Species Conservation Action Plan

Ecology, Population Dynamics and Conservation of Giant Clam *Tridacna maxima* (Roding, 1798) in Lakshadweep Archipelago

Deepak Apte
Assistant Director, Bombay Natural History Society

Idrees Babu K.K, **Karamathulla Sahib** and **Sutirtha Dutta**

Under Peer Review by
Dr. Jerry Harasewych
Curator, Division of Mollusca
Smithsonian Institute, USA

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The work of Project Giant Clam has been recognized by the international community and been awarded Whitley Conservation Award in 2008. I take this opportunity to acknowledge the Whitley Fund for Nature for identifying Project Giant Clam as a top grassroot conservation project in India. Two women members of the project team have won the Sanctuary Asia-ABN Amro conservation award for 2008 for grassroot conservation work.

1. What are Giant Clams?

Giant clam, as popularly known, are among the most specialized bivalves. These are the largest living bivalves growing over a meter in length. They have a narrow range of distribution and occur exclusively within tropical reefs under Indo-Pacific faunal region[1]. Giant clams appeared during Eocene period and fairly young family as compared to other Molluscan groups. There are nine living species under this family within two genus's namely *Tridacna* and *Hippopus*.

Giant clams grow in clear, high salinity and shallow water, are slow growing and long lived bivalves. They can be seen mostly up to the depth of 20 m. A few individuals can be seen up to the depth of 40 m. They are filter feeders and feeds on zooplankton and phytoplankton. The most striking part of giant clam is its bright and fluorescent mantle. Mantle colour varies from fluorescent blue to dull brown, pale yellow to camouflage green. Microscopic algae zooxanthellae stay in symbiosis (endosymbiosis) with in the mantle tissues of giant clams. Giant clams are fixed on coral substrate except for juveniles of 10-20 mm size which can move to some distance in search of good substrate to anchor. They are known to live over 100 years. The largest known clam is that of *T. gigas* and measures 137 cm in shell length (Rosewater, 1965).

Giant clams occasionally develop pearl. The largest known natural pearl was recovered from *T. gigas*. The pearl weigh fourteen pounds and nine and half inch long and five and half inches wide and is called as 'Pearl of Allah"[2].

They have very short larval life ranging up to 10 days[3]. This prevents to great extent the dispersal of larvae over a large area.

During early 70's to late 80's several authors worked on various aspects of giant clam and specially mariculture. Some noted work among these studies is by Rosewater (1965), Yamaguchi (1977), Fitt *et al* (1984), Yonge (1980), Alcazar (1986), Heslinga *et al* (1984), Beckvar, 1981; Wada, 1952; LaBarbera, 1975; Jameson, 1976, Rutzler & Santavy, 1983, Garrett & Ducklow, 1975, Rutzler *et al*, 1983, Antonius, 1985a, Antonius, 1988 and Bruckner and Bruckner, 1997.

Henocque (1980) studied age of giant clams while as Richard (1977, 1981) and Ricard and Salvat (1977) studied population structure of giant clams in Takapoto lagoon. Alder and Bradley (1989), Bradley (1987a, 1987b), Villanoy *et al* (1988) and Pearson and Munro (1991) studied mortality in wild populations of giant clams. Islands of Tahiti, Moorea of Polynesian islands regularly served *T. maxima* as a sea food for tourists (Planes *et al*, 1992).

This has provided new insights to these magnificent bivalves. However not much work is available on wild populations of giant clams and field ecology of and population structures of these bivalves still remain an enigma. The present comprehensive work is first of its kind in Indian Subcontinent and Arabian Sea *T. maxima* population.

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[1] Rosewater J. 1965
[2] Cobb, W.D. 1939
[3] Rosewater, J. 1965

2. Classification of Giant Clams

Phylum: Mollusca
Class: Bivalvia
Order: Veneroidea
Superfamily: Cardiacea
Family: Tridacnidae
Genus: *Tridacna*
Species: *maxima, squamosa, crocea, gigas, tevoroa, derasa* and *roswateri.*

Genus: *Hippopus*
Species: *hippopus and procellanus*

3. Living species of Giant clams

Tridacna maxima (Roding, 1798)
T. squamosa (Lamarck, 1819)
T. derasa (Roding, 1798)
T. gigas (Linne, 1758)
T. crocea (Lamarck, 1819)
T. tevoroa Lucas, Leuda and Braley, 1990
T. rosewateri Sirenko & Scarlato, 1991
Hippopus hippopus (Linne, 1758
H. porcellanus Rosewater, 1982

4. Status of Giant Clam species as per IUCN categories[4]

Hippopus hippopus (LR/cd)

Year	**Status**
1983	Indeterminate (Wells *et al*. 1983)
1986	Indeterminate (IUCN Conservation Monitoring Centre 1986)
1988	Indeterminate (IUCN Conservation Monitoring Centre 1988)
1990	Indeterminate (IUCN 1990)
1994	Indeterminate (Groombridge 1994)

H. procellanus (LR/cd)

Year	**Status**
1983	Indeterminate (Wells *et al*. 1983)
1986	Indeterminate (IUCN Conservation Monitoring Centre 1986)
1988	Indeterminate (IUCN Conservation Monitoring Centre 1988)
1990	Indeterminate (IUCN 1990)
1994	Indeterminate (Groombridge 1994)

