Journal of the Marine Biological Association of the United Kingdom, 2017, 97(8), 1635–1642.
doi:10.1017/S0025315416001053

Status of population dynamics of the Asian wedge clam, *Donax scortum* (Bivalvia: Donacidae): a first report from Asia

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For the management of mollusc resources, knowledge of various population parameters and exploitation level of the population of wedge clams are needed. Population dynamics on wedge clam, Donax scortum *is still unknown in Asia. FAO-ICLARM Stock Assessment Tools (commonly known as FiSAT) was used for calculating population parameters of this species. The specimens of* D. scortum *were collected from Padukere sandy beach at monthly intervals from February 2009 to January 2010. Asymptotic length (L_∞) was 70.88 mm and growth coefficient (K) was estimated at 0.64 year^{-1}. The sizes attained by* D. scortum *were 33.51, 51.17, 60.49, 65.40, 67.99 and 69.36 mm at the end of first, second, third, fourth, fifth and sixth years of age, respectively. Density of clams ranged from 2 ind. m^{-2} (June, July and August) to 8 ind. m^{-2} (December). Biomass (total weight) of clams ranged between 10.084 g m^{-2} (August) to 185.100 g m^{-2} (December). Total mortality (Z) for* D. scortum *was 3.20 year^{-1}. Natural mortality (M) and fishing mortality (F) were 0.64 year^{-1} and 2.56 year^{-1} respectively. Exploitation level (E) was computed as 0.80, indicating that the fishery of* D. scortum *in the coastal waters of Karnataka is overexploited.*

Keywords: Wedge clam, *Donax scortum*, density, biomass, growth curve, age, recruitment, mortality, exploitation, Karnataka

Submitted 27 October 2015; accepted 12 July 2016; first published online 30 August 2016

INTRODUCTION

Donax is a genus of bivalve molluscs that is commonly found in the swash zone and has a global distribution in tropical and temperate regions. In India, under genus *Donax* (Family: Donacidae) 10 species (*Donax faba, D. cuneatus, D. dussumieri, D. incarnatus, D. spinosus, D. aperittus, D. spiculum, D. scortum, D. lubrica* and *D. veligers*) were reported from coastal areas (Alagarswami, 1966; Ansell *et al.*, 1972a, b; Balasubramanian *et al.*, 1979; Nayar, 1955; Victor & Subramoniam, 1988; Mathew & Menon, 1992; Zacharia *et al.*, 2008; Varadharajan *et al.*, 2010). After *D. serra* (de Villiers, 1975; Donn, 1990; Laudien *et al.*, 2003) and *D. deltoides* (Willan, 1998), *D. scortum* is the third largest species of *Donax* worldwide. The wedge clam, *D. scortum* occurs abundantly on the surf-beaten sandy beaches along the north (Raghunathan *et al.*, 2003), east (Karthikeyan *et al.*, 2009; Varadharajan *et al.*, 2010) and west (Zacharia *et al.*, 2008) coasts of India. Tanyaros (2010) reported that this species tended to accumulate more sand in its body.

The molluscs of economic importance are the bivalves, gastropods and cephalopods, which contribute considerable quantities of seafood, pearls and shells to molluscan fisheries, and these molluscs are utilized mainly by the fishers for subsistence when fish are scarce. *Donax scortum* is valued as food by fishermen (Nayar, 1955; Prasad & Nair, 1973; Talikhedkar *et al.*, 1976). Despite this potential value, little is known of the population dynamics of this wedge clam in Asia. For the management of mollusc resources, knowledge of various population parameters and exploitation level of the population of wedge clams are needed. Throughout the world, bivalve exploitation plays an important role in the national economy of many countries (Vakily, 1992). There are many tools for assessing exploitation levels and population biology of a stock. Of these, FAO-ICLARM Stock Assessment Tools (commonly known as FiSAT) has been used for calculating population parameters of *Donax* species (Zeichen *et al.*, 2002; Cardoso & Veloso, 2003; Singh *et al.*, 2011). On the sandy shore of Panambur, Karnataka, *Donax* species occur in dense populations and during the peak of their breeding seasons, a thick carpeting of clams is a common sight all along the sandy beaches of Karnataka (Thippeswamy, 1985). Several authors have studied some aspects of the population dynamics of *Donax* species. An investigation has been made on the effect of various physico-chemical parameters on the abundance of wedge clam species in Karnataka coast (Thippeswamy & Joseph, 1991). There is, however, no report regarding abundance, biomass, growth, age mortality and exploitation level of *D. scortum* in India or in other regions of Asia; therefore the objective of the present study was to establish the status of the population of this species to assess the stock.

