Chapter 1

General introduction

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1.1 Introduction

With the stabilization of world finfish catches in general, and the depletion of a number of fish stocks that used to support industrial-scale fisheries, increasing attention is now being paid, to the so-called unconventional marine resources. This includes cephalopods such as squids, cuttlefishes, octopuses, and chambered nautiluses, with a total number of living species fewer than 1000 distributed in 43 families. During the last 56 years the global landings of cephalopods rose from 580,435 tonnes to 4,253,046 tonnes, in spite of a substantial decline in the rate of increase in the total world production of fish species (FAO, 2009). The explanation of this constant increase of the captures of cephalopods worldwide is complex. One of the proposed hypotheses is that the stocks of cephalopods have increased, whereas groundfish stocks have diminished (Caddy and Rodhouse, 1998). This is supported by the biological characteristic of cephalopods which are undoubtedly ecological opportunists (Guerra, 2006).

As reviewed by Boyle and Rodhouse (2005) and Pierce et al. (2010), cephalopods were historically important, equally as target species and bycatch, in the coastal artisanal fisheries of numerous countries of the world. The importance of cephalopods in fisheries is increasing year by year. Now the major international fisheries have also directly focused on them. Besides, research on the ecology of the oceans has also revealed the importance of cephalopods in the trophic networks of marine ecosystems, both as prey and subdominant predators, which tend to increase in biomass when other species (particularly their predators and competitors for food) become depleted as a result of heavy fishing (Roper et al., 1984). However, as the importance of cephalopods continues to increase

world-wide as a fisheries resource, their short life cycles and variable growth rates makes cephalopod stocks volatile and vulnerable. Pierce and Guerra (1994) reviewed the stock assessment methods used in cephalopod fisheries worldwide and found that despite a multitude of assessment techniques, only few cephalopod fisheries were well managed. This scenario has not changed substantially in the last 16 years.

Among the cephalopods the squids of the order Teuthoidea, is the major contributor to Cephalopod fishery. The two Suborders, Myopsida, “covered-eyed” and the Oegopsida, “Open eye” of the squid have formed the basis of the major cephalopod fisheries worldwide and both together contributes more than 71% of the cephalopod catches (Roper et al,1984). The suborder Oegopsida or oceanic squids comprises twenty five families (Sweeney and Roper, 2001), several of which support the major cephalopod fisheries of the world. These are one of the most diverse groups of cephalopods, with more than 240 species described, occupying key trophic roles as predators in the open ocean ecosystem (Clarke, 1996; Jereb and Roper, 2010). Some of these species undergo high fishing pressure and their catches represent half of the total cephalopod world captures (Boyle and Rodhouse, 2005; FAO, 2010). The "flying squids" (Roper et al. 1984) of the family Ommastrephidae (suborder Oegopsida) account for about 65 percent of the world's commercial cephalopods (Brunetti 1990). Although less widely recognized than the inshore Loliginidae (suborder Myopsida)- which are subjects of commercial and artisanal fisheries globally, Ommastrephids are important in commerce and ecology. Six of the 10 genera of this family currently support a fishery, and although much of the catch is not broken down between inshore squids and flying squids, it can reasonably be assumed that this family alone accounts for more than half of the world cephalopod catch.

The effective and rational utilization of the Oceanic fishery resources is of great importance, especially during the time of depletion of shallow water resources. One of such important Oceanic resource is the tropical Indo-Pacific Ommastrephid squid *Sthenoteuthis oualaniensis* (Lesson, 1830). It is the most abundant large sized squid in the Indo-Pacific region with an estimated biomass of 8-11 metric tons (Nigmatullin, 1990). Its biomass in the Indian Ocean has been estimated to be about two million tons (Zuyev et al., 1985) with high concentration of 12 to 42 ton per square km in the Arabian sea during the month of November-January (Nesis, 1993). This greatest abundance in biomass, is due to its broad ecological valency, complicated intraspecific structure, great fecundity and short life cycle with high growth rate (Zuyev and Nesis, 1971; Nesis, 1977; Zuyev et al., 1985). These features brings the *S. oualaniensis* into the spectrum of species, most interesting from the scientific and practical point of view.

