Population structure and reproductive biology of selected sciaenid species along the fishing grounds of Goa, west coast of India

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The present hypothesis on reproductive migration pattern between two species of sciaenids is based on the data collected with the help of the single-day commercial trawl with a fishing effort of 181 h along the fishing grounds of Goa, west coast of India. The observations on abundance revealed that between the two species (Johnius borneensis and Otolithes ruber) that formed bulk of the catch, a significant inverse trend in catch was observed. The pattern of migration based on the examination of female gonadal status suggested J. borneensis to be a continuous spawner and was evidenced by continuous occurrence of gravid and spent females and their juveniles. On the other hand, the rare occurrences of gravid females of O. ruber from the study area suggest that the species spawns away from the coast or might migrate to some potential spawning grounds. Further, an assessment of fecundity and the ova distribution pattern pronounced higher fecundity in O. ruber compared to J. borneensis with multiple spawning in both the species.

Keywords: Fecundity, population, spawning, Sciaenidae.

The fishing grounds off Goa support an array of vertebrate and invertebrate fauna. Of these, the sciaenids are one of the most diverse and commonly occurring teleostan faunal groups contributing to around 10% of the total demersal catches of Goa. Published literature from this region revealed that these constituted 18% and 23% of the demersal fish assemblages of Marmugao and Aguada bay respectively, in terms of their abundance. In recent years, the demersal fishery of the region is subjected to increased fishing pressure through bottom trawlers for commercial exploitation. Moreover, large-scale mortality of juveniles owing to the use of reduced mesh sizes in trawl net influences the occurrence and abundance of commercially important demersal fauna.

Reproduction and recruitment is a species-specific biological process crucial for the continued existence and proliferation of population. Studies pertaining to reproductive biology and spawning behaviour are essential for a complete understanding of population dynamics. Moreover, reproductive rate determines the resilience.

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capacity and sustainability of a species in response to environmental changes and anthropogenic activities. Further, recruitment success is also an important component of population dynamics, governed by freshwater runoff into estuaries, status of habitat and low fishing pressure. Published literature suggests extensive research on the reproductive biology of sciaenids from Indian waters. An attempt is made here to assess the sciaenid community from the nearshore fishing grounds of Goa with the following objectives: (1) to illustrate the sciaenid community structure based on species composition and abundance; and (2) to assess the abundance and reproductive biology of two major species forming bulk of the sciaenids of trawl catches of Goa.

The study area comprised potential fishing grounds off Goa, central west coast of India between 15°29'07.6"N and 15°34'44.3"N lat., and between 73°38'10.5"E and 73°46'03.1"E long. (Figure 1). The prevailing substratum is of mixed sand-silt type interspersed with submerged rocky patches. These waters receive ample quantity of nutrients and freshwater from the adjacent Mandovi estuary. It is subjected to strong seasonal upwelling during south-west monsoon period, resulting in marked differences in hydrographic regimes and productivity, thus contributing to rich fishery in the region. It also serves as nursery grounds for juveniles of several marine teleost species.

The samples were collected on-board single-day commercial shrimp trawler along the fishing grounds off Goa, central west coast of India down to 30 m depth (Figure 1) with a total sampling effort of 181 h incorporating 100 trawl hauls. The sampling period extended from November

Figure 1. Map of the study area indicating trawl operations.
Table 1. Maturity stage-wise average total length, weight of fish, weight of gonad, fecundity, ova diameter and gonado-somatic index (GSI) of Johnius borneensis and Otolithes ruber

