Aquatic pollution is a hot issue in different areas of Pakistan which is rising rapidly due to industrial revolution. Heavy metals are the major source of environmental contaminants, on entering aquatic ecosystem, cause serious problems to aquatic fauna due to their persistent nature (Farombi et al., 2007). Aquatic ecosystems contained these metals in combined form due to diversified sources of their discharge (Lange et al., 2002). Metals in combined form showed much varied effects than in single form (Vosyliene et al., 2003). The complex mixtures of toxicants in water bodies may cause injurious effects on the water living animals (Lopez-Lopez et al., 2011). Water pollution mainly affects the aquatic animals in various ways such as biochemical or physiological disturbance in response to toxicity caused by those pollutants (Begam, 2004).

Among aquatic animals, fishes are most susceptible to changes in their surrounding environment. Fish can be used as a best indicator for assessing the condition of particular water body (Mokhtar et al., 2009; Gupta et al., 2009). The toxicants present in aquatic medium may affect the water quality as well as swimming, feeding, delayed hatching and maturation period of fish (Kumar et
al., 2007; Laovithayanggoon, 2006; Atif et al., 2005). At individual level response, behavior is the one that is result of physiological and molecular modifications as well as ecological processes in organisms (Scott and Sloman, 2004; Weis, 2005). Toxicants have ability to amass in various tissues of fish (Rao and Padmaja, 2000). Therefore, in ecological, toxicological and pathological studies, the most commonly used fish organs are liver, gills, kidney and muscles (Sauer and Watabe, 1989; Velcheva, 2002; Heier et al., 2009) because all these organs are have higher ability to amass the toxicant due to their metabolic activity (Andres et al., 2000; Karadedeh, 2000; Marcovechio, 2004). Oxidative stress due to metals toxicity cause the production of reactive oxygen species (ROS), such as H₂O₂, O²− and OH− that cause oxidation of lipids, proteins, RNA and DNA, which disrupts the structure of cell finally cause the cell death (Cao et al., 2010). Fish tissues are gifted with this system to save them from oxidative stress induced by metals (Atli and Canli, 2008). Antioxidant defense system consists of enzymes like superoxide dismutase, glutathione peroxidase, catalase, glutathione-reductase and glutathione S-transferase (Pinto et al., 2003; Tripathi et al., 2006). Catalase is a key component of defensive system scavenges hydrogen peroxide which has ability to interact with biological membranes and also inhibit some enzyme activities. Evaluation of oxidative stress biomarker such as catalase activity is considered to be a useful measure before any injurious effects appeared in fish (Sanchez et al., 2005; Gul et al., 2004). The heavy metals in the riverine systems are exist in the form of mixtures and their unsafe concentrations exert their negative impacts on the fish, necessitated this research work, that was performed to estimate the acute toxicity of waterborne Fe+Ni+Pb+Zn mixture and its effect on catalase activity in different organs of freshwater fish, Cirrhina mrigala.

Materials and Methods

96 h LC₅₀ and lethal concentration

Cirrhina mrigala (Mori) was selected as an experimental fish. The experimental fish was purchased from Fish Seed Hatchery, Faisalabad. The acute toxicity test (96 h LC₅₀ and lethal concentration) was conducted in the wet laboratory at Fisheries Research Farms, University of Agriculture, Faisalabad, Pakistan. The fish were placed in cemented tank for acclimatization to laboratory conditions for 15 days. Fish were fed with a commercial fish feed twice a day at 3% body weight during the period of acclimation but were starved for 24 h prior to the experiment and throughout the experiment. No mortality was observed during the acclimatization. During acclimatization, 12 h light and 12 h dark photoperiod was maintained. Chlorides Salts of iron (FeCl₂,4H₂O), zinc (ZnCl₂), lead (PbCl₂) and nickel (NiCl₂,6H₂O) were used to make stock solutions of metal. Metals mixture of required concentration was ready by dissolving a suitable volume of stock solution in deionized water. The experimental fish C. mrigala was exposed to each of the 19 different concentrations (5-90 mg/L) of heavy metals mixture (Fe+Zn+Pb+Ni) to determine 96 h LC₅₀ and lethal concentration. The trial was conduct with three replications in 100 L glass aquaria each having ten C. mrigala (90-day old).