*S. oualaniensis*, commonly known as purple squid, is a member of the family Ommastrephidae and thought to be the most abundant large squid in the tropical and subtropical waters of the Indo-Pacific region (Young and Hirota, 1998; Dunning, 1998). The northern boundary of its range in the Indian Ocean is limited by the Asian continent. The southern boundary reaches the southernmost point of Africa (about 35°S), then is narrowed a little to the central area of the southern Indian Ocean and passes on to the Pacific Ocean approximately along the Tropic of Capricorn to the continental slope of South America. However, near America, westward of the Peru Current, the abundance of *S. oualaniensis* is low and here the Jumbo squid *Dosidicus gigas* predominates (Alexandronetz et al., 1983; Nigmatullin et al., 1988). The reproductive area of *S. oualaniensis* is located in the Indian Ocean northward of 18–22°S, and in the Pacific Ocean between 20–25°N and 16–20°S. The range boundaries are mobile and are displaced toward high latitudes with warming during summer of the
appropriate hemisphere and moved to lower latitudes with the fall of water temperature.

It has local commercial significance in the Arabian Sea and the Indian Ocean (Aravindakshan and Sakthivel, 1973; Silas et al., 1982; Roper et al., 1984), but its resources are poorly exploited. The most comprehensive earlier information on *S. oualaniensis* from the tropical zone of the Indian Ocean was presented by Zuyev and Nesis (1971) and Zuyev et al. (1985). On the basis of size differences, dorsal photophore and gladius morphology, five forms of *S. oualaniensis* has been distinguished: (1) dwarf early-maturing equatorial form without dorsal photophore; (2) dwarf late-maturing Red Sea form with dorsal photophore; (3) and (4) middle-sized late-maturing form with dorsal photophore and with single lateral axis of the gladius (3), distributed in the Red and Arabian seas and the Gulf of Aden, and with double lateral axes of the gladius (4), most common in the tropical Indian and Pacific oceans; (5) the giant form with dorsal photophore and single lateral axes, inhabiting Red Sea, Arabian Sea and the Gulf of Aden (Bizikov, 1991, 1996). The dwarf equatorial form is found roughly within 10° latitude of the equator where it co-occurs with the typical *S. oualaniensis*. The dwarf form has several morphological characters that separate it from the typical *S.oualaniensis* showing absence of the dorsal photophore patch, slightly different hectocotylus and slight differences in the spermatophore structure and in the gladius structure (Nesis, 1993).

Ecological differences were also observed between these two forms (Nigmatullin et al., 1983c; Pinchukov, 1983). Researchers have disagreed on whether or not the dwarf form is a distinct species (Clarke, 1966 and Wormuth, 1976). On the other side, research continues to reveal that squid growth can be greatly modified by temperature or seasons of hatching (Rodhouse & Hatfield, 1990; Jackson & Choat, 1992; Forsythe, 1993; Brodziak & Macy, 1996; Dawe &
Beck, 1997; Jackson et al. 1997; Hatfield, 2000; Forsythe et al. 2001) as well as food supply (Jackson & Molschaniwskyj, 2001). Okutani and Tung (1978) found *S. oualaniensis* in Taiwanese waters to consist of three different seasonal cohorts: a June-spawning group, a September-October spawning group and a February-March spawning group. In the Indian waters Mohamed et al, (2006) has reported the occurrence of medium form with double axis rachis off the south west coast. Meanwhile, a study based on Random Amplified Polymorphic DNA (RAPD) analysis has been done in the Marine Biological Laboratory of College of Marine Science and Technology of Shanghai Fisheries University. Its preliminary findings suggest that a large variation in biology among the groups (Xinjun et al ,2007). Roeleveld (http://swr.nmfs.noaa.gov/pir/feis/ Appendix%20B.pdf) considered the dwarf form to be a separate species that could only be identified as an adult. However, if the dwarf form proves itself to be a nascent divergent species, it will serve as a fascinating example of sympatric speciation, since its range is completely within that of the typical form, and would merit further study for that reason alone.

