Assessment of immunomodulator biomarkers (Tnf-α, Il-1β and Il-6) in liver of *Capoeta umbla* for biomonitoring of pollution in Uzuncayir Dam Lake (Tunceli, Turkey)

Yildirim N.C. *; Danabas S.

Received: January 2013 Accepted: May 2014

Abstract

This study was aimed to monitor water pullution of Uzuncayir Dam Lake using the changes of IL-6, IL1β and TNF-α levels in *Capoeta umbla* (Heckel, 1843) liver tissue at ten stations in March and September 2011. In this study *C. umbla* (Heckel, 1843) was used as the indicator organism. Tumor necrosis factor-α (TNF-α), interlekuin1β (IL-1β) and interleukin-6 (IL-6) levels were determined in samples of the liver tissue by ELISA kit. The lowest mean IL-1β levels were found at station 6. The mean IL-1β was reached its maximum level at station 2. The difference between the mean levels of IL-6 was found to be significant (p<0.05) amoung stations. The IL-6 levels were significantly increased in September at stations 1, 2, 7 and 8 (p<0.01) compared to the values in March. The mean levels of TNF-α were found to be significant (p<0.05) amoung stations. The TNF-α levels significantly decreased in September at stations 1 and 9 (p<0.01). TNF-α, IL-1β and IL-6 levels in *C. umbla* can be used as early diagnostic indicators against adverse environmental events and useful and reliable bioindicators in determining the pollution of the aquatic ecosystem.

Keywords: *Capoeta umbla*, TNF-α, IL-1β, IL-6, Biomonitoring, Biomarker

Department of Environmental Engineering, Faculty of Engineering, Tunceli University, Tunceli, Turkey

*****Corresponding author's email: nurancyildirim@gmail.com

[DOR: 20.1001.1.15622916.2014.13.3.12.6]

Introduction

Vast quantities of pollutants are discharged daily into water bodies, where they affect aquatic life at different stages of development. The studies on these effects on aquatic life can indicate the potential effects of pollutants on humans who are exposed to the toxins through consumption of contaminated food and water. Since these toxicants in water are taken up readily by fishes, they can prove to be a valuable model system to study the consequences of toxicant uptake and bioaccumulation on metabolic activities and immune function (Nayak, 2003; Hook *et al*., 2006).

Immune function assays have received less attention as a potential bioindicator of exposure and effect of contaminants. However, immunologists have clearly demonstrated in a variety of organisms that several classes of xenobiotics target the immune system resulting in altered immune function (Anderson and Zeeman, 1995).

The immune system and response of fish can be greatly influenced by various external factors such as temperature, light, water quality, salinity and different stress inducers (Magnadottir, 2010). Stresses imposed upon the immune system of fish by environmental pollutants may not be overtly apparent and may act indirectly to exacerbate disease states by lowering resistance and allowing the invasion of environmental pathogens (Zelikoff, 1998).

Releasing cytokine is considered to be very relevant to investigate the toxicity towards the immune system (Carfi *et al*., 2007). In particular, pro-inflammatory cytokines, including interleukin-1β (Zou *et al*., 1999), TNF-α (Laing *et al*., 2001), and IL-6 (Kishimoto and Hirano, 1988), are commonly used immune-regulatory genes in fish. Interleukin-1β (IL-1 β) is a key mediator of host response infections and a primary cause of inflammation (Dinarello, 2002), identified in 13 teleost species with a role similar to that in mammals (Mathew *et al*., 2002).

IL-1β was one of the few cytokines that discovered in fish by homology cloning (Zou *et al*., 1999). In many species of teleost fish including salmonids (Zou *et al*., 1999; Ingerslev *et al*., 2006), cyprinids (Fujiki *et al*., 2000), gadoids (Corripio-Miyar *et al*., 2007), perciforms (Pelegrin *et al*. 2001; Covello *et al*., 2009) and anguilliforms (Tsutsui *et al*., 2007), it has been cloned, and has also been cloned from cartilaginous fish (Bird *et al*., 2002). The function of IL-1β in these fish species is analogous to mammalian (Mathew *et al*., 2002). IL-1β production is stimulated by a variety of agents, including endotoxin, that stimulate molecular pattern receptors.

TNF-α is an inflammatory cytokine in mammals and is produced by macrophages, neutrophils, monocytes, natural killer cells and T cells after stimulation by bacterial lipopolysaccharide. It semes that the sam mode were happen in fish species such as rainbow trout (Laing *et al*., 2001), carp (Saeij *et al*., 2003), catfish (Zou *et al*., 2003), red seabream (Cai *et al*., 2003), Atlantic salmon (Ingerslev *et al*., 2006), Gilthead seabream (Garcia-Castillo *et al*.,

[DOR: 20.1001.1.15622916.2014.13.3.12.6]

2002) and the mandarin fish (Xiao *et al*., 2007).

