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FULL PAPER

Otolith fingerprints reveal stock discrimination of *Sperata seenghala* inhabiting the Gangetic river system

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Abstract Variations in elemental concentrations of otoliths were used to study the probable stock(s) of *Sperata seenghala* in the Gangetic river system. Fifteen trace elements from whole sagittal otoliths were analysed using inductively coupled plasma–atomic emission spectrometry. Strontium, barium, lithium, copper, iron, lead, zinc, manganese, nickel ($P < 0.001$) and magnesium ($P < 0.01$) differed significantly among locations, while no significant differences were noted for calcium, sodium and potassium ($P > 0.01$). Chromium and cadmium were not detected in the otoliths of the fish from Narora site on the river Ganga. Discriminant function analysis using cross-validation classification assigned individuals to their site of sampling origin with a mean classification accuracy of 83.2 %. The detected site-specific elemental differences in *S. seenghala* otoliths indicate a high level of site-fidelity in relation to their habitat areas. Thus target fish population from these sites can be regarded as separate stocks.

Keywords Otolith fingerprints · *Sperata seenghala* · Stock discrimination

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Introduction

A fish stock may be defined as an intra-specific group of randomly mating individuals with temporal or spatial integrity (Ihssen et al. 1981). Identification of intraspecific groups with variable life history attributes is considered necessary for understanding population dynamics and the evaluation of sustainable harvests (Cadrin 2000). Understanding the distribution and movement of the target fish species can lead to a better understanding of connectivity, philopatry, critical habitats or specific life history events that may improve fitness, which ultimately will structure populations. Such information can, in turn, be used to guide rational exploitation and conservation strategies. Over the years and more particularly during the recent past, the fish population has shown declining trend in the rivers, Ganga, Yamuna, Krishna, Sutlej, Ravi, Beas, Narmada, Tapi, Mahi, Sabarmati, Pennar, Cauvery, Betwa and Gomti because of the destruction of fish habitat by alteration of river beds, increased water abstraction, overfishing, pollution of fishery waters, indiscriminate land development and domestication of species, introduction of non-native species, global climatic variation and construction of dams, etc. (Lakra et al. 2010; Dandekar 2012).

Otoliths are innate data archives that document information in their microstructure and chemistry at different spatial and temporal scales related to their growth and environment. This information, which includes age and growth, movement patterns and habitat interactions, can be interpreted at the population level in terms of ecology, demography and life history of the species, which has become fundamental to the management of fisheries and protected species around the world. One of the most appreciated characteristics of the otoliths is being metabolically inert and showing lack of resorption

(Campana and Neilson 1985; Kalish 1989; Campana 1999; Miyan and Khan 2014). This means that once the material has been deposited, the organism will not use it again even in periods of starvation. Elemental composition of otoliths has been effectively utilized for the stock identification of various freshwater fish species such as *Oncorhynchus clarki lewisi* (see Wells et al. 2003), *Perca flavescens* (see Brazner et al. 2004), *Morone saxatilis* (see Schaffler and Winkelman 2008) *Heteropneustes fossilis* (see Khan et al. 2012), *Channa punctata* (see Miyan et al. 2014), *Wallago attu* (see Miyan 2014) and *Clarias batrachus* (see Miyan et al. 2015) etc.

Sperata seenghala is an economically important species having good food value in different south Asian countries of its distribution range and particularly in Indian sub-continent. It usually inhabits the freshwaters such as rivers, lakes, reservoirs, floodplains, and tanks with mud or silt laden bottoms and grasses (Talwar and Jhingran 1991). It is widely distributed in India, Pakistan, Bangladesh, Sri Lanka, Nepal, Burma, Thailand, Vietnam, Kampuchea, Malay Peninsula, Indonesia and Afghanistan (Talwar and Jhingran 1991; Froese and Pauly 2014). The adult fish is column feeder and carnivorous in nature and consumes a variety of living creatures including fish, frogs, snakes, insects, prawn, earthworms, tadpoles, crustaceans, molluscs and debris. Juveniles are mainly bottom and marginal feeders; feed mainly on fish fry and fingerlings of other fishes, prawns, shrimps, insects, crustacean, rarely plant matter including debris (Gupta 2015). Fish breed during April to August in Indian rivers, Bangladesh and Pakistan (Bhatt 1970; Gupta 2015). Fecundity of this fish varies from 13,005 to 119,943 eggs (Rahman et al. 2014). Current field surveys showed that it is still relatively abundant and categorized as "Least Concern" (IUCN 2015). In India, the necessary basic biological information particularly that related to stock identification of *S. seenghala* inhabiting major habitats such as the Gangetic river system is still warranted. Such information is considered essential to understand the characteristics and dynamics of a population which may be of great help in devising the strategies for maintaining the genetic diversity, conservation and rational exploitation of the target species.