Though the phenotypic plasticity of cephalopods is widely accepted as one of their main characteristics (Boyle and Boletzky, 1996), our understanding of the causes of plasticity in squid growth is still far from complete. In view of that, in this study the two forms of the *Sthenoteuthis oualaniensis*, dwarf and medium form have been separately studied and compared to understand the difference in its biology, if any, for further research and to evolve future management strategy for the resources.
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1.2 Systematics

Class: Cephalopoda
Sub Class: Coleoidea
Order: Teuthida
Suborder: Oegopsina
Family: Ommastrephidae
Subfamily: Ommastrephinae
Genus: Sthenoteuthis Verrill, 1880
Species: oualaniensis (Lesson, 1830);
pteropus (Steenstrup, 1855).

Description: Mantle long, muscular and cylindrical up to the point of origin of fins and tapers to a narrow point at the posterior end (Plate 1.1(b)). Dorsal margin is slightly produced in the middle (Plate 1.1(a)). Fins short, muscular, broad with convex anterior margin. Head large and as wide as mantle and bears comparatively short arms. Funnel short, compact and set in a deep pit present on the ventral side of the head; foveola (Plate 1.1(b) and Plate 1.2(b)) with 7-9 longitudinal folds in the central pocket and 3-5 lateral pockets on either side. Funnel locking apparatus inverted T-shaped and fused in its middle portion with the mantle groove (Plate 1.2(c)). Arms large, strong in the order III>II>I>VI and compressed with the third pair strongly keeled (Plate 1.1). Arm sucker biserial; the protecting membranes have prominent trabeculae; the larger arm suckers are provided with about 7-12 sharp teeth around the entire rim of the horny...
rings (Plate 1.2 (f)). Left arm IV in males thick, longer than the right arm and hectocotylized. Two rows of 14-15 suckers protected by flap-like membranes present on the basal portion of the hectocotylized arm. Suckers and papillae absent on about one half of its distal part. A series of pits present in a single row along the base of the protective membranes.

Tentacles are short, muscular and laterally compressed. Clubs small, slightly expanded; suckers quadriserial with the inner rows on the manus larger (Plate 1.2 (g)). Larger suckers of the club bear about 20 sharp teeth on the rims of which four are larger and located one in each quadrant (Plate 1.2 (e)). Gladius (Plate 1.3 (a-c)) thin and very slender; rachis stout anteriorly, uniformly narrowing to the posterior tip, and with median rib and two marginal ribs along the edges (Plate 1.3.b); posterior end with a small vane about one-seventh of the total gladius length. Beaks (Plate 1.3(d & e)) strong. Radula with seven transverse rows of teeth; rachidian tooth tricuspid; first lateral tooth bicuspid, outer cusp small; second and lateral marginal teeth single and slightly curved. Spermatophore long and small, sperm mass comprises 50-60% of total length; cement body oval, slightly constricted at the posterior quarter of the body; ejaculatory apparatus coiled at oral end. Head, dorsal mantle, fins and arms are uniformly of chestnut brown colour. An oval photophoric patch is present on the antero-dorsal surface of mantle. A unique character of S. oualaniensis is mantle element of T-shaped locking apparatus curved with an anterior bifurcation, fused to funnel element along the posterior third of the longitudinal groove.
Plate 1.1. *Sthenoteuthis oualaniensis* female (a) Dorsal view (b) Ventral view

1 - Tentacular club, 2 - Tentacle, 3 - Arms (I,II,III & IV), 4 - Eye, 5 - Photophore, 6 - Funnel, 7 - Foveola, 8 - Fin, 9 - Head.
Plate 1.2. *Sthenoteuthis oualaniensis* female. (a) Head and its membrane, (b) Foveola, (c) Mantle and Funnel locking cartilage, (d) Oral view, (e) Enlarged club suckers with rings, (f) Enlarged arm suckers with rings, (g) Tentacular club.  
1–Head membrane, 2-Foveola, 3–Mantle locking cartilage, 4–Funnel locking cartilage, 5 – Funnel, 6- Beak, 7- Club ring, 8 – Arm ring, 9-Carpus, 10- Manus, 11- Dactylus portion of the club region.