<table>
<thead>
<tr>
<th>Maturity stage</th>
<th>Total length (cm)</th>
<th>Weight of fish (g)</th>
<th>Weight of gonad (g)</th>
<th>Fecundity</th>
<th>Ova diameter (mm)</th>
<th>GSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Johnius borneensis (N = 21)</td>
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</tr>
<tr>
<td>Mature</td>
<td>14.69 ± 1.49</td>
<td>39.84 ± 10.35</td>
<td>1.19 ± 0.37</td>
<td>63.38 x 10^3 ± 24.66 x 10^3</td>
<td>0.32 ± 0.05</td>
<td>2.98 ± 0.42</td>
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<tr>
<td>Fully mature</td>
<td>15.13 ± 1.05</td>
<td>42.60 ± 10.59</td>
<td>2.11 ± 0.85</td>
<td>80.04 x 10^3 ± 27.75 x 10^3</td>
<td>0.37 ± 0.11</td>
<td>4.96 ± 1.44</td>
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<tr>
<td>Spent</td>
<td>13.78 ± 2.16</td>
<td>30.58 ± 12.15</td>
<td>0.71 ± 0.27</td>
<td>43.17 x 10^3 ± 15.59 x 10^3</td>
<td>0.29 ± 0.06</td>
<td>2.33 ± 0.40</td>
</tr>
<tr>
<td>Overall</td>
<td>14.70 ± 1.47</td>
<td>39.26 ± 11.17</td>
<td>1.49 ± 0.83</td>
<td>66.67 x 10^3 ± 27.43 x 10^3</td>
<td>0.33 ± 0.09</td>
<td>3.70 ± 1.49</td>
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<tr>
<td>Otolithes ruber (N = 26)</td>
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<td></td>
</tr>
<tr>
<td>Mature</td>
<td>18.25 ± 2.58</td>
<td>62.43 ± 25.93</td>
<td>2.19 ± 0.53</td>
<td>105.11 x 10^3 ± 17.07 x 10^3</td>
<td>0.33 ± 0.04</td>
<td>3.74 ± 0.87</td>
</tr>
<tr>
<td>Fully mature</td>
<td>19.44 ± 1.85</td>
<td>78.07 ± 25.30</td>
<td>3.35 ± 1.06</td>
<td>123.88 x 10^3 ± 51.81 x 10^3</td>
<td>0.44 ± 0.13</td>
<td>4.34 ± 0.80</td>
</tr>
<tr>
<td>Spent</td>
<td>16.98 ± 0.87</td>
<td>46.80 ± 04.88</td>
<td>1.11 ± 0.61</td>
<td>57.23 x 10^3 ± 30.09 x 10^3</td>
<td>0.32 ± 0.04</td>
<td>2.35 ± 1.30</td>
</tr>
<tr>
<td>Overall</td>
<td>18.60 ± 2.19</td>
<td>67.24 ± 25.67</td>
<td>2.56 ± 1.15</td>
<td>106.41 x 10^3 ± 43.92 x 10^3</td>
<td>0.38 ± 0.11</td>
<td>3.81 ± 1.11</td>
</tr>
</tbody>
</table>

Random gonad samples belonging to mature, fully mature and spent females (N = 21 for J. borneensis and N = 26 for O. ruber) from the third fishing season (October 2012–May 2013) were chosen for analysis of fecundity and ova diameter. The preserved gonads were washed thoroughly in 70% alcohol with intense care, dried with blotting paper and weighed to obtain the total weight of eggs. The fecundity was then analysed by weighing and counting 0.01 g of dried eggs under the compound microscope using counting chamber in triplicate to obtain the average number of eggs in the gonads. The absolute fecundity was then calculated using the formula given by Bagenal11 as

\[ F = \frac{\text{total weight of ovary/weight of enumerated eggs} \times \text{number of enumerated eggs}}{\text{region}^2} \]

Moreover, diameters of 150 random ova were measured from each ovary using an ocular micrometer.

The family Sciaenidae is one among the most speciose and dominant demersal fish families occurring along the region1,2, contributing to around 10% of the total demersal fish production of Goa. During the present study, it consisted of 7 genera and 15 species, which contributed 2.97% of the total trawl catch and 10.33% of the teleostean fauna in terms of their abundance. Among the fifteen species observed during the present study, two species namely, the sharpnose hammer croaker (Johnius borneensis Bleecker, 1851) and tiger tooth croaker (Otolithes ruber Bloch and Schneider, 1801) representing 46% and 11% respectively of the total sciaenid catches (Figure 2) in terms of their abundance were studied in detail owing to their higher abundance and continuous occurrence in trawl catches. The probable reasons for higher abundance of these two species could be habitat heterogeneity with favourable niches, higher fecundity, and their food preferences along with wider diet spectrum. Moreover, these species are permanent residents along the region7. Other sciaenids represented 43% to the total sciaenid catches in terms of their abundance (Figure 2); and consisted of Otolithes cuvieri (14%),
J. coitor (7%), J. elongatus (5%), Pennahia macrophalous, J. belangeri and J. amblycephalus (4% each), J. dussumieri (3%), Kathala axillaris (1.17%), Pennahia anea (0.58%), Protonibea diacanthus (0.54%), Dendrophyse russellii (0.35%) and Johnius macropterus and Paranibea semiluctuosa (0.24% each).