IL-6 is mainly secreted by T cells and macrophages to stimulate immune response to inflammation (Hirano, 1998) and has been described in Fugu (Bird *et al*., 2005), rainbow trout (Iliev *et al*., 2007) and seabream (Castellana *et al*., 2008).

Increasing attention has been paid to the immun system of fish as a biomarker of xenobiotic stress (Bowser *et al*., 1994). *C. umbla* is of great commercial importance because it is the most common fresh water fish widely consumed in Tunceli.

The cytokines are important regulators of the immune system in fish (Sahoo and Sakai, 2010), therefore, investigation of cytokine functions may provide data that can be used as a biomarker for monitoring water pollution. The main purpose of this study is to monitor physiological changes in fish that live in the lake water of Uzuncayir Dam Lake that are already collected water about three years. To reveal the effects of the pollution on the living elements in the river and lake, in fish samples, taken from ten points some cytokines (IL 1-β, TNF-α and IL-6) levels were determined.

Materials and methods

Sampling

Ten research stations were determined taking into account the pre-dam, Dam Lake and post-dam points at Munzur and Pulumur Rivers and Uzuncayir Dam Lake (Fig1).

Fishes samples were collected during March and September in 2011. Sampling months were selected that could indicate possible seasonal swings in pollution and different biological activities of the fish. The fish were collected by fishing nets.

Abiotic water parameters

The physico-chemical parameters of the water were measured at each sampling site during each fish-sampling season. The pH, temperature, the dissolved oxygen (DO) content were detected by YSI Professional Plus handheld multiparameter meter.

[DOR: 20.1001.1.15622916.2014.13.3.12.6]