Physico-chemistry of test media

The temperature, hardness and pH of water were maintained as 30°C, 225 mgL⁻¹, and 7.5, respectively. The other water quality parameters viz. carbon dioxide, ammonia, electric conductivity, dissolved oxygen, potassium, magnesium, sodium, and calcium, were also measured (APHA, 2005).

Behavioral study

During the acute test, the behavioral abnormalities such as hyperactivity, swimming rate, mucous secretion and fin movement of the healthy (control) and metals mixture exposed fish were regularly observed.

Biochemical study

After acute exposure of metals mixture, fish were sacrificed and organs viz. gills, liver, kidney, muscle and brain of fish was separated to evaluate the catalase activity.

Preparation of homogenate

The dissected organs (gills, liver, kidney, muscle and brain) were, separately, homogenized in cold phosphate buffer in ration of 1:4 (w/v) by using a blender. Organ homogenates were centrifuged for 15 min at 10,000 rpm and 4°C. The clear supernatants were used for catalase assay.

Catalase assay

Catalase activity was noted according to the method of Chance and Mehaly (1977). Buffer substrate solution of H₂O₂ (10 mM) was prepared in 60 mM phosphate buffer (pH 7.0). Reaction mixture contained 2ml of buffered substrate solution and 0.05 ml of enzyme extract. The absorbance was recorded at 240nm.

Statistical analyses

The whole experiment was performed with three replicates. Probit Analysis was applied to calculate the LC₅₀ and lethal values of metals mixture for fish C. mrigala (Hamilton et al., 1977) at 95% confidence interval. Correlation analysis was performed to find out relationship among physico-chemical parameters with Fe+Zn+Pb+Ni mixture concentrations. Statistical differences among different variables were found by performing ANOVA. A regression analysis was applied to check the relationship between various mixture concentration and behavioral parameters under study (Steel et al., 1997).

Results and Discussion

96 h LC₅₀ and lethal concentration

The obtained data on fish mortality with mean 96 h
LC₅₀ and lethal values, concentration of metals in mixture, exposure duration, 95% lower and upper confidence interval limits with their calculated chi-square values are given in Table I. The LC₅₀ and lethal value (96 h) for *C. mrigala* was computed as 47.56±0.04 and 93.89±0.07 mgL⁻¹, respectively. The Deviance Chi-Square and p-value for *C. mrigala* was determined as 3.72 and 0.994, respectively. The mortality of the fish, *C. mrigala*, increased with increasing concentrations of Fe+Ni+Pb+Zn mixture and duration of exposure. Figure 1 shows the relationship between the concentrations of Fe+Ni+Pb+Zn mixture and mortality of *C. mrigala*. Mean LC₅₀ and lethal concentrations of Pb+Ni for *Ctenopharyngodon idella* (56.42±2.51 and 120.98±7.18 mgL⁻¹) and *Hypophthalmichthys molitrix* (55.85±2.84 and 128.44±9.25 mgL⁻¹) was reported by Naz and Javed (2013). Abdullah et al. (2011) calculated the 96 h LC₅₀ value of Pb, Zn, Ni and Mn for *C. mrigala* (90-day old) as 32.68, 40.58, 23.96 and 71.24 mgL⁻¹, respectively. Naz and Javed (2012) find the 96 h LC₅₀ and lethal concentrations of Pb+Ni+Pb+Ni+Mn mixture for *Cirrhina mrigala* as 43.35±0.78 and 75.22±0.45 mgL⁻¹, respectively. The 96 h LC₅₀ and lethal value of Fe+Ni mixture for the fish *C. mrigala* was estimated as 64.44±0.70 and 100.35±0.46 mgL⁻¹, respectively (Naz and Javed, 2013).

Behavioral study

Behavioral abnormalities in the any examined individual are the most responsive signs of toxicant exposure. During acute toxicity test period (4 day) fish behavior was observed. Fish, *C. mrigala* exposed to various concentrations of Fe+Ni+Pb+Zn mixture for 96 h showed a marked change in behavior. The alter behavior of fish such as hyper-activity, swimming rate, mucous secretion and fin movement were increased with increasing the concentration of metals mixture and finally fish became settled at the bottom and all activities were stopped before death. Figure 2 represents the relationship between fish behavior and Fe+Ni+Pb+Zn concentrations used during this experiment. The exposed Fe+Ni+Pb+Zn concentrations showed strong and direct relationship with, fin movement followed by mucous secretion, hyperactivity and swimming rate for *C. mrigala* with R² value of 0.858; 0.853; 0.216 and 0.005, respectively. In control fish, no behavioral changes were recorded. The response and survival of aquatic organism mainly depends on the biological conditions of organisms and physico-chemical parameter of water. In addition, it also depends upon toxicity, type and nature of toxicants (Batool et al., 2014). According to Remyla et al. (2008) modifications in behavioral patterns of organisms is the major responsive sign of anxiety caused by contact to chemicals.