MATERIALS AND METHODS

At Padukere, the shore consists of compacted fine sand. The majority of the population of *D. scortum* occurred along the

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mid intertidal zone. *Donax scortum* is more abundant on the flatter portions of the beach where the wave wash is more uniform thus providing better conditions for filter-feeding. The largest-sized donacid, *D. serra* (de Villiers, 1975; Donn, 1990) also occupies the flatter portions of the beach and showed semi-lunar migrations, which are a response by this species to the spring-neap cycle of movement of the water table (Donn *et al.*, 1986). Live *D. scortum* clams were collected at monthly intervals for a period of 1 year from February 2009 to December 2010 from the intertidal sandy beach at Padukere (13°20′51.80″N 74°41′30.92″E) near Udupi town (Fig. 1). *Donax scortum* (from an area of 1 m²) were excavated to 20 cm depth. Sand excavated from each plot was sieved on a 1 mm mesh to collect the clams. Extra clams were also collected from the study area.

Densities of the species were expressed as number of individuals per metre square, representing those wedge clams retained on a 1 mm mesh sieve. Hand-collected clams were not taken into account in calculating densities. The total weight of clams was recorded and the result was expressed as biomass in g m^{-2}. A total of 2367 individuals was measured for shell length (maximum anterio-posterior distance) using Vernier calipers. For estimating von Bertalanffy growth parameters, asymptotic length (L_α) and growth coefficient (K), the length measurements of 1-year data were pooled month-wise and grouped into length classes by 5 mm intervals, and analysed using the ELEFAN (Electronic Length Frequency Analysis) of FiSAT software (Gayanilo *et al.*, 1996). Estimates of L_α and K were used to estimate the growth performance index (ø′) (Pauly & Munro, 1984) of *D. scortum* using the equation, $ø' = 2\log 10\ L_\alpha + \log 10\ K$. From the values of L_α, K and t_o the growth curve was fitted to the von Bertalanffy growth equation. Growth was described by the von Bertalanffy growth function (*VBGF*) (von Bertalanffy, 1938). The *VBGF* is defined by the equation, $L_t = L_\alpha\ [1 - e^{-K(t-to)}]$, where L_t is the length at time *t*, *e* is the base of the natural logarithm, *t* the time of observation and t_o is the hypothetical age at which the length is zero (Newman, 2002).

Taking into account that non-linear growth functions are difficult to compare, several authors demonstrated the suitability of composite indices for overall growth performance (*OGP*) for inter- and intra-specific comparisons (Pauly, 1979; Munro & Pauly, 1983). The *OGP* is calculated by $OGP = \log(K[L_\alpha]^3)$. The total mortality ($Z$) was estimated by a length converted catch curve method (Pauly, 1984). The natural mortality coefficient (M) was determined using $M \approx K$ approximation (Gayanilo & Pauly, 1997). However, the fishing mortality coefficient (F) was estimated by subtracting M from Z. The exploitation level (E) was obtained from the relationship of Gulland (1965), i.e. $E = F/Z = F/F + M$. The recruitment pattern was obtained by projecting the length-frequency data backwards on the time axis using growth parameters (Moreau & Cuende, 1991).

RESULTS

Temporal variations of population density and biomass

Data on temporal variations in the population density (ind. m^{-2}) are presented in Fig. 2. The values of maximum and minimum densities of *D. scortum* were 8 ind. m^{-2} (December) and 2 ind. m^{-2} (June, July and August) respectively. The average density of clams in the study area was 4 ind. m^{-2}. The maximum and minimum total weights of clams were 185.100 g m^{-2} (December) and 10.084 g m^{-2} (August) respectively. Biomass showed an increasing trend from August onwards. The average biomass of *D. scortum* was 71.088 g m^{-2} during the study period.

Growth parameters

Asymptotic length (L_α) of the *VBGF* was 70.88 mm and the growth coefficient (K) was 0.64 $year^{-1}$ for *D. scortum*. The