There is lack of published information on the stock structure of *S. seenghala* from the selected river system. However, few reports are available on genetic variability of *S. seenghala* from other rivers such as Sutlej and Beas (Saini et al 2010) and Bhadbada reservoir, Mohinisagar reservoir, Bansagar reservoir, Bargi reservoir and Gandhisagar reservoir in Madhya Pradesh, India (Garg et al. 2014). The present study was, therefore, undertaken to investigate the stock structure of *S. seenghala* population inhabiting the river Ganga and its tributaries: river Yamuna and river Gomti using variation in elemental composition of otoliths.

Materials and methods

Study area. Samples of *Sperata seenghala* were collected from three rivers in northern India, the Ganga, Yamuna and Gomti. The river Ganga originates in the Garhwal Himalayas (30°55′ N, 70°07′ E) at an elevation of 4,100 m above mean sea level from Gaumukh glacier in the western Himalayas in the Uttarakhand state of India. It flows about 2,525 km before falling into the sea (Kamyotra 2009) and finally drains into the Sundarban delta in the Bay of Bengal. The river Ganga harbours about 265 fish species of which 34 including the prized Gangetic carps (*Labeo rohita*, *Catla catla, Cirrhinus mrigala* and *Labeo calbasu*), large catfishes (*Sperata aor, Sperata seenghala, Wallago attu, Bagarius bagarius*), featherbacks (*Notopterus notopterus, Notopterus chitala*) and murrels (*Channa marulius, Channa punctata*) are of great commercial interest (Sinha and Khan 2001). The river Yamuna originates from the Yamunotri glacier (Saptrishi Kund) near Bander punch peaks (38°59′ N, 78°27′ E) at an elevation of circa 6,320 m above mean sea level in the Mussoorie range of the lower Himalayas in Uttarkashi district of Uttarakhand, India, and traverses some 1,336 km through five states before finally merging into the river Ganga in Allahabad, Uttar Pradesh, India (Sengupta 2006). It is the largest tributary of river Ganga. Choudhury et al. (2002) reported 87 fish species from the Okhla bird sanctuary site on the river Yamuna. The river Gomti originates from a natural lake (28°34′ N, 80°07′ E) Gomat Taal near Madho Tanda, Pilibhit town in Uttar Pradesh, India, about 50 km south of the Himalayan foothills (Sarkar et al. 2010). It travels about 750 km to finally merge into the river Ganga near Saidpur Kaithi in Ghazipur district bordering Varanasi district in Uttar Pradesh, India (Sarkar et al. 2010). Sarkar et al. (2010) have documented 56 fish species belonging to 20 families and 42 genera from the river Gomti. The authors further argued that the fish fauna of the river Gomti is adversely affected due to human induced threats like sewage pollution, habitat alteration, etc.

Sample collection. Fish samples of *S. seenghala* were collected during September 2012 to January 2013 from Narora located at 27°30′ N, 78°25′ E [$n = 25$; mean standard length and standard deviation, MSL ± SD (cm) = 41.47 ± 2.33], Kanpur located at 26°28′ N, 80°24′ E [$n = 25$, MSL ± SD (cm) = 40.18 ± 3.29] and Bhagalpur located at 25°16′ N, 87°01′ E [$n = 25$, MSL ± SD (cm) = 41.12 ± 2.89] on the river Ganga, Firozabad site located at 27°09′ N, 78°24′ E [$n = 25$, MSL ± SD (cm) = 40.68 ± 2.98] on the river Yamuna and Lucknow site located at 26°55′ N, 80°59′ E [$n = 25$, MSL ± SD (cm) = 39.91 ± 2.62] on the river Gomti (Fig. 1).

Otolith removal and decontamination. The sagittal otoliths were removed from otic capsules by opening the otic

bulla. The otoliths were collected in plastic vials, brought to the laboratory and stored in eppendorf tubes. Otoliths were taken from the fishes of similar lengths to include the fishes of same cohort. Prior to decontamination of otoliths, all implements and glasswares were cleaned with analytical grade 1 % nitric acid (HNO_3). We have taken left sagittal otoliths for elemental analysis. We kept right sagittal otolith for age estimation of the fish. All the adhering biological residues were removed by putting the otoliths in ultra pure water overnight. To remove surface contamination, otoliths were soaked in 3 % hydrogen peroxide for 5 min and immersed for 5 min in 1 % HNO_3. Otoliths were then flooded with ultra-pure water for 5 min to remove the acid. After decontamination, the otoliths were dried under a laminar flow hood and weighed to the nearest 0.1 mg (Turan 2006; Khan et al. 2012).