Abundance of total sciaenids did not show any significant trend ($R^2 = 0.384$); however it showed trivial increasing trend from the first to the third fishing season. Among the sciaenids, the species J. borneensis is one of the most commonly occurring and abundant sciaenid species observed during the present study along the region. Analysis of monthly abundance revealed an inverse trend between J. borneensis and O. ruber with an overall increasing trend in the case of former species (Figure 3 a) and an overall decreasing trend observed in the case of latter species (Figure 3 b). J. borneensis showed higher abundances during December and May throughout the study period. However, it showed consistent higher abundance from February 2013 to May 2013. On the other hand, O. ruber was abundant during the months of December and March–May throughout the study period. The mean abundance (number hr$^{-1}$) observed for J. borneensis and O. ruber was 255 ± 281 and 64 ± 48 respectively. The higher abundance of sciaenids during this period (December–May) can be attributed to recruitment of new juveniles as evidenced by predominance of their juveniles in sub-samples.

Females of J. borneensis and O. ruber were found throughout the study period (Figure 3). The juveniles/immature females of both species were found abundantly during October–December and February–May suggesting a prolonged/continuous spawning activity. The continuous and abundant occurrence of mature (gravid) and spent females of J. borneensis (Figure 3 a) in the study area indicates that the majority of their spawning process takes place in near shore coastal waters with peak spawning from November to April. These observations have been validated by the continuous occurrence of their juveniles from the study area. Further, published literature also reported November–June as the spawning period for J. borneensis in Kakinada region whereas Muthiah reported June–July and October–November as spawning period for J. borneensis in Bombay waters. On the other hand, the mature (gravid) and spent females of O. ruber occurred rarely (November–December, February and April; Figure 3 b) in the study area, suggesting occasional spawning activity in the nearshore coastal waters. One of the reasons for lower occurrences of mature and spent females of O. ruber in the study area could be its reported spawning season which extends from June to October along the west coast of India, which corresponds to the monsoon fishing ban along the study area followed by prevailing rough weather conditions along the coastal belt during August–September, thus hindering the sampling process.

The observations made on the fecundity and ova diameter of J. borneensis ($N = 21$), and O. ruber ($N = 26$) revealed that the former species exhibited lower fecundity and ova diameter ($66.67 \times 10^3 \pm 27.43 \times 10^3$; $0.33 \pm 0.09$ mm) compared to the latter one ($106.41 \times 10^3 \pm 43.92 \times 10^3$; $0.38 \pm 0.11$ mm; Table 1). Published literature also reported fecundity ranging from $43810 \pm 179.65 \times 10^3$ numbers of eggs for O. ruber and $9253 \pm 151.69 \times 10^3$ numbers of eggs for J. borneensis.

The ova distribution pattern (mature, fully mature and spent females) of both the species (Figure 4) revealed unimodal distribution of ova in mature and spent females (Figure 4 a, c, d, f) with a mode at 0.30–0.35 mm and a distinct bimodal distribution was observed in fully mature/ripe females (Figure 4 b and e) with primary mode at 0.30–0.35 mm in both species and secondary mode at 0.50–0.55 mm and 0.55–0.60 mm in J. borneensis and O. ruber respectively. In these species (J. borneensis and O. ruber), once the ova has been ovulated from the ready batch (0.45–0.80/0.45–70 mm), the ova from the intermediate or smaller size class (0.30–0.45/0.20–0.40 mm) transforms into a new ready batch for spawning as a result of asynchronous development of ova. This sequential event continues till the last batch of eggs shed-off indicating a multiple/intermittent spawning process and this has also been reported in many other teleostean species.