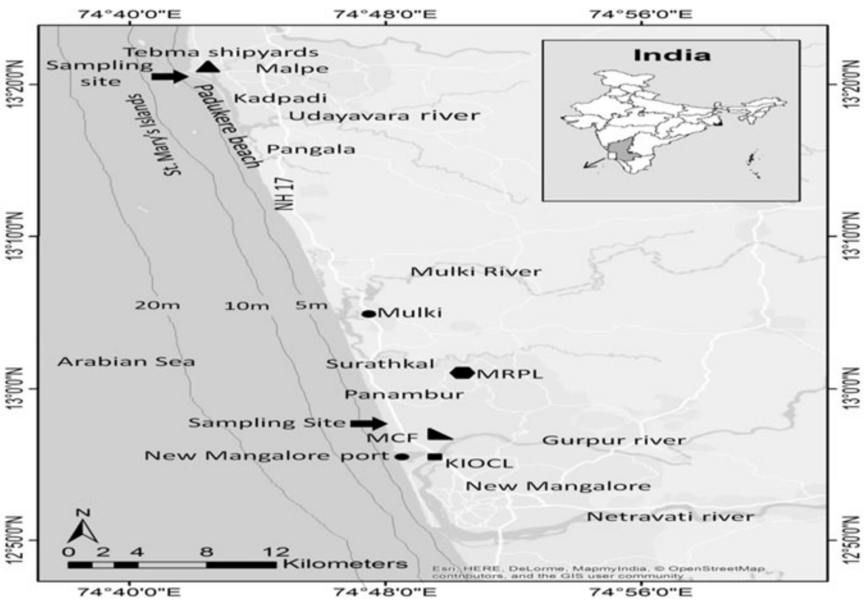

Fig. 1. Location of sampling site at wedge clam-growing area along Karnataka coast.

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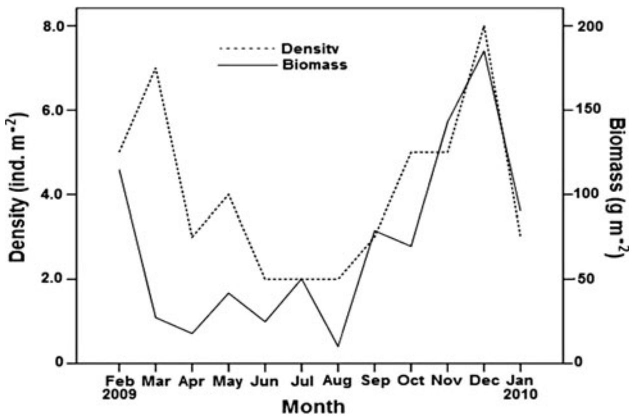

Fig. 2. Density and biomass of *D. scortum* in the present study.

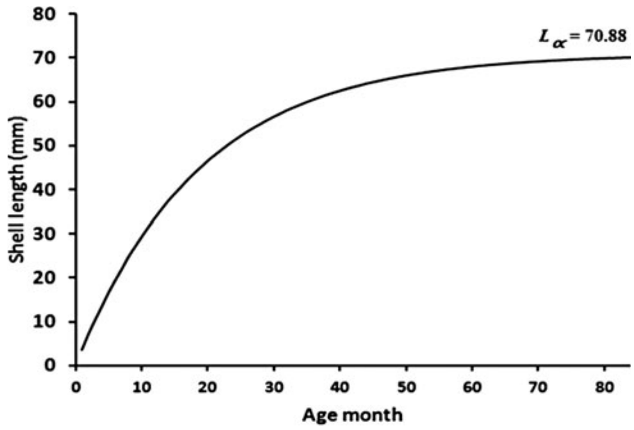

Fig. 4. Plot of age and growth of *D. scortum* based on computed growth parameters.

growth curve using these parameters is shown over the length-frequency distribution in Fig. 3. The growth performance index (ø′) was found to be 3.51. The range at 95% confidence interval of extreme length (80 mm) was between 65.78 and 71.10 mm. The calculated overall growth performance (*OGP*) of *D. scortum* was 5.36.

Age and growth

Using the growth parameters, age and growth of *Donax scortum* were calculated. The growth rate and the absolute increase in age are presented in Fig. 4. It was assumed in the age and growth analysis that the value of the third parameter of the von Bertalanffy growth function was zero (Newman, 2002). The sizes attained by *D. scortum* were 33.51, 51.17, 60.49, 65.40, 67.99 and 69.36 mm at the end of first, second, third, fourth, fifth and sixth years of age, respectively. The average growth rates for *D. scortum* from first to sixth years were 2.79, 1.47, 0.78, 0.41, 0.22 and 0.11 mm respectively. The lifespan of this species reached up to 6.5 years.

Recruitment pattern

Whole recruitment pattern of *D. scortum* was continuous throughout the year with one major peak in May (Fig. 5). The per cent recruitment varied from 0.24 to 15.63 during the present study. The highest and lowest recruitment per cent were observed in May and November respectively.

Mortality and exploitation

The total mortality (Z) was estimated as 3.20 year^{-1} using the length converted catch curve (Fig. 6). The natural mortality (M) and fishing mortality (F) were 0.64 and 2.56 year^{-1} respectively. From this figure, the exploitation level (E) of 0.80 was obtained for the *D. scortum* fishery.

