The planktonic world
Summary of findings

- The present study elucidated combined taxonomic and ecological studies of the microzooplankton tintinnids, a species-rich group of marine ciliates from Hooghly Estuary and provides some new information on their spatiotemporal distribution and community structure in the context of environmental parameters.

- The microzooplankton community consists of 32 species of tintinnid ciliates (11 genera and 8 families) followed by 2 species of copepod nauplii (*Acartia sp.* and *Oithona sp.*) and solitary species of rotifer (*Brachionus sp.*).

- Tintinnid community was dominated by the family Codonellidae (63%) of total species abundance followed by Tintinnidiidae (13%), Tintinnidae (6%), Codonellopsidae (6%), Xystonellidae, Coxliellidae, Dictyocystidae & Metacylididae (each comprising 3%).

- Tintinnids were primarily grouped into agglomerated and non-agglomerated forms where the former constituted the major part both qualitatively (27 species) and quantitatively (~84% of total species). Non-agglomerated genera comprised of single species of *Favella sp.*, *Dadayiella sp.*, *Eutintinnus sp.*, *Metacylis sp.* and *Helicostomella sp.*, contribute 16% of the total community.

- The agglutinated genus *Tintinnopsis* (20 sp) was predominant in total tintinnid community followed by *Tintinnidium* (2 sp), *Leprotintinnus* (2 sp), *Codonellopsis* (1 sp), *Stenosemella* (1 sp) *Helicostomella* (1 sp), *Favella sp.* (1 sp), *Eutintinnus sp.* (1 sp), *Metacylis sp.* (1 sp), *Dadayiella sp.* (1 sp) and *Wangiella* (1 sp).

- The contribution of 3 core species (*Tintinnopsis beroidea*, *Tintinnidium primitivum*, *Leprotintinnus simplex*) was dominant and representing 58.40% of total tintinnid abundance followed by 13 seasonal species (35.92%) and 16 occasional (5.68%). The ubiquitous presence of three core species throughout the season was an evident for their flexible adaptive strategies.

- A wide range of seasonal variations in tintinnid abundance was observed with maximum value (~1995 ind. l⁻¹) during post-monsoon in mouth of the estuary (Gangasagar) and minimum (~52 ind. l⁻¹) during monsoon in brackish water site (Diamond Harbour). Highest abundance was coupled with high salinity (24), Chl *a* (2.24 mg m⁻³) in association with high phytoplankton density (4440 cells l⁻¹).
The maximum species diversity index ($H' = 2.65$) in mouth of the estuary (close proximity to Bay of Bengal) suggests a migratory inclusion of neritic species, while a low value ($H' = 0.71$) in fresh water site indicates a less healthy or degraded ecosystem.

The biomass of the loricate ciliates was minimum ($0.004 \, \mu g \, C \, l^{-1}$) during monsoon and maximum ($2.764 \, \mu g \, C \, l^{-1}$) during pre-monsoon months. Minimum and maximum daily production rate was recorded $0.04 \, \mu g \, C \, l^{-1}\, day^{-1}$ during post-monsoon to $3.54 \, \mu g \, C \, l^{-1}\, day^{-1}$ during pre-monsoon season respectively.

The loria length and loria oral diameter of tintinnid was ranged from $22.76 \, \mu m \ (T. \, nana)$ to $183.25 \, \mu m \ (F. \, ehrenbergii)$ and $10.10 \, \mu m \ (T. \, beroidea)$ to $56.10 \, \mu m \ (T. \, bermudensis)$ respectively.

An overall dominance and diversity of the small-sized tintinnid (lorica length <76μm) belonging to the genera *Tintinnopsis* sp., *Tintinnidium* sp., *Codonellopsis* sp., *Wangiella* sp., *Eutintinnus* sp., *Metacylis* sp. and *Helicostomella* sp. was pronounced, accounting ~66% of the total tintinnid abundance. The large-sized tintinnids accounting 34% of the total tintinnid abundance and mainly contributed by *F. \, ehrenbergii*, *T. \, cylindrica*, *T. \, radix*, *T. \, bermudensis*, *T. \, karajacensis* and *D. \, ganymedes*.