Sample preparation and elemental analysis. The decontaminated otoliths were dissolved in 10 ml of 37 % HNO_3 and the volume was brought up to 25 ml with Milli Q water. Inductively coupled plasma–atomic emission spectrometry (ICP–AES) (Thermo Electron IRIS Intrepid II XSP DUO) was used to analyse the elements (Ca, Na, Mg, Sr, Ba, Mn, Fe, Cu, Pb, Ni, Zn, Li, Cr, Cd and K) in the otoliths. Blank samples were prepared similarly but without the otolith and were used to correct for background noise in readings and to calculate detection limits. Internal standards Ga and In were added in samples and blanks which were used to correct for the remaining matrix effect and to compensate instrument drift. For external calibration, multi-elemental standards were prepared with high purity ICP multi-element standard solution IV certiPUR (NIST SRM) obtained from Merck (Germany) using ultra pure Milli Q water and 2 % v/v HNO_3 analytical grade. A calibration blank was also prepared in similar manner. The calibration curve was obtained for five points. The concentration of elements in the sample and blank were calculated and expressed as microgram per gram on dry weight basis. To minimize the possibility of contamination, all samples, standards and blanks were prepared in a laminar flow hood (Turan 2006; Khan et al. 2012).

Data analysis. To check the effects of the standard length (SL) on elemental concentrations, correlations were carried out between elemental concentrations and the SL of fish. Significant correlations were observed between the fish size and elemental concentrations of samples. The data were standardized according to Bergenius et al. (2005) to remove the effect of the SL from each elemental concentration:

$$C_{ij\,adj} = C_{ij} \pm b\left(L_{Sij} - L_{S\,Mi}\right)$$

where $C_{ij\ adj}$ is the sample concentration of fish i adjusted to the mean SL of group j, C_{ij} is the sample concentration of fish i from group j, b is the slope of the relationship of C_{ij} to L_{Sij} common to all groups, $L_{S\ ij}$ is the SL of fish i in group j and $L_{S\ Mi}$ is the average SL in group j.

Fig. 1 Collection sites of *Sperata seenghala*

Data were tested for normality using Shapiro–Wilk test. Levene's test and homogeneity of the group covariance matrix by Box's M test (MANOVA) was used to examine the assumption of homogeneity of variance for each dependent variable. The adjusted concentrations for all elements of interest were then analysed by a multivariate analysis of variance (MANOVA) to test for spatial differences in the multivariate elemental chemistry. Wilk's λ criterion was used to test for group differences in the MANOVAs. A univariate ANOVA was used to compare the mean elemental concentrations of otoliths among different sites of the rivers. Elemental concentrations of otoliths were subjected to post hoc test (Tukey's) to assess significant differences in the fish otoliths from the different collection sites. A stepwise discriminant function analysis (DFA) was used to examine the elemental chemistry in discriminating populations among the sites and to investigate whether elements could be used to classify samples into their original group. A leave-one-out classification with cross-validation was carried out to assign individuals to their original group. The scatterplots of first two discriminant scores were drawn to depict the separation of stocks on the graph.

All the statistical analyses were carried out on MS-EXCEL (Microsoft Corporation, Redmond, WA, USA) and SPSS vers. 16 (SPSS, Chicago, IL, USA).

Results

Differences in mean elemental concentrations of otoliths among sites were significant (MANOVA, $P < 0.001$). Strontium, barium, lithium, copper, iron, lead, zinc, manganese, nickel (ANOVA, $P < 0.001$) and magnesium (ANOVA, $P < 0.01$) differed significantly among locations, while no significant differences were noted for calcium, sodium and potassium (ANOVA, $P > 0.01$) (Table 1). Thus, calcium, sodium and potassium were removed from further analysis. Chromium and cadmium were excluded from the final analysis since these elements were not detected in the otoliths of the fish from Narora site on the river Ganga. Otoliths of fish collected from Kanpur site on the river Ganga exhibited significantly (ANOVA, $P < 0.001$) higher values of Sr, Li and Zn compared to fish otoliths from other sites. However, Ca, Na and K exhibited comparable (ANOVA, $P > 0.01$) values among different sites. Ba was significantly higher (ANOVA, $P < 0.001$) in otoliths of fish from Narora site on the river Ganga. Mn, Cu and Fe were significantly higher (ANOVA, $P < 0.001$) in otoliths of the fish collected from Bhagalpur site on the river Ganga. A significantly higher (ANOVA, $P < 0.001$) concentration of Pb was found in otoliths of the fish from Firozabad site on the river Yamuna. Mean elemental concentration of Ni was significantly (ANOVA, $P < 0.001$) higher in otoliths of the fish collected from Lucknow on the river Gomti (Fig. 2). The Wilks' λ test of discriminant function analysis showed significant differences in otolith elemental concentration of all the populations ($P < 0.001$) (Table 2). The first discriminant function (DF I) accounted for 63.5 % of the total variation. DF II and DF III accounted for 24.1 % and 9.6 %, respectively, of the group variability among the populations while DF IV accounted for 2.8 % variation. The elements Cu, Ba and Fe contributed most in discriminating among the populations in DF I, the elements Ni and Zn contributed to DF II, and Sr and Mn contributed to DF III in discriminating the populations (Table 3). DF I and DF II accounted for 87.6 % of the group variability among the population. DF I vs. DF II graph depicted the presence of five distinct units and showed clear separated stocks (Fig. 3). DFA using cross-validation classification was able to discriminate fish among original locations with high degree of accuracy: Lucknow (92 %), Firozabad (88 %), Bhagalpur (84 %), Kanpur (80 %) and Narora (72 %). A total of 83.2 % fishes were correctly classified to their site of capture (Table 4).