Batool et al. (2014) checked the acute impacts of cadmium and copper on behavioral responses of *Channa marulius* and *Wallago attu*. During the acute exposure of both metals, the fish showed increased surface behavior, hyperactivity and erratic swimming. These results are also similar to the findings of Biuki et al. (2010). Exposure of high concentration of cadmium chloride to fish (*Chanos chanos*) showed behavioural changes such as swimming disorder and fin movements. According to Susan and Sobha (2010) exposure of fenvalerate change the behavior (such as swimming at the water surface, increased mucus production and hyperexcitation) of *C. catla*, *L. robota* and *C. mrigala*. Hesni et al. (2010) reported that the milkfish (*Chanos chanos*) exposed to lead nitrate showed behaviour changes such as downward and vertical swimming patterns, increased mucus secretion, hyperactivity and loss of balance. The abnormal behavior like hyperactivity was dose and duration dependent (Tiwari et al., 2011).

---

Figure 1: Relationship between *C. mrigala* mortality (%) and exposed concentrations of Fe+Ni+Pb+Zn mixture (mgL⁻¹) during 96 h acute toxicity test.
Table I: 96 h acute toxicity of heavy metals mixtures (mgL⁻¹) for *Cirrhina mrigala*.

| Fish species | Metals mixture | Mixture ratio | LC₅₀ 95% CI (LCL-UCL) | Lethal conc. 95% CI (LCL-UCL) | Pearson goodness of fit tests |
|--------------|----------------|---------------|-----------------------|-----------------------------|-----------------------------|
| *Cirrhina mrigala* | Fe+Ni+Pb+Zn | 1:1:1:1 | 47.56 38.93-53.62 | 93.89 84.07-111.44 | 3.72 13 0.994 |

CI, confidence interval (mgL⁻¹); LCL, lower confidence limit (mgL⁻¹); UCL, upper confidence limit (mgL⁻¹); Lethal Conc., lethal concentrations (mgL⁻¹); DF, degree of freedom.

Figure 2: Behavioral response of *C. mrigala* exposed to various concentrations of Fe+Ni+Pb+Zn mixture.

Figure 3: Catalase activity in different organs of *C. mrigala* exposed to 96 h LC₅₀ concentration of Fe+Ni+Pb+Zn mixture.
**Catalase activity**

Figure 3 shows the exposure of Fe+Ni+Pb+Zn mixture at 96 h LC_{50} concentration caused significant depletion in catalase level in all observed organs of C. mrigala as compared to control. Results were statistically highly significant (p>0.001). According to Batool et al. (2014) acute exposure of metals (chromium and cadmium) to fish caused reduction in catalase activity. Mohanty and Samanta (2016) reported the significantly reduced catalase activity in Notopterus notopterus muscle tissues exposed to Fe, Cu, Ni, Cd, Pb and Zn from Mahanadi River. Present work was supported by Atli and Canli (2010), who reported the reduced catalase level in kidney and liver of tilapia under the acute exposure of metals viz. Cu, Cd, Zn, Cr and Fe. Heavy metals (Cr, Ni, Pb and Cd) altered the antioxidant enzymes activities in all tissues (gills, brain, kidney and liver) of Heteropneustes fossilis and Channa striatus inhabiting Kali River of northern India (Fatima and Usmani, 2015). According to Atli and Canli (2010) fluctuation in antioxidant enzymes responses against metal exposures, depend upon nature of toxicants, organ and type of exposure. CAT is primarily a peroxisomal enzyme that converts the hydrogen peroxide into water and oxygen (Fatima and Usmani, 2015). According to the Atli and Canli (2010) the inhibition in catalase may be due to the binding of metal ions to–SH groups on catalase which results in increased O_2^- and H_2O_2 radicals. According to Orun et al. (2008) catalase level dropped off significantly in liver of Oncorhynchus mykiss when exposed to metals (Cd+2, Cr+3 and Se).