It is noteworthy to mention here that O. ruber, in spite of being a multiple or continuous spawner and having higher fecundity compared to J. borneensis, was observed to have low abundance during the present study. It is connotative from the above observations that the species O. ruber spawns away from the coastal waters probably in less productive offshore waters. However, the continuous occurrence of their juveniles from the study area indicates migration to the productive coastal waters which serves as potential nurseries as this species is found to feed upon zooplankton (51% index of relative importance (IRI)), small teleosts (23% IRI) and prawns (19% IRI).
Figure 3. Monthly variation in abundance (h⁻¹) and percentage of immature, mature and spent females of (a) *Johnius borneensis* and (b) *Otolithes ruber*.

Figure 4. Percentage ova distribution plot of *Johnius borneensis*. a, Mature; b, fully mature; c, spent females and *Otolithes ruber*; d, mature; e, fully mature; f, spent females.
During this process there might be some mortality of their larvae and juveniles due to starvation and predation by potential predators\textsuperscript{26,29} and hence low survival rate, leading to reduced species abundance in the study area. In contrast, \textit{J. borneensis} spawns in productive coastal waters which also serve as good nurseries\textsuperscript{30}, leading to high survival rate of juveniles and this might be responsible for its increased abundance compared to \textit{O. ruber} along the region. Moreover, the higher dietary breadth in \textit{J. borneensis} ($B = 0.34$) might have favoured their increased abundance\textsuperscript{31,32} as compared to \textit{O. ruber} ($B = 0.21$). Secondly, there is also a possibility of migration of gravid females of \textit{O. ruber} to the deeper offshore waters or some other potential spawning grounds for spawning as reported in other finfishes\textsuperscript{33,34} and hence the lower occurrences of their gravid and spent females from the study area.

Further, an analysis of sciaenid landings along the Goa coast displayed an overall decreasing trend\textsuperscript{35,35} ($R^2 = 0.349$) (Figure 5), attributed to the combined effect of elevated exploitation and resultant by-catch generation and coastal anoxia. In recent years, high demand for fish and consequent intensification in fishing efforts for elevated yields/catch along with the by-catch have made the sciaenid fishery of Goa highly vulnerable to sustained fishing pressure. Apart from this, the seasonal anoxia occurring over the western Indian continental shelf\textsuperscript{34} results in mortality of fish larvae and juveniles of sciaenids\textsuperscript{36} as the anoxic period coincides with the spawning period of sciaenids\textsuperscript{37} and may also compel some of the sciaenid species to migrate to other places\textsuperscript{38}. The anoxic conditions or hypoxia is widely reported to affect some of the aspects of fish population such as reproduction and development\textsuperscript{39}, larval survivorship, quality and fitness of juveniles\textsuperscript{39}, biodiversity loss\textsuperscript{40}, relocation of fish populations\textsuperscript{40}, etc. Therefore, the situation necessitates continuous monitoring of trawl catches and its by-catch coupled with studies pertaining to eco-biological aspects and population dynamics of sciaenids for sustainable exploitation and management of sciaenid fishery along the region.

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Fragilariopsis sp. bloom yellowish-brown waters off Alappuzha, south-central Kerala coast, India, during the mud bank-upwelling phase.

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Mud banks (Chakara) of Kerala are calm coastal waters that form in several isolated stretches along the coast usually during the southwest monsoon (SWM) period (June–September). They are characterized by the damping of incident waves, generating localized calm sea environment conducive for fishing activities, while the high monsoon waves create hostile environment in the rest of the region. Here, we present the scientific basis of the yellowish-brown discoloration of water column that occurs off Alappuzha, Kerala annually during the peak and late SWM associated with coastal upwelling-mud bank event. The discoloured waters that occur off Alappuzha associated with these events are locally known as ‘pola vellam’, which is nothing but diatom blooms. In 2014, pola vellam was actually caused by the bloom of Fragilariopsis (= Fragilaria) sp.; hereafter Fragilariopsis, which was

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