Polymorphism is very much pronounced in three core species (*T. \, beroidea*, *T. \, primitivum* and *L. \, simplex*) based on temperature and salinity. The increase of loria length and loria oral diameter (LOD) was noticed in high salinity (11-18) and high temperature (>30°C), whereas reduced length of loria was attributed in fresh water site (salinity<0.3) and low temperature (<20°C).

The abundance of tintinnid community was affected by multiple environmental factors such as temperature, salinity, nutrients (nitrate, phosphate, silicate), dissolved oxygen, chl a and prey-predator interaction. Among them, the response of tintinnid community to nitrate and chl a concentration provided an evidence for tintinnids as bio-indicators, revealed from multivariate statistics.

The pronounced adverse impact of anthropogenic and human-induced stresses on tintinnid community was evident which could leads to eco-environmental deterioration, disrupting the productivity in benthic and pelagic ecosystems and fishery potentialities which directly related to livelihood services.
Conclusion

The study used a combined taxonomic and ecological approach of the microzooplankton dominated by tintinnids from neritic eutrophicated Hooghly estuarine ecosystem and provides some new information on their spatiotemporal distribution and community structure in the context of environmental parameters. Well-defined TINs assemblages are evident representing the “fingerprint” of a specific ecological zone of the estuary, characterized by a set of environmental variables, especially water temperature, chl \( a \) and salinity followed by inorganic nutrients. In addition, tintinnid diversity is also related to various biological factors (predators, resilience of dominant tintinnids etc.,) as well as by particular physical and hydrological characteristics of each sampling site (water currents, wind and wave action etc.). The maximum diversity of tintinnid was coincided with the high density and diversity of phytoplankton mainly during post monsoon period. The ubiquitous presence of \( T. \) beroidea, \( T. \) primitivum and \( L. \) simplex revealed distinct seasonal variations in oral diameter and length of the lorica mainly linked to water temperature as well as salinity. The occurrence of less abundant tintinnid species were mostly site-specific and season-specific, suggests their co-existence as well as sustainability in the estuarine water. The morphological characteristics of both the core and occasional tintinnid assemblages differed in terms of distribution as well as abundances among LOD size classes. Small-sized tintinnid (lorica length <76 µm) was found to be dominated over the large-sized and this might be favored by environmental variables (low Chl \( a \), salinity and high turbidity) as well as biotic interaction (e.g. reduced prey size). Moreover, this low-lying gangetic plain is vulnerable to a number of geo-hazards that lead to water logging and flooding, including cyclones, tidal upsurges, storms and intense local precipitation. This is mainly due to impact of climate change which would have direct /indirect impact on the existing biodiversity of Hooghly Estuary. The discrete acute impacts (eg., storm surges, cyclones, tidal upsurges and intense precipitation) and continuous chronic impacts (eg., gradual increase in mean temperature) are a matter of great concern as these would have negative impact on the biomass, species composition and trophic activities of the pelagic communities disturbing the ecological and economic stability. The negative impact and conspicuous changes in water quality characteristics and plankton community structure due to Annual Gangasagar Festival (AGF) and immersion of idols activities along the Hooghly estuary. These festivals were responsible for multiple driver of changes relating to beach erosion, shoreline modifications, pollution of beaches by discarded plastic and electronic wastes as well as destruction of natural habitats (mud-flats, coastal dunes, vegetation etc.) resulting immense adverse impact on the coastal
diversity. The bioaccumulation of heavy metal in biological system transfers the toxic element from producer to consumer level, which would post several health hazards. There is an increasing trend of tourism, recreation and festival activities at this sensitive ecotone and hence it is strongly recommend for adopting strategies of integrated river basin management policy emphasizing on sewage treatment facilities, recycling of waste products and riparian management. Adverse negative impacts due to intensive human activities resulted eco-environmental deterioration, disrupting the productivity in benthic and pelagic ecosystems and fishery potentialities which directly related to livelihood services. The Government should implement strict legislative measures and administrative sound management strategies to mitigate the present problems. Further investigations about the relative grazing impact of nano- and pico-plankton by microzooplankton through trophic dynamics has to be worked out for better understanding of their role in the microbial food webs. Small-sized tintinnids reached some of the greatest abundances in this estuarine system might be due to high turbidity as well as predation pressure, hence a long term trend analyses is needed to identify the complex biota–environment interactions.