Table 1 ANOVA results for the elemental concentration for otoliths of *Sperata seenghala* collected from the Ganga river and its tributaries: the Yamuna and Gomti Rivers

Elements	Wilks' λ	*F*	*df*1	*df*2	Sig.
Ca	0.908	3.052	4	120	0.020
Na	0.961	1.223	4	120	0.305
Mg	0.883	3.962	4	120	0.005**
Mn	0.463	34.835	4	120	0.000*
Sr	0.631	17.555	4	120	0.000*
Cu	0.287	74.665	4	120	0.000*
Fe	0.561	23.456	4	120	0.000*
Li	0.462	34.915	4	120	0.000*
K	0.929	2.295	4	120	0.063
Pb	0.631	17.534	4	120	0.000*
Zn	0.524	27.207	4	120	0.000*
Ni	0.240	94.801	4	120	0.000*
Ba	0.414	42.418	4	120	0.000*

* $P < 0.001$, ** $P < 0.01$

Discussion

Otoliths are now becoming an important tool serving as invaluable resource for fisheries science (Campana 2005). The deposition of trace elements into otolith structure is a multicomplex procedure which is still not fully studied and understood, but we assume that several abiotic (e.g. salinity

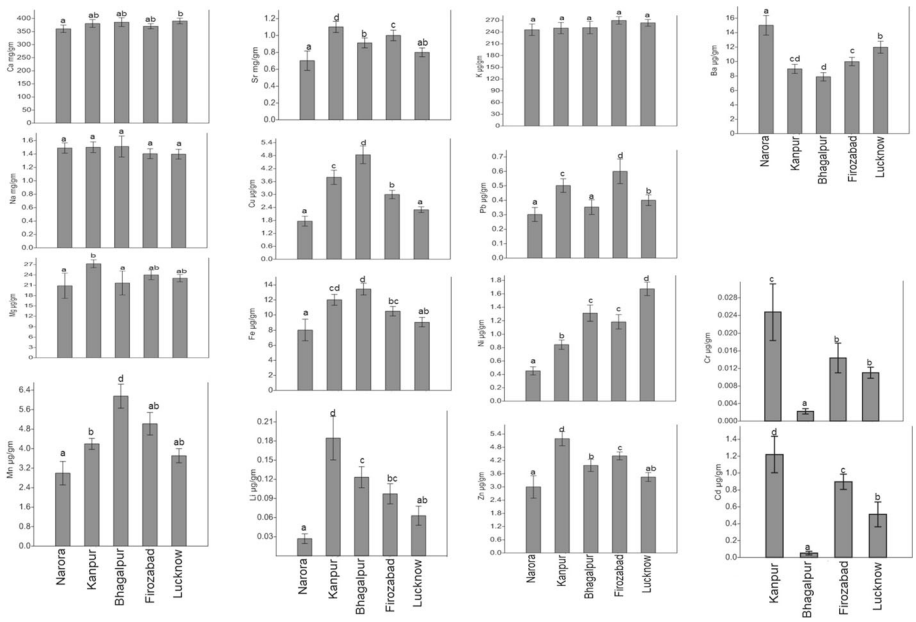

Fig. 2 Mean elemental concentrations and standard error for otoliths of *Sperata seenghala*; bars having similar letters are insignificantly different ($P > 0.05$); Cr and Cd were below the detection limit in the fish otoliths collected from Narora site of the river Ganga

Table 2 Wilks' λ test for verifying differences among stocks of *Sperata seenghala* with otolith chemistry using DFA