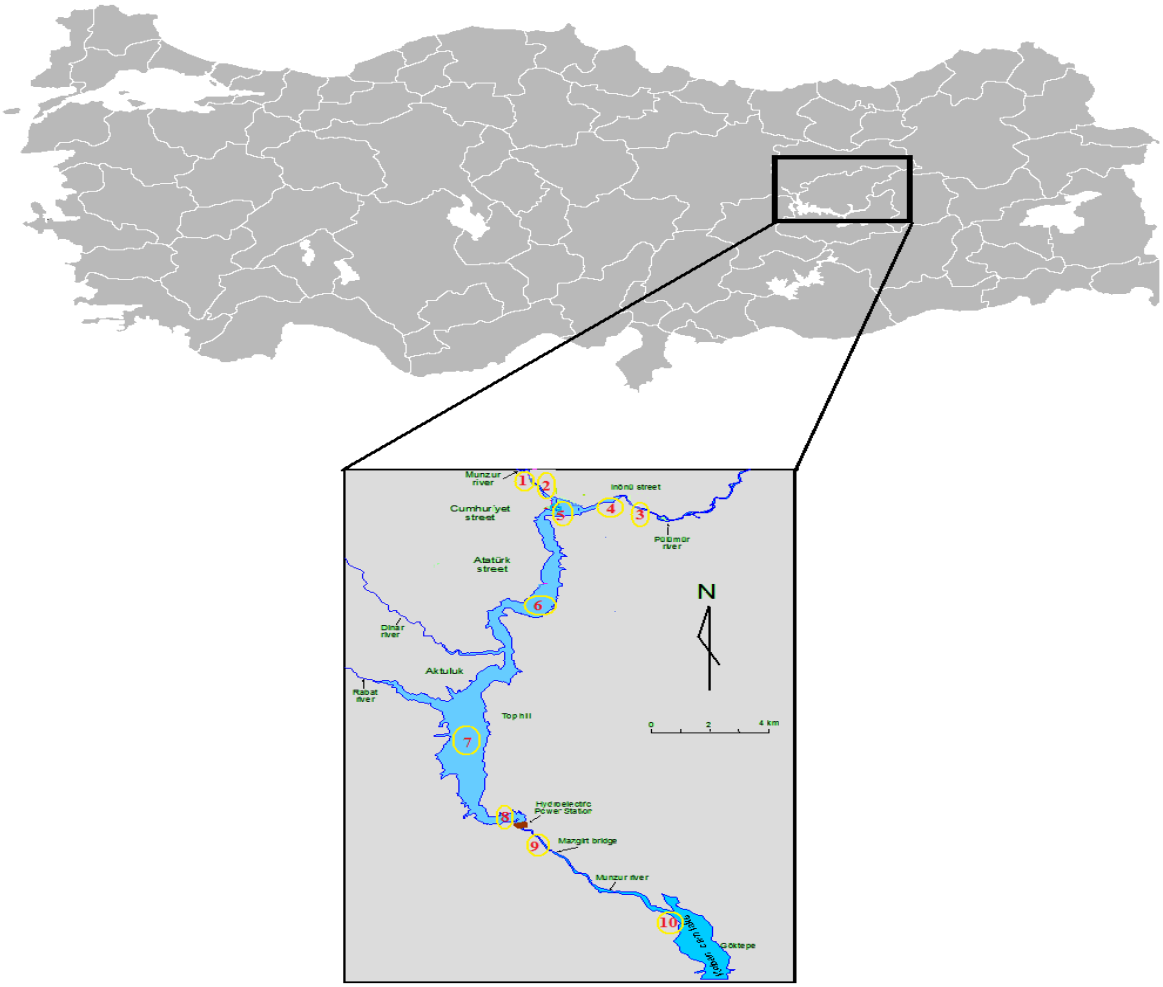

Figure 1: Station 1, Pre-settlement area at Munzur River; station 2, The point just before Munzur River flows into dam lake; station 3÷, The point just before the discharge point of seepage water into Pulumur River; station 4, The point just before Pülümür River flows into dam lake; station 5, Just after Pülümür River converges with Munzur River in the dam area; station 6, In the middle of the dam lake; station 7, In the middle of the dam lake; station 8, The point in the dam lake near hydroelectric power plant; station 9, Just after hydroelectric power plant; station 10, The point where Munzur River flows into Keban Dam Lake. Map of sampling stations on Uzuncayir Dam Lake, Munzur and Pulumur River systems.

Biochemical analyses

Total 200 male *C. umbla* were captured. At first, fish were anaesthetized to deep sedation whit 0.7 gL^{-1} benzocaine dissolved in ethyl alcohol (Sardella *et al*., 2004; Altun and Danabas, 2006) and then were placed in freezer plastic bags and transported to laboratory with ice.

In Lab, The livers of fish were dissected. The liver tissues were rinsed with 0.9% NaCl and were homogenised in PBS buffer (pH 7.4). The homogenated samples were centrifuged (15.000 g, 10 min, 4°C), and supernatants, if not used immediately, were kept in the deep freeze at –70°C (Yildirim and Yurekli, 2010).

[DOR: 20.1001.1.15622916.2014.13.3.12.6]

IL-6 Levels

IL-6 levels were assayed by an enzyme-linked immunosorbent assay (ELISA) kit [CUSABIO BIOTECH CO., LTD. IL-6 Assay Kit]. Catalog No: CSB-E13258Fh

IL-1β levels

IL-1β levels were assayed by an enzyme-linked immunosorbent assay (ELISA) kit. [CUSABIO BIOTECH CO., LTD. IL-1β Assay Kit].Catalog No. CSB-E13259Fh

TNF-α Levels

TNF-α Levels were assayed by an enzyme-linked immunosorbent assay (ELISA) kit. [CUSABIO BIOTECH CO., LTD. TNF-α Assay Kit]. Catalog No. CSB-E13254Fh

Statistical analysis

One-way ANOVA and the multiple range test of Duncan were used to determine the significance of differences in TNF-α, IL-1β and IL-6 levels between stations (p<0.05). Independent-samples T test was used for the evaluation of oxidative stress biomarkers between months in the same station.

Results

The results of physico-chemical parameters of water sampling sites are shown in Table 1. The lowest dissolved oxygen level among stations was 7.72 mg/L in September at station 9. The pH values ranged from 7.44 to 8.63 throughout the sites; the highest value was determined in September at station 10. The water tempature was higher in September than March.

Table 1: The physico-chemical parameters of water at sampling time from the sampling stations on Uzuncayir Dam Lake.

Months	Parameters	Station Number 1	2	3	4	5	6	7	8	9	10
March	Temperature (°C)	9.56	10.8	9.20	9.20	10.9	11.8	13.3	13.5	14.1	13.9
	pH	8.42	8.38	8.35	8.40	8.28	8.28	8.55	8.44	8.32	8.28
	Disolved Oxygen (mg/l)	15.46	13.77	15.32	16.5	16.44	13.2	14.05	14.07	15.18	13.75
Septembr	Temperature (°C)	12.6	13.4	12.2	14.1	18.7	20.4	19.4	20.8	23.3	21.1
	pH	7.68	7.44	7.88	8.30	7.78	7.89	8.22	8.10	7.66	8.63
	Disolved Oxygen (mg/l)	9.44	9.28	10.64	9.23	9.95	9.12	8.28	8.68	7.72	9.55

Some immunomodulatory factors (IL-1β, IL-6 and TNF-α) determined in *Capoeata umbla* collected from ten sampling sites in different seasons, are shown in Table 2.

