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Impact of Paper Mill Effluent on Reproductive Physiology of Teleost Fish: a Mini Review

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ABSTRACT *The effluents from pulp and paper mills are highly toxic and are a major source of aquatic pollution. Many chemicals have been identified in effluents which are produced at different stages of papermaking which are known to be endocrine disrupting besides being carcinogenic, mutagenic and teratogenic. The major concern for paper mill effluents is its potential for affecting fish reproductive physiology like reductions in sex steroid hormone levels, gonad size, fecundity and delayed sexual maturity and even male-biased sex ratios among fish embryos. It is predicted that the endocrine modulating compounds may interact with steroid hormones and their receptors, or other hormones and transcription factors in the biochemical pathway of hormonal activity. Pulp mill effluents contain ligands for nuclear sex steroid receptors and the plasma sex steroid–binding protein, thereby having the potential to affect steroid hormone signaling and transport in fish.*

Introduction
Teleost fish reproduction is an intricate and well coordinated phenomenon based on hypothalamo-hypophyseal-gonadal axis. Hormones cause gonadal growth, maturation and breeding in teleost with strong support from endogenous rhythm of reproductive physiology in the form of photoperiod, rainfall, temperature and nutritional status. Secretions of trophic (GtH) and gonadal hormones play prime role in this axis. Yet other internal and external factors including hormones (TSH, prolactin), sex pheromones, social quos and even xenobiotic compounds exert modulating effect in this axis directly or indirectly. The last mentioned substances are manmade, non biodegradable or degrade very slowly and can be pesticides (Singh et al. 2003) or industrial discharges or even paper mill effluents (Burton et al. 2007).

Based on numerous international studies, it is now ascertained that pulp and paper mill effluents have the potential to affect fish reproduction. Needless to say that the reduced fish population and large scale fish mortality in water bodies, in the mill vicinity, is due to the deleterious effect of mill effluent.

Paper mill effluent and teleost reproduction
Impairment of reproductive fitness in fish exposed to pulp and paper mill effluents is one of the most well documented cases of wildlife endocrine disruption (McMaster, 2001). Effects documented since the late 1980s at sites where in-depth reproductive studies have been conducted include reductions in gonadal size, reduced fecundity, increased age to maturity, diminished secondary sex characteristics and decreased circulating levels of reproductive sex steroids (McMaster et al. 1991, 1992, 1996, Munkittrick et al. 1991, 1992, 1998, Van Der Kraak, 1998 & Van Der Kraak et al. 1992). It is widely recognized that certain chemicals possess the potential ability of modulating the endocrine systems, and thereby interfere with reproduction and developmental processes (Singh et al. 2003). Co relational evidence is derived from wildlife and laboratory studies associating reproductive and developmental problems in fishes (such as feminization of males, lower fertility and higher progeny mortality) with exposure to 'high' concentrations of synthetic environmental estrogens, for example, feminization and masculinization of fish from water bodies receiving discharges of industrial effluents. Abnormal levels of circulating steroid hormones have been reported in fish exposed to pulp and paper mill effluents (McMaster et al. 1992). Paper mill effluents possess non persistent compounds, capable of altering the endocrine system of fish, and include natural wood components such as fatty acids, resin acids and plant sterols. Several reports have implicated β-sitosterol and genistein, plant products, as a possible significant factor contributing to the reproductive effects observed in fish exposed to paper mill effluents (Cook et al., 1997; Kiparissis et al. 2001).