Test of function(s)	Wilks' λ	χ-square	*df*	*P*
1 through 4	0.009	555.088	40	0.000*
2 through 4	0.079	296.079	27	0.000*
3 through 4	0.325	131.013	16	0.000*
4	0.730	36.662	7	0.000*

* $P < 0.001$

Table 3 Contribution of otolith chemistry to the discriminant functions for *Sperata seenghala*

Elements	DF1	DFII	DFIII	DFIV
Cu	0.514*	0.018	-0.495	-0.090
Ba	-0.412*	0.064	0.026	-0.074
Fe	0.325*	0.024	-0.220	-0.052
Ni	0.218	-0.929*	0.241	0.047
Zn	0.270	0.393*	0.186	-0.111
Sr	0.226	0.123	0.662*	0.027
Mn	0.069	0.059	0.404*	-0.181
Pb	0.314	-0.124	-0.335	0.532*
Li	0.126	0.039	0.525	-0.485*
Mg	0.336	0.173	0.205	0.237*

* Largest correlation between each variable and any DF

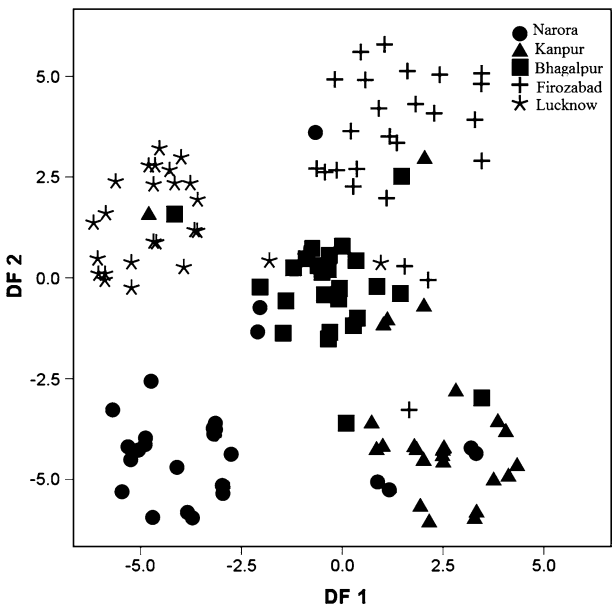

Fig. 3 Scatterplot of the first two canonical discriminant scores from the DFA for otolith chemistry

and temperature) and biotic (e.g. feeding regimes, metabolic rates, ontogenetic events, and vital effects such as, age, growth rate, gonad maturation) factors are responsible to control the rate and uptake of elemental incorporation into otoliths (Bath et al. 2000; Milton and Chenery 2001; Gillanders and Kingsford 2003; Sturrock et al. 2012). Univariate ANOVA showed that the mean elemental concentrations obtained in the whole otolith analysis, namely Sr, Ba, Mg, Li, Cu, Fe, Pb, Zn, Mn, Ni and Mg showed significant differences among the five sites of three rivers. In addition, the concentrations of Sr, Li, Zn and Mg were higher in the otoliths of the fish collected from Kanpur site on the river Ganga. One plausible reason for this may be

Table 4 Classification matrix of *Sperata seenghala* specimens based on whole otolith elemental concentrations used in DFA

Sampling sites	Narora	Kanpur	Bhagalpur	Firozabad	Lucknow	Total
Narora	18	4	2	1	0	25
%	72	16	8	4	0	100
Kanpur	0	20	3	1	1	25
%	0	80	12	4	4	100
Bhagalpur	0	2	21	1	1	25
%	0	8	84	4	4	100
Firozabad	0	1	2	22	0	25
%	0	4	8	88	0	100
Lucknow	0	0	2	0	23	25
%	0	0	8	0	92	100