Virtual population analysis

The length structured virtual population analysis of *D. scortum* is presented in Fig. 7 and indicated that the minimum and maximum fishing mortalities were 0.0010 year^{-1} and 3.2614 year^{-1} for the mid lengths of 12.5 and 57.5 mm respectively. The fishing mortality (F) was high over the mid lengths from 47.5 to 57.5 mm.

DISCUSSION

Considerable changes take place in the beach profile along the south-west coast of India due to accretion and erosion during the monsoon period (Ansell *et al.*, 1972a). In the intertidal zone of the sandy beach, juvenile and adult wedge clams

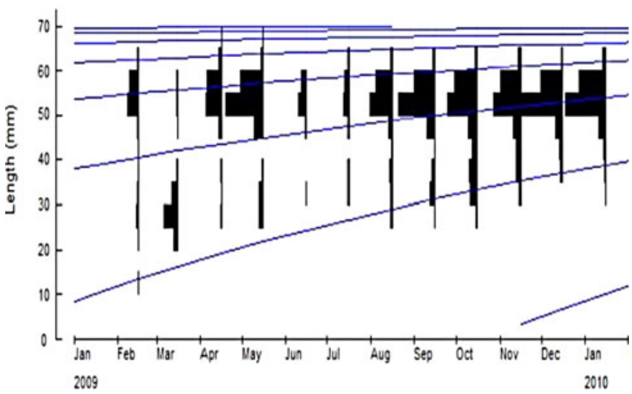

Fig. 3. Growth curves of *D. scortum* as superimposed on the length–frequency distribution using ELEFAN-I.

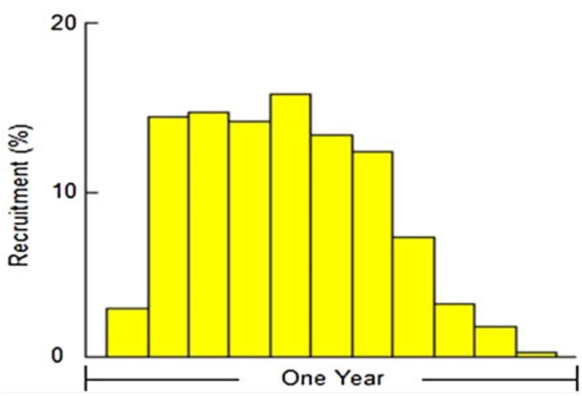

Fig. 5. Recruitment pattern of *D. scortum*.

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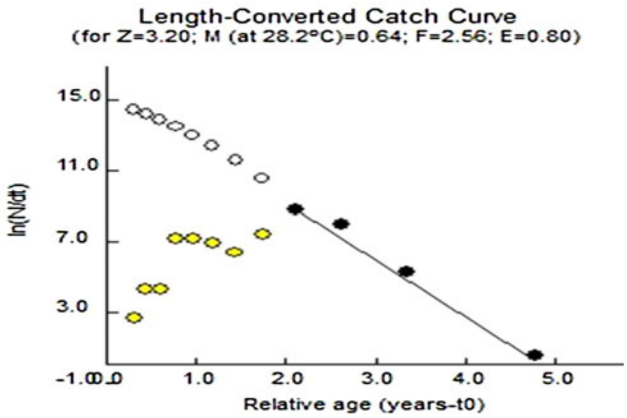

Fig. 6. Mortality estimation of *D. scortum* using Pauly's linearized length converted catch curve method and estimation of exploitation.

appeared, whereas a few adult clams were found in the upper intertidal zone in the study area. The small-sized wedge clam, *D. hanleyanus* reached the maximum density (2254 ind. m^{-2}) (Marcomini *et al.*, 2002). Nayar (1955) observed a maximum density (5267 ind. m^{-2}) of the wedge clams, *D. cuneatus* from Palk Bay in the south-east coast of India. A population density of *D. faba* ranging between 89 and 217 ind. m^{-2} was reported from the coast of Mandapam (Alagarswami, 1966). However, in the present investigation, the lowest density (2 ind. m^{-2}) was recorded during the monsoon season when the sea was rough. The maximum density (8 ind. m^{-2}) of *D. scortum* was recorded during December followed by March (Fig. 2) in the present study. In contrast, *D. incarnatus* showed high population densities ranging between 89 ind. m^{-2} (April) and 39,446 ind. m^{-2} (January) (Thippeswamy, 1985). Wide ranges of density values for *D. denticulatus* at different locations have been shown depending partially on environmental factors, such as particulate organic carbon and nitrate (Sastre, 1984). Based on the present data, fluctuations in abundance might have been driven primarily by natural fluctuation in wind, or associated hydrological conditions, during the larval phase. A similar suggestion was also noticed by King (1985). In one case, Hussain *et al.* (2010) reported the presence of the Madras Atomic Power Plant affected variation in *D. cuneatus* populations along Kalpakkam coast, Chennai due to thermal discharge. Victor & Subramoniam (1988) reported the population density of *D. cuneatus* from three