[DOR: 20.1001.1.15622916.2014.13.3.12.6]

Table 2: Changes in TNF-α, IL-1β and IL-6 in *C. umbla* captured from different sites in the Uzuncayir Dam Lake in September and March.

Station Number /	Mean of Months /	IL-1β (pg/ml)	IL-6 (pg/ml)	TNF-α (pg/ml)
1	March	1151.16±236.22	5.13±0.45	2894.19±117.72
	September	1144.58±14.53	18.10±0.02**	1014.58±70.73**
	Mean	1147.87±105.85 [ab]	11.62±2.91 [a]	1954.39±424.76 [ab]
2	March	1333.58±7.31*	4.35±0.53	2689.58±158.60
	September	1121.70±50.20	17.15±0.59**	2366.79±117.57
	Mean	1227.64±52.53 [a]	10.74±2.88 [a]	2528.19±114.04 [a]
3	March	1058.83±117.94	4.87±0.58	2657.38±223.06
	September	847.12±11.38	4.18±0.23	1665.52±411.83
	Mean	953.00±71.05 [ab]	4.52±0.32 [bc]	2161.45±305.06 [ab]
4	March	1314.25±63.71*	4.28±0.43	2578.78±5.31
	September	974.53±79.59	2.76±0.98	2279.81±314.55
	Mean	1144.39±88.60 [ab]	3.52±0.59 [c]	2429.30±155.77 [a]
5	March	904.29±24.63	2.70±0.49	2355.50±163.67
	September	1142.55±138.56	3.49±1.61	1845.80±167.78
	Mean	1023.42±82.46 [ab]	3.08±0.76 [c]	2100.65±154.85 [ab]
6	March	819.15±115.13	4.12±0.93	1391.30±122.63
	September	949.88±77.31	9.99±4.52	1409.29±106.94
	Mean	884.52±68.56 [b]	7.05±2.45 [abc]	1400.30±72.88 [b]
7	March	1182.55±14.56	3.37±0.56	2500.17±25.59
	September	746.82±256.86	11.72±0.01**	2390.62±562.47
	Mean	964.69±150.77 [ab]	7.55±1.88 [abc]	2445.40±253.00 [a]
8	March	1039.48±116.94	6.59±0.22	2721.77±184.43
	September	955.98±44.02	12.24±0.68**	2412.69±133.43
	Mean	997.73±58.92 [ab]	9.42±1.30 [ab]	2567.73±122.73 [a]
9	March	1024.02±127.69	12.68±3.21	3080.11±16.66**
	September	928.90±0.54	6.70±1.33	739.48±41.75
	Mean	976.46±60.94 [ab]	9.69±2.05 [ab]	1909.80±523.77 [ab]
10	March	1128.43±79.39	6.00±0.40	3015.71±362.82*
	September	727.16±128.50	5.80±1.29	1015.41±382.14
	Mean	927.76±275.06 [b]	5.90±0.60 [abc]	2015.57±505.57 [ab]

Different letters indicate significant difference, based on Duncan test (p<0.05).

[DOR: 20.1001.1.15622916.2014.13.3.12.6]

Different letters over the means indicate differences between sites according to multiple range test of Duncan ($p< 0.05$).

Independent-samples t test was used for the evaluation of measured data between months, *p<0.05 and **p<0.01 were regarded as statistically significant. The number of sampled male fish from the studied sites in different season was: *n:* 10.

The lowest mean of IL-1β levels were found at station 6. The mean of IL-1β reached its maximum level at station 2. The IL-1β levels were lower in September than March at all sampling sites, except stations 5 and 6.

At all stations, the differences among the mean levels of IL-6 were found to be significant (p<0.05). The IL-6 levels were significantly increased in September at stations 1, 2, 7 and 8 (p<0.01) compared to the values in March.

The differences between the mean levels of TNF-α at all stations were found to be significant (p<0.05). The TNF-α levels significantly decreased in September at stations 1 and 9 (p<0.01). The lowest mean of TNF-α level was found at station 6. The mean of TNF-α reached its maximum level at station 8. TNF-α level were lower in September than in March at all stations.

Discussion

Domestic wastes of Tunceli are discharged directly to Munzur and Pülümür Rivers with no treatment. Therefore, over time, the physico-chemical properties of this water system will change and cause some ecotoxicological impacts on the living elements of this ecosystem.

Biological indicators of exposures to different pollutants and their effects are ancillary approaches to traditional methods in fisheries science to assess the potential impact of environmental contaminants and other anthropogenic sources of stress on fish health (Rice *et al*., 1995). Fish are one of the important indicators of environmental contaminants of water but there are limited data available on the effects of pollution on fish health and particularly on the immune system (Dunier and Swicki, 1993). The present study was designed to monitor water pullution of Uzuncayir Dam Lake by using the changes of IL1β, IL-6 and TNF-α levels in liver of *C. umbla* (Heckel, 1843) at ten stations in March and September.