Plate 1.3. *Sthenoteuthis oualaniensis* female (a) Gladius, (b) Enlarged central part of the rachis, (c) Enlarged posterior cone, (d) Lower beak, (e) Upper beak.

### 1.3 Review of literature

At first, the purpleback squid was described under the name *Loligo oualaniensis* by Lesson in 1830, then the orangeback squid was described by Steenstrup as *Ommastrephes pteropus* in 1855. Both descriptions were rather brief, the size and sex of the holotype specimens were not indicated, and both are now lost. Both species were included in the genus *Ommastrephes* d’Orbigny, 1835, but then Verrill (1880) established a new genus, *Sthenoteuthis*, for these ommastrephids. Soon, Pfeffer (1900) separated purpleback squid into a new genus *Symplectoteuthis*. However, the taxonomy of the genus *Ommastrephes* was in a confused condition, without any precise criteria for species identification. Representatives of this genus were described under different names even from the
northern Atlantic (Verrill, 1882; Pfeffer, 1912; Naef, 1923; Rees, 1950; Adam, 1952; Jaeckel, 1958; Clarke, 1966).

In 1950-1970s the majority of specialists accepted the following system: genus *Ommastrephes* d’Orbigny, 1835 with three species: *O. bartramii* (Lesueur, 1821), *O. pteropus* Steenstrup, 1855, and *O. caroli* (Furtado, 1887), and genus *Symplectoteuthis* Pfeffer, 1900 with two species *S. oualaniensis* (Lesson, 1830) and *S. luminosa* (Sasaki, 1915). It was considered that *O. caroli* is endemic of North Atlantic, *O. pteropus* is the tropical Atlantic species and *O. bartramii* is widely distributed in the North Atlantic, North Pacific and South Atlantic (Clarke, 1966; Roper et al., 1984). The main reason for such taxonomic complexity lies in the lack of rich comparative material. The casual and isolated specimens, which fell into specialist’s hands, were usually collected from storm strandings or caught near the coast. Development of the oceanic fishery of tunas and other large fishes started from mid-1950 activated national and international scientific programs, and many vessels began work in open oceanic waters. Observations and fishing for squid were included in the routine procedures of oceanographic expeditions.

First observations and collections of oceanic nektonic squids were conducted by Baker, (1957, 1960), Clarke (1965, 1966), Voss (1956, 1966, 1973), Wormuth (1970, 1976), Okutani (1977). From the 1970s significant interest in oceanic resources arose due to the introduction of 200-mile exclusive economic zones and the exhaustion of fish stocks in traditional fishing grounds. The subfamily Ommastrephinae was put in order and revealed the main features of their evolution (Nigmatullin, 1979) and delineated the boundaries of species ranges (Zuyev et al., 1976). As a result of the revision of the subfamily Ommastrephinae in the genus *Ommastrephes*, only one species *O. bartramii* was left with *O. caroli* as junior synonym, orangeback and purpleback squids were united in the genus *Sthenoteuthis*, and *Symplectoteuthis luminosa* Okada, 1927

was transferred to Eucleoteuthis (Zuyev et al., 1975). Independently Wormuth (1976), using method of numerical classification, had come to a similar conclusion about the association of O. pteropus and S. oualaniensis in one genus Symplectoteuthis. However, this was found to be incorrect later because Symplectoteuthis Pfeffer, 1900 is junior synonym of Sthenoteuthis Verrill, 1882.


Main results of these multidisciplinary researches of squid were systematized in the monograph “Nektonic oceanic squids (genus Sthenoteuthis)” by Zuyev et al. (1985). Many papers were devoted to their physiological and

In 1980–1990s some interesting ecological publications appeared about S. oualaniensis based on local data (Silas et al., 1982; Harrison et al., 1983; Dunning, 1988; Young, 1994; Yatsu et al., 1998; Snyder, 1998). The most detailed information on S. oualaniensis in the Arabian Sea was published by Chesalin (1993) and Nesis (1993). Recently Mohamed et al. (2006) has reported the occurrence of medium form with double axis rachis off the south west coast of India and have done preliminary studies on its biology. Xinjun et al. (2007) has studied and reported the biology of the species in the northwest Indian Ocean. However, detailed study on the phenotypic composition of S. oualaniensis of the Arabian Sea as well as many features of its distribution, biology, productivity and life cycle are still poorly known, so that any new information of this species in the waters off the south west coast of India has important scientific significance.
1.4 Sample collection