Endocrine disruption in fish
Number of species of fish such as white sucker, Catostomus commersoni (Munkittrick et al., 1999, Parrott et al., 1999); gold fish, (McMaster et al., 1996), mummichog, (Dubé and MacLatchy, 2000), zebrafish (Örn et al., 2001), perch, Perca fluviatilis (Sandström and Neuman 2003); and fat head minnow (Lowell et al.,2004) living downstream of pulp- and paper-mill effluents have been found to exhibit an array of altered features in their reproductive development, including reductions in gonadal growth, inhibition of spermatogenesis, depressed sex steroids, induction of hepatic mixed-function oxidase (MFO) activities, reduced pituitary hormone concentrations, and delayed sexual maturity. In the studies on perch viability of the developing larvae was also affected (Sandström and Neuman 2003). Lowered egg production and delayed reproduction have also been induced in fathead minnows in life-long exposures to bleached kraft mill effluents (BKMEs) (Borton et al. 2001). Furthermore, the endocrine changes seen in wild fish are less severe during periods of reduced effluent discharge and decrease with increasing distance from the effluent outfalls into the rivers. There is, thus, very strong evidence to suggest that something in the BKME is causing the adverse effects seen. In vitro studies suggest that mixtures of both estrogenic (e.g., β-sitosterol, lignans, stilbenes, and resin acids) and androgenic chemicals (e.g., stigmastanol and a β-sitosterol degradation products), together with Ah-receptor agonists (e.g., polychlorinated dibenzofurans and thianthrenes, dibenzothiphenes, and diphenyl sulfides), are found in these effluents, and these studies are supported by in vivo studies that show that fish, living in the vicinity of BKME discharges, rapidly accumulate chemicals that bind to the estrogen receptor, androgen receptor, and sex steroid binding protein (Parrott et al. 2006). Although it has not been possible to link endocrine disruption (leading to deleterious effects on reproduction and development) in these various species of fish to a specific chemical or group of chemicals, it is clear that the endocrine effects are clearly linked to the constituents of pulp-mill effluents.

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Decreased production of gonadal sex steroids

Abnormal levels of circulating steroid hormones have been reported in fish exposed to pulp and paper mill effluents (McMaster et al. 1992). Endocrine modulating compounds, both environmental and endogenous, may interact with steroid hormones and their receptors, or other hormones and transcription factors in the biochemical pathway of hormonal activity. β-Sitosterol, a phytosterol present in PME, binds weakly to hepatic estrogen receptor (ER) and weakly induces plasma vitellogenin in fish exposed (Tremblay & Van Der Kraak, 1998). Male brook trout (Salvelinus fontinalis) injected with β -sitosterol exhibited up to 36% decreases in plasma cholesterol after 20–21 d (Gilman et al. 2003). While male goldfish implanted with β-sitosterol exhibited >50% decrease in pregnenolone production by gonadal mitochondria (Leusch & MacLatchy 2003). Similarly, newly hatched Japanese medaka (Oryzias latipes) exposed to high concentrations of genistein, a plant isoflavonoid, exhibited altered secondary sex characteristics and abnormal gonadal development (Kiparissis et al. 2001).

Masculinization in fish

Effluents from pulp and paper mills displayed androgenic activity, often with sufficient potency to masculinize and/or sex reverse female fish (Howell et al. 1980; Parks et al. 2001). The induction of male secondary sexual characteristic, namely the development of a male-like gonopodium in female mosquitofish (Gambusia affinis holbrooki) in the vicinity of a pulp mill in Florida has been reported (Howell et al. 1980). Since the development of a gonopodium is androgen-dependent, it has been suggested that the observed masculinization was due to exposure to androgenic substances. In fact, it was demonstrated later on by using bioassays that the pulp mill effluents exhibited androgenic activity. Another example of an environmental androgen inducing masculinization responses is the growth promoter trenbolone acetate and its metabolite 17β-trenbolone, which is found in feedlot effluents. They reported masculinization involving a total natural population of Gambusia holbrooki inhabiting a stream receiving paper-mill effluents (Wilson et al. 2002). Occurrences of male sex characteristics in female fathead minnows, or female sex characteristics in male fathead minnows as was reported in pulp mill effluent exposures by Parrott et al. (2004) and Rickwood et al. (2006). Borton et al. (2000) saw a delay in the development of secondary sex characteristics in fathead minnows exposed to high concentrations of BKME from a mill located in the U.S.A.

Conclusion

The intricate balance in hypothalamo-hypophyseal-gonadal axis of teleost reproduction can be derailed by external disturbances in the form of pulp and paper mill effluents. Based on abundant international studies, it is now ascertained that pulp and paper mill effluents have the potential to affect fish reproduction. Needless to say that the reduced fish population and large scale fish mortality in the rivers, in the mill vicinity, can be due to the deleterious effect of mill effluent.

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