Temperature decrease which has an important role on the poikilothermic nature of fish, affects the rate of their physiological functions (Hayward *et al*., 2009). One recent report indicated that cytokine expression (IL-1, IL-10 and IFNg) was up-regulated in rainbow trout maintained at 25°C (Raida and Buchmann, 2007). Indeed, they found that there was a generalised up-regulation of cytokine expression at both 15°C and 25°C compared to animals at 5°C (Bowden, 2008). In our study, the levels of IL1β and TNF-α generally were decreased in *C. umbla* in September. The rise of temperature affects the immune response. The decrease of IL1β and TNF-α level were monitored as an indicator of degree and duration of fish exposure to pollutants. Artificial environmental stress factors, i.e. pollutants, are generally considered to be immunosuppressive (Dunier and Swicki,

[DOR: 20.1001.1.15622916.2014.13.3.12.6]

1993). In general, regardless of fish species, elevated water temperatures within the physiological range of fish (i.e. 5-10°C above ambient temperature) frequently enhance immune functions. The mechanisms involved may be attributable to induction of heat shock proteins (HSP) which can function to protect protein folding and trafficking from the adverse effects of elevated tempatures (Dietz *et al*., 1994). Signalling mechanisms responsible for various stress effects on fish immunity have not been yet well understood, although it is clear that elevated ACTH serum and cortisol levels are involved in some cases. Cortisol can weaken the activity of the immune system (Bly, et al., 1997). The effects of seasonal and in vitro assay temperatures on fish immune function have been well established and there is a little doubt that low tempatures can suppress adaptive (i.e. T and B cell-mediated) immune responses (Carlson *et al*., 1995). However, there is still controversy over the effects of temperature on innate (non-specific) immune responses. Some studies were reported enhanced activities while the majority of reports were shown immune suppression (Bly *et al*., 1992).

Changes in environmental pH levels show conflicting results for immune system parameters, such as levels of circulatory lysozyme and IgM (Uribe *et al*., 2011). In present study, the highest pH values were found in September at station 10 (the point where Munzur River flows into Keban Dam Lake). IL1β, IL-6 and TNF-α levels were found generally low at station 10 compared to other stations. In our study, station 10 is a dam lake area and in dam lakes, pH levels determine the toxicity of pollutants (Camargo and Alanso, 2006).

Oxygen levels in the environment may modulate the immune response; hypoxia depresses the respiratory burst activity of macrophages and decreases the levels of circulating antibodies, which in turn, are elevated by hyperoxia (Bowden, 2008). In this study, the lowest TNF-α levels and the lowest dissolved oxygen levels were found in station 9. The TNF-α level at station 9 in September confirmed the important contamination effects in station 9 that exhibited lowest dissolved oxygen concentration.

Stress has been defined as a change in the environment (either physical or physiological) that can disrupt normal host homeostasis (Bly *et al*., 1997). The contibution of the environmental pollutants to stress in fish has been subjected to extensive reviews (Dunier and Swicki, 1993). Several studies showed that the immune function of collected fish from contaminated marine and estuarine environments were severely impaired (Faisal *et al*., 1991). Stress, at the first phase (alarm phase) affects various aspects of immune function, depending on the nature and duration of the stress (Dhabhar, 2003). For example, stressors can directly affect the cells of the immune system and modulate the secretion of proinflammatory cytokines (Dhabhar and McEwen, 1996; Ruzek *et al*., 1997).

The mechanism of immunomodulation of pollutants could be a direct toxic effect on immun cells or/and organs, or an indirect effect because the neuroendocrine

[DOR: 20.1001.1.15622916.2014.13.3.12.6]

system is the first target organ of the pollutants (Dunier and Swicki, 1993). Cytokines play a key role in bidirectional communication between the endocrine and immune systems. They interplay between hormones and cytokines during stress and may influence immune homeostasis in response to environmental challenges (Castillo *et al*., 2009; Yildirim and Yurekli, 2010) suggested that the cytokine expression in head kidney is highly regulated by stress related hormones, and it is another evidence of the existence of endocrine-immune interactions in the teleost fish. Adrenaline inhibited cytokine expression levels, being IL-1β the most sensitive cytokine to adrenaline in vitro. On the other hand, adrenocorticotropic hormone (ACTH) rapidly inhibited IL-1β and increased TNF-α, TGF-β1 and IL-6 expression. Cortisol inhibited the expression of all cytokines and its immunosuppressive effects is confirmed (Castillo *et al*., 2009). In our study, the mean IL-1β and TNF-α were at minimum level at station 6 (In the middle of the dam lake) in September. These results indicate that the area is polluted by municipal discharges, and that decrease in IL-1β and TNF-α levels of liver may be due to pollution stress.