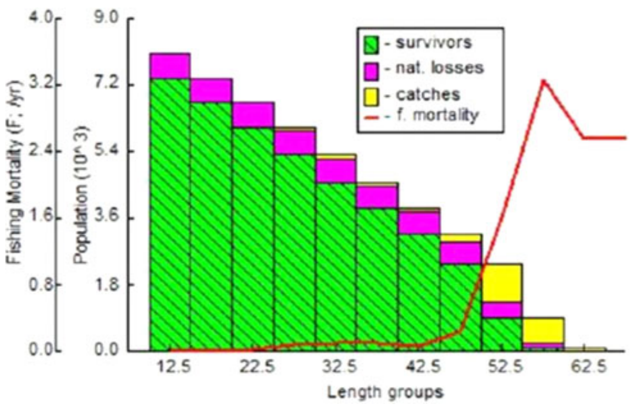

Fig. 7. Length-structured virtual population analysis of *D. scortum*.

beaches along the east–west coast of Tamil Nadu. They suggested that beach slope seemed to play a significant role in the distribution and abundance of *D. cuneatus* among the various environmental parameters. The data on the biomass (total weight) of *D. scortum* in the present study revealed that the biomass ranged between 10.084 g m^{-2} (August) and 185.100 g m^{-2} (December). In contrast, Thippeswamy (1985) reported that the biomass (total weight) of *D. incarnatus* varied from 124 g m^{-2} (October) to 1892 g m^{-2} (January) in Panambur beach. Thus, the biomass of *D. incarnatus* (Panambur) was much higher than that of *D. scortum* (Padukere). The biomass was higher when the large number of young clams settled and lower when large-sized clams were recorded in the present study.

From Table 1, the highest value of L_α (82.0 mm) is from Namibia and South Africa (de Villiers, 1975; Laudien *et al.*, 2003) for *Donax serra* and the lowest value (18.5 mm) is in Venezuela for *D. denticulatus* (Vélez *et al.*, 1985). On the other hand, the highest *K* value was 1.79 $year^{-1}$ in Venezuela for *D. denticulatus* (Marcano *et al.*, 2003) and the lowest value was 0.04 $year^{-1}$ in India for *D. cuneatus* (Talikhedkar *et al.*, 1976). Among the tropical/subtropical *Donax* species, the *D. scortum* showed the highest (70.88 mm) value of L_α and the *K* value is very close to Colombia, but quite different from other parts of India (Table 1). The calculated growth performance index (ø′) and overall performance index (*OGP*) values of *D. scortum* are higher compared with the values reported from different regions of India. The *OGP* of this species conforms well with values calculated from data sets of the largest-sized clam, *D. serra* species found in South Africa and Namibia (de Villiers, 1975; Laudien *et al.*, 2003) This may be due to the large size of these two species compared with other donacids.

Alagarswami (1966) recorded growth of 19.5 mm in *D. faba* by the end of the first year of life and 22.5 mm at the end of the second year of life from Mandapam. Talikhedkar *et al.* (1976) found that *D. cuneatus* reached the size of 13–14, 21–22 and 22–23 mm in first, second and third years respectively. The wedge clam, *D. cuneatus* in Palk Bay along the east coast of India attained a length of 14 mm within 10 months, 19 mm by the second year and after this they died (Nayar, 1955). Nair *et al.* (1978) recorded average monthly growth of 2.2 mm for 1 year in *D. incarnatus* from the sandy beach at Benaulim along the west coast of India. Coe (1955) determined that increase in size in *D. gouldi* at 1 and 2 years of age averaged about 12 and 18 mm in length, respectively. The lifespan of *D. scortum* was more than 6.5 years and the growth rate of juvenile clams was rather high during the first few months after settlement. The highest size of clams recorded in the size group of 65–70 mm class interval and maximum size of the clam was about 78 months old (Fig. 4). Thus, the population comprises individuals of more than 1 year in age. Thippeswamy & Joseph (1991) reported that the lifespan of *D. incarnatus* was above 1 year (less than 15 months) at Panambur. Like *D. incarnatus*, the small-sized clam, *D. denticulatus* has a shorter lifespan of 18 months (Marcano *et al.*, 2003), even *D. hanleyanus* showed a lifespan of about 17 months (Cardoso & Veloso, 2003). In contrast, Marcomini *et al.* (2002) reported that the lifespan of *D. hanleyanus* can be up to 3 years. Most wedge clams (*Donax* spp.) have a relatively short lifespan of 1–2 years (Ansell, 1983; McLachlan, 1979). But the present study indicates that *D.*