the presence of the higher concentrations of these elements in the ambient environment of the sampling site (Purushothaman and Chakrapani 2007; Kamyotra 2009; Gowd et al. 2010). Kanpur is the hub of a large number of industries, viz; plastics, leather, textiles, a thermal power plant, cement, fertilizers, ordnance, two wheeler automobiles, electronic products, etc. The effluents of these industries drain into river Ganga, contributing to a greater abundance of trace elements in the ambient water of the river Ganga at Kanpur site and probably in otoliths of the fishes caught from Kanpur site. Gowd et al. (2010) reported that soil in the river Ganga at Jajmau site (Kanpur) is heavily contaminated with Sr along with various heavy metals, which could have been incorporated into the river water from surface runoff and also suggested that the higher concentration of strontium might be due to the water contamination resulting from industrial effluents in adjoining areas. Otoliths of the fish collected at the Narora site on the river Ganga showed highest concentration of Ba. This may be due to relatively better water quality at Narora site as it lies on the upper stretch of the river Ganga (Purushothaman and Chakrapani 2007; Kamyotra 2009). The source of Ba in the river Ganga is the Himalayan rocks. It was observed that mobility of Ba decreased compared to other elements in the downstream stretch (Das and Krishnaswami 2006). Highest concentration of Pb was detected in the otoliths of fish sampled at Firozabad site on the river Yamuna. This may be due to large number of glass industries pouring effluents into the river Yamuna at Firozabad. High levels of organic contents, nutrients, heavy metals (Cd, Cr, Ni, Pb, Fe, Cu and Zn) and pesticides have been reported from river Yamuna (Sengupta 2006). Highest concentration of Mn, Cu and Fe was detected in the otoliths of fish sampled at Bhagalpur site on the river Ganga. Several studies have shown that higher levels of heavy metals in otoliths are in accordance with an environmental exposure history of fish to aquatic contamination (Geffen et al. 2003; Ranaldi and Gagnon 2010). The DFA showed highly significant divergence among the populations of *Sperata seenghala*. It is assumed that if different fish populations inhabit different aquatic environments, or at least have a very prolonged exposure to different water environments, the otolith elemental composition should serve as a natural tag for these groups (Campana 1999). This could be due to the characteristic of fish otoliths to retain permanent record of the elements incorporated onto its growing surface and being chiefly regulated by the physico-chemical environment in which fish lives. Differences in habitat quality due to geographical separation of the sampling sites could have resulted in different elemental concentrations of otoliths of the fish collected from different sites not only in different rivers but also at three sampling sites within the river Ganga. It was assumed that various factors such as temperature (Fowler et al. 1995; Elsdon and Gillanders 2004; Walther et al. 2010), salinity (Fowler et al. 1995), water chemistry (Bath et al. 2000; Elsdon and Gillanders 2004), growth rate (Kalish 1989), diet (Buckel et al. 2004), ontogeny (Walther et al. 2010), stress (Kalish 1992), genetics (Clarke et al. 2011) and physiology (Kalish 1989) may control the uptake and incorporation of elements into otoliths. However, the mechanism of incorporation of elements in the otoliths is poorly understood for most of the fish species (Clarke et al. 2011) and has also not been investigated in the present study.

The multi-elemental analysis of whole otolith composition using DFA showed that the elements Cu, Ba, Fe, Ni, Zn, Sr, Mn, Pb and Li are the potent discriminator of target species stocks in the study area. Multi-elemental concentrations obtained for each site showed a good trace-back result to the original location areas (83.2 % mean correct classification) suggesting a limited movement among the areas where fishes were captured. The incorrect classification (16.8 %) may be due to the movement of fish for the feeding/breeding purpose (Gupta 2015). Mixing of fishes was observed more between the sites, which are near to

each other viz, Narora and Kanpur sites on the river Ganga. A lesser misclassification observed in the fish from river Gomti could be because of the fact that this tributary joins the river Ganga at a place downstream to which only one sampling site, Bhagalpur is located. The extent of potamodromous migration (Froese and Pauly 2014) of *S. seenghala* is not well studied. Although it seems probable that the fish is not highly migratory and the migration occurs presumably for the purpose of acquiring food. Furthermore, the movement of fish is inhibited by the Dams constructed at Narora and Kanpur on the river Ganga that could have consequently led to the stock separation in the river Ganga. Our results showed that elemental concentrations of whole otoliths are site-specific and that they can provide natural tags of their feeding/growing areas. The high classification success (92 %, 88 %, 84 %, 80 % and 72 % to Lucknow, Firozabad, Bhagalpur, Kanpur and Narora, respectively) implied that *S. seenghala* shows fidelity to its feeding/growing area. Similar variation trends in the elemental composition of otoliths were obtained for the stinging catfish, *Heteropneustes fossilis* (see Khan et al. 2012) and *Channa punctata* (see Miyan et al. 2014) population from the same habitats of the Ganga river system.

It may be concluded that the *S. seenghala* populations collected from different sites of the Gangetic river system may be categorized as separate stocks based on the variation in the elemental profile of otoliths. For validation and better inference of the present findings, further studies are warranted on the elemental analysis in environmental water of each collection site of three studied rivers.