To our knowledge, this is the first report that showed the immunonodulatory factors (IL-1β, IL-6 and TNF-α) in fish could be used as bioindicators in fish health and water quality assessment. The results of our experiments suggested that environmental contaminants supresssed the function of immune system. Further studies are needed to understand the exact role of cytokines in response to pollution stress. The study of biomonitoring of the water pollution is a broad topic, and our group intends to investigate different biomarkers on the suggested fish model.

Acknowledgment

This study is a part of a comprehensive project that is supported by The Scientific and Technical Research Council of Turkey (TUBITAK), Research Grant Committee of Environment, Earth, Marine, and Atmospheric Sciences (Project no: TUBITAK, CAYDAG 110Y118). This study was carried out under the permission of the Firat University Animal Welfare Committee.

Refrences

Altun, T. and Danabas, D., 2006. Effects of short and long exposure to the anesthetic 2-phenoxyethanol mixed with ethyl alcohol on common carp (*Cyprinus Carpio* L., 1758) fingerlings. *Israeli journal of aquaculture Bamidgeh*, 58, 1-5.

Anderson, D.P., and Zeeman, M.G. ,1995. Immunotoxicology in fish. In fundamentals of aquatic toxicology: Effects, environmental fate, and a risk assessment (G. Rand, Ed.), pp.371–404.

Bird, S., Wang, T., Zou, J., Cunningham, C. and Secombes, C.J., 2002. The first cytokine sequence within cartilaginous fish: IL-1 β in the small spotted catshark (*Scyliorhinus canicula*). *Journal of Immunology*, 168, 3329–3340.

Bird, S., Zou, J., Savan, R., Kono, T., Sakai, M. and Woo, J., 2005. Characterisation and expression analysis

[DOR: 20.1001.1.15622916.2014.13.3.12.6]

of an interleukin 6 homologue in the Japanese pufferfish, *Fugu rubripes*. *Developmental and Comparative Immunology*, 29, 775–89.

Bowden, T.J., 2008. Modulation of the immune system of fish by their environment. *Fish and Shellfish Immunology*, 25, 373–83.

Bowser, D.H., Frenkel, K. and Zelikof, J.T., 1994. Effects of in vitro nickel exposure on macrophage-mediated immune function of rainbow trout (*Oncohrynchus mykiss*), *Bulletin of Environmental Contamination and Toxicology*, 52, 367-369.

Bly, J.E. and Clem, L.W. 1992. Temperature and teleost immune functions. *Fish and Shellfish Immunology*, 2, 159-171.

Bly, J., Quiniou, M. A. and Clem, L. W., 1997. Environmental effects on fish immune mechanisms. *Developments in Biological Standardization*, 90, 33-43.

Cai, Z.H., Song, L.S., Gao, C.P., Wu, L. T., Qiu, L.H., and Xiang J.H., 2003. Cloning and expression of tumor necrosis factor (TNFα) cDNA from red seabream *Pagrus major*. ***Acta*** *Biochimica et Biophysica Sinica*, 35, 1111–1116.

Camargo, J.A. and Alanso, A., 2006. Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assesment; *Environment International*, 32, 831-849.

Carfi, M., Gennari, A., Malerba, Corsini, I.E., Pallardy, M., Pieters, R., Van Loveren, H., Vohr, H. W., Hartung, T. and Gribaldo, L., 2007. In vitro tests to evaluate immunotoxicity: VA preliminary study.*Toxicology*,229, 11-22.

Carlson, R.E., Baker, E.P., Fuller, R.E., 1995. Immunological assessment of hybrid striped bass at three culture temperatures. *Fish and Shellfish Immunology*, 5, 359-373.

Castellana, B., Iliev, D. B., Sepulcre, M. P., Mackenzie, S., Goetz, F.W. and Mulero, V., 2008. Molecular characterization of interleukin-6 in the gilthead seabream (*Sparus aurata*). *Molecular Immunology*, 45, 3363–70.

Castillo, J., Teles, M., Mackenzie, S. and Tort L., 2009. Stress-related hormones modulate cytokine expression in the head kidney of gilthead seabream (*Sparus aurata*). *Fish and Shellfish Immunology*, 27, 493–499.

Corripio-Miyar, Y., S. Bird, K. Tsamopoulos, and Secombes C. J., 2007. Cloning and expression analysis of two pro-inflammatory cytokines. IL-1β and IL-8, in haddock (*Melanogrammus aeglefinus*). *Molecular Immunology*, 44, 1361–1373.