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Table 1. Values of the von Bertalanffy growth parameter L_α (mm) and K (year^{-1}), ø′ and *OGP* for several *Donax* species in comparison with *D. scortum*. Climate areas are: tropical/subtropical (X), temperate (Y) and upwelling (Z).

Species	L_α	K	ø′	OGP	Climate area	Location	Sources
Donax scortum[a]	70.88	0.64	3.51	5.36	X	India	Present study
D. incarnatus[a,d]	25.13	0.09	1.75	3.15	X	India	Ansell *et al.* (1972b)
D. incarnatus[a,d]	29.04	0.09	1.88	3.34	X	India	Ansell *et al.* (1972b)
D. incarnatus[a,d]	20.06	0.09	1.56	2.86	X	India	Nair *et al.* (1978)
D. incarnatus[a]	30.94	0.16	2.19	3.68	X	India	Thippeswamy & Joseph (1991)
D. cuneatus[a]	22.87	0.06	1.50	2.86	X	India	Nayar (1955)
D. cuneatus[a,d]	33.02	0.04	1.64	3.16	X	India	Talikhedkar *et al.* (1976)
D. faba[a,d]	26.15	0.10	1.83	3.25	X	India	Alagarswami (1966)
D. faba[a]	26.67	0.89	2.80	4.23	X	India	Singh *et al.* (2011)
D. striatus[a]	20.20	0.29	2.07	3.37	X	Venezuela	McLachlan *et al.* (1996)
D. striatus[a]	25.10	1.16	2.86	4.26	X	Brazil	Rocha-Barreira de Almeida *et al.* (2002)
D. denticulatus[a]	18.50	0.43	2.17	3.43	X	Venezuela	Vélez *et al.* (1985)
D. denticulatus[a]	31.47	1.48	3.17	4.66	X	Venezuela	García *et al.* (2003)
D. denticulatus[a]	30.20	1.79	3.21	4.69	X	Venezuela	Marcano *et al.* (2003)
D. dentifer[a]	46.00	0.30	2.80	4.19	X	Costa Rica	Palacios *et al.* (1983)
D. dentifer[a]	29.30	0.62	2.73	4.19	X	Colombia	Riascos & Urban (2002)
D. vittatus[a]	33.15	0.61	2.83	4.35	Y	France	Ansell & Lagardère (1980)
D. vittatus[a]	29.76	1.32	3.07	4.54	Y	France	Ansell & Lagardère (1980)
D. vittatus[a]	35.90	1.01	3.11	4.67	Y	France	Ansell & Lagardère (1980)
D. vittatus[a]	31.28	1.06	3.02	4.51	Y	France	Ansell & Lagardère (1980)
D. vittatus[a,c]	38.00	0.68	2.99	4.57	Y	France	Guillou & Le Moal (1980)
D. trunculus[a,c]	43.48	0.45	2.93	4.57	Y	France	Ansell & Lagardère (1980)
D. trunculus[a,c]	36.33	0.70	2.97	4.53	Y	France	Ansell & Lagardère (1980)
D. trunculus[a,c]	35.55	0.79	3.00	4.55	Y	France	Ansell & Lagardère (1980)
D. trunculus[a,c]	32.25	0.68	2.85	4.36	Y	France	Ansell & Lagardère (1980)
D. trunculus[a,c]	38.22	0.70	3.01	4.59	Y	France	Ansell & Lagardère (1980)
D. trunculus[a,c]	38.41	0.72	3.02	4.61	Y	France	Ansell & Lagardère (1980)
D. trunculus[a,c]	39.78	0.74	3.07	4.67	Y	France	Ansell & Lagardère (1980)
D. trunculus[a,c]	39.70	0.77	3.09	4.68	Y	France	Ansell & Lagardère (1980)
D. trunculus[a]	48.90	0.38	2.96	4.65	Y	France	Guillou & Le Moal (1980)
D. trunculus[a]	35.99	0.96	3.09	4.65	Y	France	Bodoy (1982)
D. trunculus[a]	43.80	0.97	3.27	4.91	Y	Spain	Fernández *et al.* (1984)
D. trunculus[a]	52.84	0.55	3.19	4.19	Y	Spain	Mazé & Laborda (1988)
D. trunculus[a]	46.00	0.58	3.09	4.75	Y	Spain	Ramón *et al.* (1995)
D. trunculus[b]	41.80	0.71	3.09	4.71	Y	Spain	Ramón *et al.* (1995)
D. trunculus[a]	47.30	0.58	3.11	4.79	Y	Portugal	Gaspar *et al.* (1999)
D. trunculus[a]	47.56	0.30	2.83	4.51	Y	Italy	Zeichen *et al.* (2002)
D. hanleyanus[a]	33.50	1.18	3.12	4.65	Y	Argentina	Penchaszadeh & Olivier (1975)
D. hanleyanus[a]	33.00	0.80	2.94	4.46	Y	Uruguay	Defeo (1996)
D. hanleyanus[a]	26.40	0.80	2.75	4.17	Y	Brazil	Cardoso & Veloso (2003)
D. hanleyanus[a]	28.50	0.90	2.86	4.32	Y	Brazil	Cardoso & Veloso (2003)
D. hanleyanus[a]	44.00	0.47	2.96	4.60	Y	Argentina	Herrmann *et al.* (2009)
D. hanleyanus[a]	44.00	0.48	2.97	4.61	Y	Argentina	Herrmann *et al.* (2009)
D. serra[a]	82.00	0.28	3.28	5.19	Z	South Africa	de Villiers (1975)
D. serra[a]	75.00	0.43	3.39	5.26	Z	South Africa	de Villiers (1975)
D. serra[a]	82.00	0.28	3.27	5.19	Z	South Africa	de Villiers (1975)
D. serra[a]	78.00	0.32	3.29	5.18	Z	South Africa	de Villiers (1975)
D. serra[a]	82.00	0.27	3.27	5.17	Z	Namibia	Laudien *et al.* (2003)
D. marincovichi[a]	46.00	1.00	3.33	4.99	Z	Peru	Arntz *et al.* (1987)-before El Niño
D. marincovichi[a]	35.00	1.17	3.16	4.70	Z	Peru	Arntz *et al.* (1987)-during El Niño
D. marincovichi[a]	42.00	0.70	3.09	4.71	Z	Peru	Arntz *et al.* (1987)-after Niño
D. deltoides[a]	59.00	0.86	3.48	5.25	Y	Australia	King (1985)
D. deltoides[a]	56.00	1.59	3.70	5.45	Y	Australia	Saenger & Keyte (1990)
D. deltoides[a]	75.00	1.07	3.78	5.65	Y	Australia	Murray-Jones (1999)