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References

Bath GE, Thorrold SR, Jones CM, Campana SE, McLaren JW, Lam JWH (2000) Strontium and barium uptake in aragonitic otoliths of marine fish. Geochim Cosmochim Ac 64:1705–1714

Bergenius MAJ, Mapstone BD, Begg GA, Murchie CD (2005) The use of otolith chemistry to determine stock structure of three epinepheline serranid coral reef fishes on the Great Barrier Reef, Australia. Fish Res 72:253–270

Bhatt VS (1970) Studies on the biology of some freshwater fishes. Part V *Mystus seenghala* (Sykes). J Bom Nat Hist Soc 67:194–211

Brazner JC, Campana SE, Tanner DK (2004) Habitat fingerprints for Lake Superior coastal wetlands derived from elemental analysis of yellow perch otoliths. Trans Am Fish Soc 133:692–704

Buckel JA, Sharack BL, Zdanowicz VS (2004) Effect of diet on otolith composition in Pomatomus saltatrix, an estuarine piscivore. J Fish Biol 64:1469–1484

Cadrin SX (2000) Advances in morphometric identification of fishery stocks. Rev Fish Biol Fish 10:91–112

Campana SE (2005) Otolith science entering the 21st century. Mar Freshw Res 56:485–495

Campana SE (1999) Chemistry and composition of fish otoliths: pathways, mechanisms and applications. Mar Ecol Prog Ser 188:263–297

Campana SE, Neilson JD (1985) Microstructure of fish otoliths. Can J Fish Aquat Sci 42:1014–1033

Choudhury BC, Badola R, Hussain SA, Sivakumar K (2002) Ecological, social and hydrological factors affecting the management of wetland systems in UP with special reference to Vijay Sagar and associated water bodies in Mohaba district, Okhla and associated water bodies in Ghaziabad district, Bakhira Bird Sanctuary and Nawabganj Bird Sanctuary. Research reports. Wildlife Institute of India, Dehra Dun

Clarke LM, Thorrold SR, Conover DO (2011) Population differences in otolith chemistry have a genetic basis in *Menidia menidia*. Can J Fish Aquat Sci 68:105–114

Dandekar P (2012) Damaged Rivers, Collapsing Fisheries: Impacts of Dams on riverine fisheries in India South Asia Network on Dams, Rivers and People http://sandrp.in/dams/Impacts_of_Dams_on_Riverine_Fisheries_in_India_ParineetaDandekar_Sept2012. Accessed 1 November 2014

Das A, Krishnaswami S (2006) Barium in Deccan Basalt Rivers: Its Abundance, Relative Mobility and Flux. Aquat Geochem 12:221–238

Elsdon TS, Gillanders BM (2004) Fish otolith chemistry influence by exposure to multiple environmental factors. J Exp Mar Biol Ecol 313:269–284

Fowler AJ, Campana SE, Jones CM, Thorrold SR (1995) Experimental assessment of the effect of temperature and salinity on elemental composition of otoliths using solution based ICPMS. Can J Fish Aquat Sci 52:1421–1430

Froese R, Pauly D. (2014) FishBase. World Wide Web electronic publication. http://www.fishbase.org. Accessed 15 April 2014

Garg RK, Sairkar P, Chouhan S, Batav N, Silawat N, Sharma R, Singh RK, Mehrotra NN (2014) Characterization of genetic variance within and among five populations of *Sperata seenghala* (Skyes, 1839) revealed by random amplified polymorphic DNA markers. J Genet Engineer Biotech 12:7–14

Geffen AJ, Jarvis K, Thorpe JP, Leah RT, Nasha RDM (2003) Spatial differences in the trace element concentrations of Irish Sea plaice *Pleuronectes platessa* and whiting *Merlangius merlangus* otoliths. J Sea Res 50:245–254

Gillanders BM, Kingsford MJ (2003) Spatial variation in elemental composition of otoliths of three species of fish (family Sparidae). Estuar Coast Shelf Sci 57: 1049–1064

Gowd SS, Reddy MR, Govil PK (2010) Assessment of heavy metal contamination in soils at Jajmau (Kanpur) and Unnao industrial areas of the Ganga Plain, Uttar Pradesh, India. J Hazard Mat 174:113–121

Gupta S (2015) Review on *Sperata seenghala* (Sykes, 1839), A Freshwater Catfish of Indian Subcontinent. J Aquac Res Development 6:290 doi:10.4172/2155-9546.1000290

Ihssen PE, Booke HE, Casselman JM, McGlade JM, Payne NR, Utter FM (1981) Stock identification: materials and methods. Can J Fish Aquat Sci 38:1838–1855

IUCN (International Union for Conservation of Nature) (2015) IUCN red list of threatened species, version 2014.3. http://www.iucnredlist.org. Accessed 23 April 2015

Kalish JM (1989) Otolith microchemistry: validation of the effects of physiology, age and environment on otolith composition. J Exp Mar Biol Ecol 132:151–178

Kalish JM (1992) Formation of a stress-induced chemical check in fish otoliths. J Exp Mar Biol Ecol 162:265–277