[DOR: 20.1001.1.15622916.2014.13.3.12.6]

Covello, J.M., Bird, S., Morrison, R.N., Battaglene, S.C., Secombes, C.J. and Nowak, B.F., 2009. Cloning and expression analysis of three striped trumpeter (*Latris lineata*) pro-inflammatory cytokines, TNF-, IL-1βand IL-8, in response to infection from the ectoparasitic, *Chondrachanthus goldsmidi*. *Fish and Shellfish Immunology*, 26, 773–86.

Dhabhar, F.S. and McEwen, B.S., 1996. Stress-induced enhancement of antigen specificb cell-mediated *immunity. Journal of Immunology*, 156, 2608–15.

Dhabhar, F.S. ,2003. Stress, leukocyte trafficking, and the augmentation of skin immune function. *Annals of the New York Academy of Sciences*, 992, 205–17.

Dietz, T.J., 1994. Acclimation of the threshold induction temperatures for 70-kDa and 90-kDa a heat shock proteins in fish *Gillichthys mirabilis. Journal of Experimental Biology*, 188, 333-338.

Dinarello, C.A. ,2002. The IL-1 family and inflammatory diseases. *Clinical and Experimental Rheumatology*, 20, 1–13.

Dunier, M., and Swicki, A.K. ,1993. Effects of pesticides and other organic pollutants in the aquatic environment on immunity of fish: a review. *Fish and Shellfish Immunology*, 3, 423-38.

Faisal, M., Huggett, R.J. Vogelbein, W.K. and Weeks, B.A., 1991. Evidence of aberration of the natural cytotoxic cell activity in *Fundulus heteroclitus* (Pisces: Cytprinodontidae) from the Elizabeth River, Virginia. *Veterinary Immunology and Immunopathology*, 29, 339–351.

Foa, A., and Bertolucci, C., 2001. Temperature cycles induce a bimodal activity pattern in ruin lizards: masking or clock-controlled event? A seasonal problem. *Journal of Biological Rhythms*, 16, 574-84.

Fujiki, K., Shin, D.H. Nakao, M. and Yano, T., 2000. Molecular cloning and expression analysis of carp (*Cyprinus carpio*) interleukin-1 beta, high affinity immunoglobulin E Fc receptor gamma subunit and serum amyloid A. *Fish and Shellfish Immunology*, 10, 229–42.

Garcia-Castillo, J., P. Pelegrin, V. Mulero, and Meseguer J., 2002. Molecular cloning and expression analysis of tumor necrosis factor alpha from a marine fish reveal its constitutive expression and ubiquitous nature. *Immunogenetics*, 54, 200–7.

Hayward, C.J., Bott, N.J. and Nowak, B.F., 2009. Seasonal epizootics of sea lice, Caligus spp., on southern bluefin tuna, *Thunnus maccoyii* (Castelnau), in a long-term farming trial. *Journal of Fish Diseases*, 32, 101–106.

Hirano, T., 1998. Interleukin 6 and its receptor: ten years later. *International Reviews of Immunology*, 16, 249–84.

Hook, S.E., Skillman, A.D., Small, J.A. and Schultz, I.R., 2006. Gene expression patterns in rainbow trout,

[DOR: 20.1001.1.15622916.2014.13.3.12.6]

Oncorhynchus mykiss, exposed to a suite of model toxicants. *Aquatic Toxicology*, 77, 372-85.

Iliev, D. B., Castellana, B., Mackenzie, S., Planas, J.V. and Goetz, F.W., 2007. Cloning and expression analysis of an IL-6 homolog in rainbow trout (*Oncorhynchus mykiss*). *Molecular Immunology*, 44, 1803–7.

Ingerslev, H.C., Cunningham, C. and Wergeland, H.I., 2006. Cloning and expression of TNF-alpha, IL-1 beta and COX-2 in an anadromous and landlocked strain of Atlantic salmon (*Salmo salar* L.) during the smolting period. *Fish and Shellfish Immunology*, 20, 450–61.

Kishimoto, T. and Hirano, T. ,1988. A new interleukin with pleiotropic activities. *Bioessays*, 9, 11–5.

Lagadic, L., Caquet, T., Amiard, J.C. and Ramade, F., 1998. Utilisation de biomarqueurs pour la surveillance de la qualité de l'environnement. In: Lavoisier (Eds), Tec & Doc, Londres, Paris, New York; 320P.

Laing, K.J., Wang, T. Zou, J., Holland, J., Hong, S. and Bols, N. ,2001. Cloning and expression analysis of rainbow trout *Oncorhynchus mykiss* tumour necrosis factor-alpha. *European Journal of Biochemistry*, 268, 1315–22.

Le Morvan, C., Clerton, P., Deschaux, P. and Troutaud, D. ,1997. Effects of environmental temperature on macrophage activities in carp. *Fish and Shellfish Immunology*, 7, 209–12.