Specimens of *S. oualaniensis* were collected between January 2007 and December 2008 in the area Lat 07° N to 11° N and Long 74° E to 77° E along the south west coast of India in the depth range of 180 – 2601 m. (Table 1.1, Figure 1.1). Samples were collected from different sources to get the continuity of data, as the specimens are of oceanic in nature and do not have a regular fishery.

Table 1.1. Details of the sampling stations and sample size of the species *Sthenoteuthis oualaniensis* along the South west coast of India. M-medium form, D- dwarf form.

<table>
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<th>Period</th>
<th>Lat°N</th>
<th>Long°E</th>
<th>Depth range</th>
<th>Sample size (Nos)</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>Total</td>
</tr>
<tr>
<td>January’07</td>
<td>8 – 10</td>
<td>75</td>
<td>193 – 2450</td>
<td>45</td>
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<tr>
<td>February’07</td>
<td>8 – 10</td>
<td>75</td>
<td>300 - 2534</td>
<td>29</td>
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<tr>
<td>March’07</td>
<td>9 &amp; 10</td>
<td>74 &amp; 75</td>
<td>350 - 2228</td>
<td>38</td>
</tr>
<tr>
<td>April ’07</td>
<td>8 &amp; 10</td>
<td>74 &amp; 75</td>
<td>1400- 2400</td>
<td>19</td>
</tr>
<tr>
<td>May’07</td>
<td>9 &amp; 10</td>
<td>75</td>
<td>350 - 1800</td>
<td>14</td>
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<td>400 - 1505</td>
<td>22</td>
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<td>42</td>
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<td>74 &amp; 76</td>
<td>820 - 2403</td>
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<td>180 – 2000</td>
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<td>75 &amp; 76</td>
<td>400 - 1450</td>
<td>26</td>
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<tr>
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<td>8 &amp; 9</td>
<td>75 &amp; 76</td>
<td>250 - 1209</td>
<td>30</td>
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<td>75</td>
<td>550 - 2402</td>
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| Total      | 1015  | 565    | 450        |
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Figure 1.1. Map of the South west coast of India showing the oceanic squid sampling area during the study period.

M V Matsya Sugundhi (31.5m OAL, 245.8 GRT and 650 BHP), a long liner-cum-squid jigger of the Fishery Survey of India (FSI) and the 44-60 footer Gill netters/ Tuna long liners of the Cochin based Colachal fishing boats were of the prime source of collection. Besides, squids were also collected by hand jigging operation from onboard the FSI trawler Matsya Varshini during its night drifting. Matsya Sugundhi employed automatic squid jigging machine (Figure 1.2) to collect the samples, while the fishing boats and Matsya Varshini employed hand line with jigs to collect the samples. No sample could be collected in the month of July due to the 45 days seasonal fishing ban in the west coast of India, from June
15\textsuperscript{th} to July 30\textsuperscript{th}. Specimens of \textit{Sthenoteuthis oualaniensis} in both the phenotypic forms and other oceanic squids such as \textit{Histiotethis bonnellii}, \textit{Chiroteuthis imperator} and \textit{Moroteuthis lonnbergii} were immediately preserved on board the vessel at -20\textdegree C by blast freezing. At shore lab, specimens were brought to the ambient temperature by allowing it to be thawed gradually.

Figure 1.2. Squid jigging in action

1.5 Objectives of the study

The main objectives of the study are

- To investigate and identify the presence of different types of plastic phenotype of the species based on the morphometric data collected in the study area.
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- To understand the growth and mortality parameters and life span of the different plastic phenotypes identified.

- To investigate the maturity, fecundity and spawning period of the squid plastic phenotypes in the study area.

- To understand the food and feeding habit of the species in the study area.

- To investigate the biochemical composition of the mantle tissue of the available plastic forms of the species in comparison to the co existing other oceanic squid species.