**Conclusion**

This study demonstrated that acute toxicity of heavy metals mixture not only affects the behavior of fish but also had negative impact on antioxidant enzyme (catalase) of fish. It was also concluded that catalase enzyme can be taken as a sensitive biomarker in eco-toxicology and fish can be used as a good indicator of water contamination.

**Conflicts of interest**

The authors declare no conflicts of interest.

**References**

APHA, 1998. *Standard method for examination of water and waste water*, 20th ed. American Public Health Association, New York, pp. 1193.

Abdullah, S., Javed, M., Yaqub, S. and Ahmad, N., 2011. Metal bioaccumulation patterns in major carps during acute toxicity tests. *Int. J. agric. Biol.*, **13**: 756-760.

Andres, S., Ribeyre, F.J., Tourenq, N. and Boudou, A., 2000. Interspecific comparison of cadmium and zinc contamination in the organs of four fish species along a polymetallic pollution gradient (Lot River, France). *Sci. Total Environ.*, **248**: 11-25. https://doi.org/10.1016/S0048-9697(99)00477-4

Atif, F., Parvez, S., Pandey, S., Ali, M., Kaur, M., Rehman, H., Khan, H.A. and Raisuddin, S., 2005. Modulatory effect of cadmium exposure on deltamethrin induced oxidative stress in *Channa punctatus* Bloch. *Arch. Environ. Contam. Toxicol.*, **49**: 371-377. https://doi.org/10.1007/s00244-003-9231-4

Atli, G. and Canli, M., 2008. Responses of metallothionein and reduced glutathione in freshwater fish *Oreochromis niloticus* following metal exposures. *Environ. Toxicol. Pharm.*, **25**: 33-38. https://doi.org/10.1016/j.etap.2007.08.007

Atli, G. and Canli, M., 2010. Response of antioxidant system of freshwater fish *Oreochromis niloticus* to acute and chronic metal (Cd, Cu, Cr, Zn, Fe) exposures. *Ecotoxicol. Environ. Safe.*, **73**: 1884-1889. https://doi.org/10.1016/j.ecss.2010.09.005

Batool, M., Abdullah, S. and Abbas, K., 2014. Antioxidant enzymes activity during acute toxicity of Chromium and cadmium to *Channa marulius* and *Wallago attu*. *Pak. J. agric. Sci.*, **51**: 1017–1023.

Begam, G., 2004. Carbofuran insecticide induced biochemical alterations in liver and muscle tissues of the *Clarias batrachus* (Linn) and recovery response. *Aquat. Toxicol.*, **66**: 83-92. https://doi.org/10.1016/j.aquatox.2003.08.002

Biuki, N.A., Savari, A., Mortazavi, M.S. and Zolgharnein, H., 2010. Acute toxicity of cadmium chloride (CdCl_2.H_2O) on *Chanos chanos* and their behavior responses. *World J. Fish. Mar. Sci.*, **2**: 481-486.

Cao, L., Huang, W., Liu, J., Yin, X. and Dou, S., 2010. Accumulation and oxidative stress biomarkers in Japanese flounder larvae and juveniles under chronic cadmium exposure. *Comp. Biochem. Physiol. C: Toxicol. Pharmacol.*, **151**: 386–892.

Chance, M. and Mehaly, A.C., 1977. Assay of catalase and peroxidase. *Methods Enzymol.*, **2**: 764-817. https://doi.org/10.1016/S0076-6879(55)02300-8

Farombi, O., Adelowo, O.A. and Ajimoko, Y.R., 2007. Biomarkers of oxidative stress and heavy metal levels as indicators of environmental pollution in African cat fish (*Clarias gariepinus*) from Nigeria Ogun River. *Int. J. environ. Res. Publ. Hlth.*, **4**: 158-165. https://doi.org/10.3390/ijerph2007040011

Fatima, M. and Usmani, N., 2013. Histopathology and bioaccumulation of heavy metals (Cr, Ni and Pb) in fish (*Channa striatus* and *Heteropneustes fossilis*) tissue: A study for toxicity and ecological impacts. *Pak. J. biol. Sci.*, **16**: 412-420. https://doi.org/10.3923/pjbs.2013.412.420