[a]Age estimated from length-frequency distributions.
[b]Age estimated from hyaline growth rings.
[c]Age estimated from external growth rings.
[d]Values calculated on monthly basis from raw data reported by the authors.

scortum from Karnataka coast with maximum length (69.8 mm) has a longer lifespan of approximately around 7 years. The lifespan of *D. scortum* was quite different when compared with *D. incarnatus* (Ansell *et al.*, 1972b; Nair *et al.*, 1978; Thippeswamy & Joseph, 1991), *D. spiculum* (Ansell *et al.*, 1972b), *D. cuneatus* (Nayar, 1955; Talikhedkar *et al.*, 1976) and *D. faba* found along both the east and west coasts of India (Alagarswami, 1966; Singh *et al.*, 2011).

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Thippeswamy & Joseph (1991) observed that recruitment of young wedge clams to the population occurred in several stages due to occurrence of clams of size less than 4 mm in January, May and November indicating a prolonged/staggered breeding period for the population. Tirado & Salas (1999) reported continuous and unimodal recruitment during the period of sexual activity. From the findings of Neuberger-Cywiak *et al.* (1990) the recruitment period of *Donax trunculus* was July–September while several recruitments occurred for *D. semistriatus* in the sandy beach of Haifa Bay, northern Israel. The density increment observed during pre-monsoon was identified as a recruitment peak of juveniles, which became the dominant age group in the present study. Two recruitments of different intensity were observed during this study and the per cent recruitment varied from 0.24 to 15.63. The highest and lowest per cent recruitment was observed in May and November respectively. For most bivalves, peak recruitment periods are thought to coincide with the spawning patterns of local adults. However, few studies have quantified this. Recruitment patterns may, therefore, be independent of the resident bivalve population and recently settled juveniles may be spatially separated from the remaining parts of the population (McLachlan *et al.*, 1996). Recruitment patterns observed in the findings of other studies provide clear evidence that juvenile wedge clams occur only sporadically and recruitment varies between years (Arntz *et al.*, 1987; Laudien *et al.*, 2001; Herrmann *et al.*, 2009). A unimodal pattern of recruitment was reported (Ansell & Lagardère, 1980; Zeichen *et al.*, 2002), whereas a bimodal recruitment is the common pattern observed (Ramón *et al.*, 1955; Ansell & Bodoy, 1979; Marcano *et al.*, 2003) from different geographic areas. At Padukere also, a bimodal recruitment was found for the *D. scortum*.

