt episodes can still cause short term drops in pH and elevated concentrations of bioavailable aluminum. Technical malfunction in lime dozers will cause short termed episodic spates in the limed rivers. The current situation has prompted a need for dose-response relationships based on short term exposures of Atlantic salmon to assess the potential population effects of episodic acidification. Water quality guidelines for salmon have been lacking, despite a large number of experiments, all demonstrating dose-response relationships between water chemistry and fish health. We have summarized results from 347 short-term (<14 days) exposures of salmon parr and smolt performed between 1990 and 2003 in Norway. The experiments have been performed as bioassays, where fish have been exposed in tanks fed river water, in tanks where the river water quality has been manipulated (added H^+ and Al) and as Carlin-tagged smolt releases after preexposure to moderately acidic waters. The results from the various bioassays are compared to water quality limits proposed on basis of the relationship between water quality and population status/health in Norwegian rivers. The focus of this article is placed on chemical-biological interactions that can be drawn across experiments and exposure protocols. We propose dose-response relationships for acid neutralizing capacity (ANC), pH, cationic Al and gill accumulated Al, versus mortality in freshwater, effects on hypo-osmoregulatory capacity in seawater challenge tests and on smolt to adult survival in release experiments. The "no effect" dose depends on the life history stage tested and on the sensitivity of the biomarkers. Parr are more tolerant than smolt. Concentrations of Al that have no significant impact on freshwater life history stages can still have major population effects if they occur prior to smolt migration. While smolt can survive in freshwater for a prolonged period of time (>10 days) at an Al dose resulting in a gill Al concentration of up to 300 µg Alg^{-1} dw, a 3 day exposure resulting in a gill Al accumulation in the range of 25 to 60 µg Alg^{-1} dw reduces smolt to adult survival in a dose related manner by 20 to

50%. For smolt to adult survival, the biological significant response is delayed relative to the dose and occurs first after the fish enters the marine environment. In addition to exposure intensity and timing, exposure duration is important for the setting of critical limits.

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