Gul, S., Belge-Kurutas, E., Yildiz, E., Sahin, A. and Doran, F., 2004. Pollution correlated modifications of liver antioxidant systems and histopathology of fish (Cyprinidae) living in Seyhan Dam Lake, Turkey.
Gupta, A., Rai, D.K., Pandey, R.S. and Sharma, B., 2009. Analysis of some heavy metals in the riverine water, sediments and fish from river Ganges at Allahabad. *Environ. Monit. Assess.*, 157: 449-458. https://doi.org/10.1007/s10661-008-0547-4

Hamilton, M.A., Rusoo, R.C. and Thurstan, R.V., 1977. Trimmed spearman–karber method for estimation for medical lethal concentration in toxicity bio-assay. *Eviren. Sci. Toxicol.*, 11: 714-719. https://doi.org/10.1021/es60130a004

Heier, L.S., Lien, I.B., Stromseng, A.E., Ljones, M., Roseland, B.O., Tollefsen, K.E. and Salbu, B., 2009. Speciation of lead, copper, zinc and antimony in water draining a shooting range–Time dependent metal accumulation and biomarker responses in brown trout (*Salmo trutta* L.). *Sci. Total Environ.*, 407: 4047-4055. https://doi.org/10.1016/j.scitotenv.2009.03.002

Hesni, M.A., Savari, A., Dadolahi, A., Mortazavi, M.S. and Rezaee, M., 2010. *The study of acute toxicity of lead nitrate Pb (NO₃)₂ metal salt and behavioural changes of milkfish* (*Chanos chanos*). Conference Hand Book, Farming the Waters for People and Food, Thailand.

Karadedeh, E.U., 2000. Concentrations of some heavy metals in water, sediment and fish species from the Ataturk Dam Lake (Euphrates), Turkey. *Chemosphere*, 41: 1371-1376. https://doi.org/10.1016/S0045-0326(00)00563-9

Kumar, P., Prasad, Y. and Patra, A.K., 2007. Levels of cadmium and lead in tissues of freshwater fish (*Clarias batrachus* L.) and chicken in Western UP (India). *Bull. Environ. Contam. Toxicol.*, 79: 396–400. https://doi.org/10.1007/s00128-007-9263-y

Lange, A., Ausseil, O. and Senger, H., 2002. Alterations of tissue glutathione level and metallothionein mRNA in rainbow trout during single and combined exposure to cadmium and zinc. *Comp. Biochem. Physiol.,* 131: 231-243. https://doi.org/10.1016/S1532-0456(02)00108-0

Laovitthyanggoon, S., 2006. *Effects of cadmium level on chromosomal structure of snakehead-fish* (*Ophiocephalus stiatus*). Faculty of Graduate Studies, Mahidol University, Thailand.

Lopez-Lopez, E., Sedeno-Diaz, J.E., Soto, C. and Favari, L., 2011. Responses of antioxidant enzymes, lipid peroxidation, and Na⁺/K⁺-ATPase in liver of the fish *Goodea atripinnis* exposed to Lake Yuriria water. *Fish Physiol. Biochem.*, 37: 511-522. https://doi.org/10.1007/s10695-010-9453-0

Marcovecchio, J.E., 2004. The use of *Micropogonias furnieri* and *Magil fiza* as bioindicators of heavy metals pollution in La Plata river estuary, Argentina. *Sci. Total Environ.*, 323: 219-226. https://doi.org/10.1016/j.scitotenv.2003.09.029

Mohanthy, D. and Samanta, L., 2016. Multivariate analysis of potential biomarkers of oxidative stress in *Notopterus notopterus* tissues from Mahanadi River as a function of concentration of heavy metals. *Chemosphere*, 155: 28-38. https://doi.org/10.1016/j.chemosphere.2016.04.035

Mokhtar, M.B., Ahmad, Z.A., Vikneswaran, M. and Sarva, M.P., 2009. Assessment level of heavy metals in *Paeneaus monodon* and *Oreochromis mossambicus* spp. in selected aquaculture ponds of high densities development area. *Europ. J. Scient. Res.*, 30: 348-360.

Naz, S. and Javed, M., 2012. Evaluation of acute toxicity of metals mixture and bioacccumulation in freshwater fish. *Biosci. Methods*, 4: 11-18.

Naz, S. and Javed, M., 2013. Studies on the toxic effects of lead and nickel mixture on two freshwater fishes, *Ctenopharyngodon idella* and *Hypophthalmichthys molitrix*. *J. Anim. Pl. Sci.*, 23: 798-804.