Mortality of the adult clams, *D. cuneatus* was highest during October–November and June–July, which are preceded by the highest salinity and temperature conditions of the inshore waters respectively (Nayar, 1955). Thippeswamy & Joseph (1991) suggested that mortality occurred due to differences in salinity and grain size of the sandy beach at Panambur. Riascos & Urban (2002) reported that the mortality pattern of *D. dentifer* suggested that the population was selectively affected by El Niño 1997/98, due to smaller individuals inhabiting the lowest areas of the beach, where they are exposed to abnormal seawater conditions. They reported that the total mortality was higher (2.65 $year^{-1}$) for small individuals (2–5 mm) while a lower value (1.71 $year^{-1}$) was obtained for larger ones (19–25 mm). In *D. denticulatus*, García *et al.* (2003) reported that the total mortality for larger individuals (greater than 22 mm) was high (2.93 $year^{-1}$). In one case, parasitic interactions and inter-specific interactions generally were shown to play a role in mortality events of molluscs (Dugan *et al.*, 2004). Thippeswamy & Joseph (1991) reported that monthly instantaneous total mortality based on the mean size in the sample of whole population varied from 0.1368 (January) to 0.3963 (March) for *D. incarnatus*. They stated that high mortality rates are due to high sediment temperature, reduced salinity and instability of the sandy beach. Cardoso & Veloso (2003) reported that the instantaneous mortality rate in *D. hanleyanus* was 1.70 $year^{-1}$ in 1998 and 1.55 $year^{-1}$ in 1999. McLachlan (1979) and McLachlan & van der Horst (1979), working on *D. sordidus* on several beaches in South Africa, found similar values of total mortality (1.27 and 1.98 $year^{-1}$). However, in India, *D. incarnatus* ($Z = 6.24$ and 8.72 $year^{-1}$) (Ansell *et al.*, 1972a) and *D. spiculum* ($Z = 22.67$ $year^{-1}$) (Ansell *et al.*, 1978) showed higher mortality values. High mortality of *D. incarnatus* was also observed by McLusky *et al.* (1975) from the Indian region. In the present study, the total mortality (3.20 $year^{-1}$) was lower when compared with the above values found from India. Thus, it can be concluded that the lifespan increases and mortality decreases for *Donax* species from tropical to temperate regions. High flows from the Murray River were implicated in high mortality of clams on Goolwa beach in October–November 1984 (Clarke, 1985; King, 1985). This may be in accordance with a mortality of *D. scortum* living near the mouth of the Udyavara River.

The distribution of intertidal clams could be affected by human exploitation. The largest-sized wedge clam is the target of a recreational fishery (McLachlan *et al.*, 1996). Clams are exploited for bait and their unique, delicate taste makes them a potentially valuable food resource. Exploitation of *D. faba* was reported on the Tuticorin harbour beach. These clams were exploited purely for ornamental purposes in the shell craft industry as these shells exhibited multi-hued colours and attractive patterns (Dharmaraj *et al.*, 2005). The largest-sized species, *D. serra* is subject to intensive exploitation by bait dealers and anglers in South Africa (de Villiers, 1975; McLachlan *et al.*, 1996; Laudien *et al.*, 2003). According to Gulland (1965), the yield is optimized when $F = M$; therefore, when E is more than 0.5, the stock is over-fished. Exploitation level (E) was computed as 0.80, indicating that the fishery of *D. scortum* in the coastal waters of Karnataka is overexploited.

CONCLUSIONS

The growth and mortality parameters described in the present study can provide important guidelines for fishery management of the wedge clam, *D. scortum*. The result also shows that the population studied was overexploited. To maintain this valuable resource, the exploitation rate should therefore be reduced below the optimum value.

ACKNOWLEDGEMENTS

The author is grateful to the authorities of Mangalore University (Karnataka) for providing research facilities during research work.

FINANCIAL SUPPORT

The research work was supported by BSR-UGC Meritorious Fellowship (UGC No.4-1/2008(BSR) from University Grant Commission, New Delhi, India.

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