Magnadottir, B., 2010. Immunological control of fish diseases. *Journal of Marine Biotechnology*, 12, 361–79.

Mathew, J.A., Guo, Y.X., Goh, K.P., Chan, J., Verburg van Kemenade, B.M. and Kwang, J. ,2002. Characterisation of a monoclonal antibody to carp IL-1beta and the development of a sensitive capture LISA. *Fish and Shellfish Immunology*, 13, 85–95.

Nayak, A., 2003. Characterızatıon of the zebrafish innate immune system in response to the environmental toxicant, arsenic. B.S. thesis Bangalore University, India.

Pelegrin, P., Garcia-Castillo, J., Mulero, V. and Meseguer, J., 2001. Interleukin- 1 beta isolated from a marine fish reveals p-regulated expression in macrophages following activation with lipopolysaccharide and lymphokines. *Cytokine*,16,67–72.

Raida, M.K., and Buchmann, K. ,2007. Temperature-dependent expression of immune-relevant genes in rainbow trout following *Yersinia ruckeri* vaccination. *Diseases of Aquatic Organisms*,77,41-52.

Rice, C.D., Banes, M.M. and Ardelt, T. C. ,1995. Immunotoxicity in Channel

[DOR: 20.1001.1.15622916.2014.13.3.12.6]

Catfish, *Ictalurus punctatus,* following acute exposure to Tributyltin. *Environmental Contamination and Toxicology*, 28, 464–470.

Ruzek, M.C., Miller, A.H., Opal, S.M. Pearce, B.D. and Biron, C.A. ,1997. Characterization of early cytokine responses and an interleukin (IL)-6-dependent pathway of endogenous glucocorticoid induction during murine cytomegalovirus infection. *Journal of Experimental Medicine*, 185, 1185–92.

Saeij, J.P., Stet, R.J. de, B. Vries, J., van Muiswinkel, W.B. and Wiegertjes, G.F., 2003. Molecular and functional characterization of carp TNF: a link between TNF polymorphism and trypanotolerance? *Developmental and Comparative Immunology*, 27, 29–41.

Sahoo, P.K., and Sakai, M., 2010. Immunostimulants in aquaculture. In: Koumoundouros, G. (Ed.), Recent Advances in Aquaculture Research. Transworld. Research Network, Trivandrum, Kerala, India; pp.204–229.

Sardella, B.A., Matey, V., Cooper, J., Gonzalez, R.J. and Brauner, C.J. ,2004. Physiological, biochemical and morphological indicators of osmoregulatorystress in `california' Mozambique tilapia (*Oreochromis mossambicus* x *O.urolepishornorum*) exposed to hypersaline water. *Journal of Experimental Biology*, 207, 1399-1413.

Tsutsui, S., Iwamoto, T., Nakamura, O. and Watanabe, T., 2007. LPS induces gene expression of interleukin-1 beta in conger eel (*Conger myriaster*) macrophages: first. *Fish and Shellfish Immunology*, 23, 911–16.

Uribe, C., Folch, H., Enriquez, R. and Moran, G., 2011. Innate and adaptive immunity in teleost fish: a review. *Journal Veterinarni Medicina*, 56, 486–503.

Xiao, J., Zhou, Z.C., Chen, C., Huo, W. Yin, L.Z.X. and Weng, S.P., 2007. Tumor necrosis factoralpha gene from mandarin fish, *Siniperca chuatsi*: molecular cloning, cytotoxicity analysis and expression profile. *Molecular Immunology*, 44, 3615–22.

Yildirim, N. C., and Yurekli M., 2010. The effect of adrenomedullin and cold stress on interleukin-6 levels in some rat tissues. *Clinical and Experimental Immunology*, 161, 171–75.

Zelikoff, J. T., 1998. Biomarkers of immunotoxicity in fish and other non-mammalian sentinel species: predictive value for mammals? *Toxicology*, 129, 63–71.

Zou, J., Grabowski, P.S. Cunningham, C. and Secombes, C. J. ,1999. Molecular cloning of interleukin 1beta from rainbow trout *Oncorhynchus mykiss* reveals no evidence of an ice cut site. *Cytokine*, 11, 552–60.

[DOR: 20.1001.1.15622916.2014.13.3.12.6]

Zou, J., Secombes, C.J., Long, S., Miller, N., Clem, L.W. and Chinchar, V.G. ,2003. Chinchar. Molecular identification and expression analysis of tumor necrosis factor in channel catfish (*Ictalurus punctatus*). *Developmental and Comparative Immunology*, 27, 845–58.

[DOR: 20.1001.1.15622916.2014.13.3.12.6]