Orun, I., Talas, Z.S., Ozdemir, I., Alkan, A. and Erdogan, K., 2008. Antioxidative role of selenium on some tissues of (Cd²+, Cr³+) induced rainbow trout. *Ecotoxicol. enviro. Safe.,* 71: 71-75. https://doi.org/10.1016/j.ecoenv.2007.07.008

Pinto, E., Sigaud-Kutner, T.C.S., Leitao, M.A.S., Okamoto, O.K., Morse, D., Colepcolpo, P., 2003. Heavy metal-induced oxidative stress in algae. *J. Phycol.,* 39: 1008-1018. https://doi.org/10.1111/j.0022-3796.2003.0193.x

Rao, L.M. and Padmaja, G., 2000. Bioaccumulation of heavy metals in *M. cyprinoids* from the harbor waters of Visakhapatnam. *Bull. Pure appl. Sci.,* 19: 77-85.

Remyla, S.R., Mathan, R, Kenneth, S.S. and Karunthchalam, S.K., 2008. Influence of zinc on cadmium induced responses in a freshwater Teleost fish *Catla catla*. *Fish Physiol. Biochem.*, 34: 169–174. https://doi.org/10.1007/s10528-007-9157-2

Saima, N. and Javed, M., 2012. Acute toxicity of metals mixtures for fish, *Catla catla, Labeo rohita* and *Clarias batrachus*. *Pak. J. agric. Sci.*, 49: 357–361.

Sanchez, W., Palluel, O., Meunier, L., Coquery, M., Porcher, J.M. and Ait-Aissa, S., 2005. Copper-induced oxidative stress in three-spined stickleback: Relationship with hepatic metal levels. *Environ. Toxicol. Pharmacol.*, 19: 177–183. https://doi.org/10.1016/j.etap.2004.07.003

Sauer, G.R. and Watene, N., 1989. Ultrastructural and histochemical aspects of zinc accumulation in freshwater fish scales. *Tissue Cell*, 21: 935–943. https://doi.org/10.1016/0106-8833(89)90044-X

Scott, G.R. and Sloman, K.A., 2004. The effects of environmental pollutants on complex fish behavior: Integrative behavioral and physiological indicators of toxicity. *Aquat. Toxicol.*, 68: 369–392. https://doi.org/10.1016/j.aquatox.2004.03.016
Steel, R.G.D., Torrie, J.H. and Dinkkey, D.A., 1997. Principles and procedures of statistics: a biometrical approach, 2nd ed. McGraw Hill Book Co., Singapore.

Susan, T.A. and Sobha, K., 2010. A study on acute toxicity, oxygen consumption and behavioural changes in the three major Carps, *Labeo rohita* (Ham), *Catla catla* (Ham) and *Cirrhus mrigala* (Ham) exposed to fenvalerate. *Biol. Res. Bull.*, 1: 24-28.

Tiwari, M., Nagpure, N.S., Saksena, D.N., Kumar, R., Singh, S.P., Kushwaha, B. and Lakra, W.S., 2011. Evaluation of acute toxicity levels and ethological responses under heavy metal cadmium exposure in freshwater teleost, *Channa punctata* (Bloch). *Int. J. aquat. Sci.*, 2: 36-47.

Tripathi, B.N., Mehta, S.K., Amar, A. and Gaur, J.P., 2006. Oxidative stress in *Scenedesmus* sp. during short- and long-term exposure to Cu$^{2+}$ and Zn$^{2+}$. *Chemosphere*, 62: 538-544. https://doi.org/10.1016/j.chemosphere.2005.06.031

Velcheva, I., 2002. Content and transfer of cadmium (Cd) in the organism of freshwater fishes. *Acta Zool. Bulgarica*, 54: 109-114.

Vosyliene, M.Z., Kazlauskiene, N. and Svecevicius, G., 2003. Effect of a heavy metal model mixture on biological parameters of rainbow trout, *Oncorhynchus mykiss*. *Environ. Sci. Pollut. Res.*, 10: 103-107. https://doi.org/10.1065/espr2002.02.109

Weis, J.S., 2005. Does pollution affect fisheries? Book critique. *Environ. Biol. Fish.*, 72: 357-359. https://doi.org/10.1007/s10641-004-1618-1