Kamyotra JS (2009) Ganga: water quality trend. Monitoring of Indian Aquatic Resources Series: MINARS/31/2009 –2010. CPCB Ministry of Environment and Forests, Delhi

Khan MA, Miyan K, Khan S, Patel DK, Ansari NG (2012) Studies on elemental profile of otoliths and truss network analysis for stock discrimination of the threatened stinging catfish, *Heteropneustes fossilis* (Bloch 1794), from the river Ganga and its tributaries. Zool Stud 51:1195–1206

Lakra WS, Sarkar UK, Gopalkrishnan A, Kathirvelpandian A (2010) Threatened freshwater fishes of India. NBFGR, ICAR, Lucknow

Milton DA, Chenery SR (2001) Sources and uptake of trace metals in otoliths of juvenile barramundi (*Lates calcarifer*). J Exp Mar Biol Ecol 264:47–65

Miyan K, Khan MA, Khan S (2014) Stock structure delineation using variation in otolith chemistry of snakehead, *Channa punctata* (Bloch, 1793), from three Indian rivers. J Appl Ichthyol 30:881–886

Miyan K, Khan MA (2014) Otoliths - An important tool for fish population studies. In: Shukla V (ed) Reviewed Proceedings of National Seminar "Next Generation Sciences: Vision 2020 and beyond". Dept Zool, MDU Univ, Rohtak, pp 227–236

Miyan K (2014) Stock identification of selected freshwater fish species inhabiting three rivers of the Gangetic river system. Ph.D. Thesis, Aligarh Muslim University, Aligarh

Miyan K, Khan MA, Patel DK, Khan S, Ansari NG (2015) Truss morphometry and otolith microchemistry reveal stock discrimination in *Clarias batrachus* (Linnaeus, 1758) inhabiting the Gangetic river system. Fish Res doi:10.1016/j.fishres.2015.10.024

Purushothaman P, Chakrapani GJ (2007) Heavy metals fractionation in Ganga river sediments, India. Environ Monit Assess 132:475–489

Rahman MA, Arshad A, Yusoff FM, Amin SMN, Marimuthu K, Ara, R (2014) Development of captive breeding and seed production techniques for giant river catfish *Sperata seenghala*. Nor Amer J Aquacul 76: 97–103

Ranaldi MM, Gagnon MM (2010) Trace metal incorporation in otoliths of pink snapper (*Pagrus auratus*) as an environmental monitor. Comp Biochem Physiol Part C 152:248–255

Saini A, Dua A, Mohindra V (2010) Genetic variability analysis of Giant river cattish (*Sperata seenghala*) populations from Indus river system by RAPD-PCR. Russian J Genet 46:982–987

Sarkar UK, Gupta BK, Lakra WS (2010) Biodiversity, ecohydrology, threat status and conservation priority of the freshwater fishes of river Gomti, a tributary of river Ganga (India). Environmentalist 30:3–17

Schaffler JJ, Winkelman DL (2008) Temporal and spatial variability in otolith trace-element signatures of juvenile striped bass from spawning locations in Lake Texoma, Oklahoma, Texas. Trans Am Fish Soc 137:818–829

Sengupta B (2006) Water quality status of Yamuna River (1999–2005). Assessment and Development of River Basin Series: ADSORBS/41/2006-07, CPCB Ministry of Environment and Forests, Delhi

Sinha M, Khan MA (2001) Impact of environmental aberrations on fisheries of the Ganga (Ganges) River. Aquat Ecosys Health Manage 4:493–504

Sturrock AM, Trueman CN, Darnaude AM, Hunter E (2012) Can otolith elemental chemistry retrospectively track migrations in fully marine fishes? J Fish Biol 81:766–795

Talwar PK, Jhingran AG (1991) Inland Fishes of India and Adjacent Countries, vol. 2. Oxford and IBH Publ, New Delhi

Turan C (2006) The use of otolith shape and chemistry to determine stock structure of Mediterranean horse mackerel *Trachurus mediterraneus* (Steindachner). J Fish Biol 69 (Suppl C):165–180

Walther BD, Kingsford MJ, O'Callaghan MD, McCulloch MT (2010) Interactive effects of ontogeny, food ration and temperature on elemental incorporation in otoliths of a coral reef fish. Environ Biol Fish 89:441–451

Wells BK, Rieman BE, Clayton JL, Horan DL, Jones CM (2003) Relationships between water, otolith, and scale chemistries of west slope cutthroat trout from the Coeur d'Alene River, Idaho: the potential application of hard-part chemistry to describe movements in freshwater. Trans Am Fish Soc 132:409–424