T. crocea (LR/lc)

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[4] www.iucn.org

Year	Status
1983	Indeterminate (Wells *et al*. 1983)
1986	Indeterminate (IUCN Conservation Monitoring Centre 1986)
1988	Indeterminate (IUCN Conservation Monitoring Centre 1988)
1990	Indeterminate (IUCN 1990)
1994	Indeterminate (Groombridge 1994)
1996	Removed from the IUCN Red List

T. deresa (VU A2cd)

Year	Status
1983	Indeterminate (Wells *et al*. 1983)
1986	Indeterminate (IUCN Conservation Monitoring Centre 1986)
1988	Indeterminate (IUCN Conservation Monitoring Centre 1988)
1990	Indeterminate (IUCN 1990)
1994	Indeterminate (Groombridge 1994)

T. gigas (VU A2cd)

Year	Status
1983	Vulnerable (Wells *et al*. 1983)
1986	Vulnerable (IUCN Conservation Monitoring Centre 1986)
1988	Vulnerable (IUCN Conservation Monitoring Centre 1988)
1990	Vulnerable (IUCN 1990)
1994	Vulnerable (Groombridge 1994)

T. maxima (LR/cd)

Year	Status
1983	Insufficiently Known (Wells *et al*. 1983)
1986	Insufficiently Known (IUCN Conservation Monitoring Centre 1986)
1988	Insufficiently Known (IUCN Conservation Monitoring Centre 1988)
1990	Insufficiently Known (IUCN 1990)
1994	Insufficiently Known (Groombridge 1994)

T. rosewateri (VU A2cd)

T. squamosa (LR/cd)

Year	Status
1983	Indeterminate (Wells *et al*. 1983)
1986	Indeterminate (IUCN Conservation Monitoring Centre 1986)
1988	Indeterminate (IUCN Conservation Monitoring Centre 1988)
1990	Indeterminate (IUCN 1990)
1994	Indeterminate (Groombridge 1994)

T. tevora (VU B1+2c)

Year	Status
1983	Insufficiently Known (Groombridge 1994)

Protection Status of Giant clams in India
Out of nine species known world wide, four species are known to occur in Indian waters. These are *Tridacna maxima, Tridacna squamosa, T. crocea* and *Hippopus hippopus*. However, in Lakshadweep only *T. maxima* and *T. squamosa* are found. All the four species are included under Schedule I of the Indian Wildlife (Protection) Act, 1972 thereby giving the highest degree of protection.

Nothing is known about ecology and biology of these species in India. The present work is the first work on these endangered species in India. The present study focused on ecology and population dynamics of *Tridacna maxima* and *Tridacna squamosa* in Lakshadweep Archipelago. However, in this book we have included studies only on *T. maxima* as some of the data for *T. squamosa* is yet to be collected.

5. Distribution of Giant clams in India

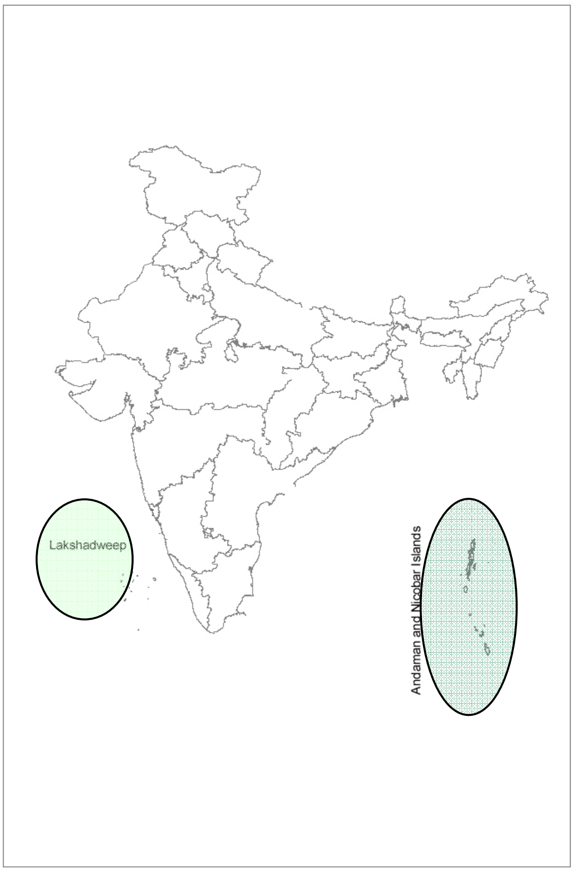
T. maxima (Roding, 1798): It is the commonest species among four species of giant clams occurring in India. It is found in Lakshadweep, Andaman and Nicobar Islands.

T. squamosa (Lamarck, 1819): It occurs along with *T. maxima* but in smaller numbers. It is found in Lakshadweep, Andaman and Nicobar Islands.

T. crocea ((Lamarck, 1819)): Distributed only in Andaman and Nicobar and smallest clam.

Hippopus hippopus (Linne, 1758): Known only from Nicobar Islands. No information on its status or population is available.

Giant clams are commonly called as Kakka in Lakshadweep and Gaahaka in Dhivehi (Maldives).

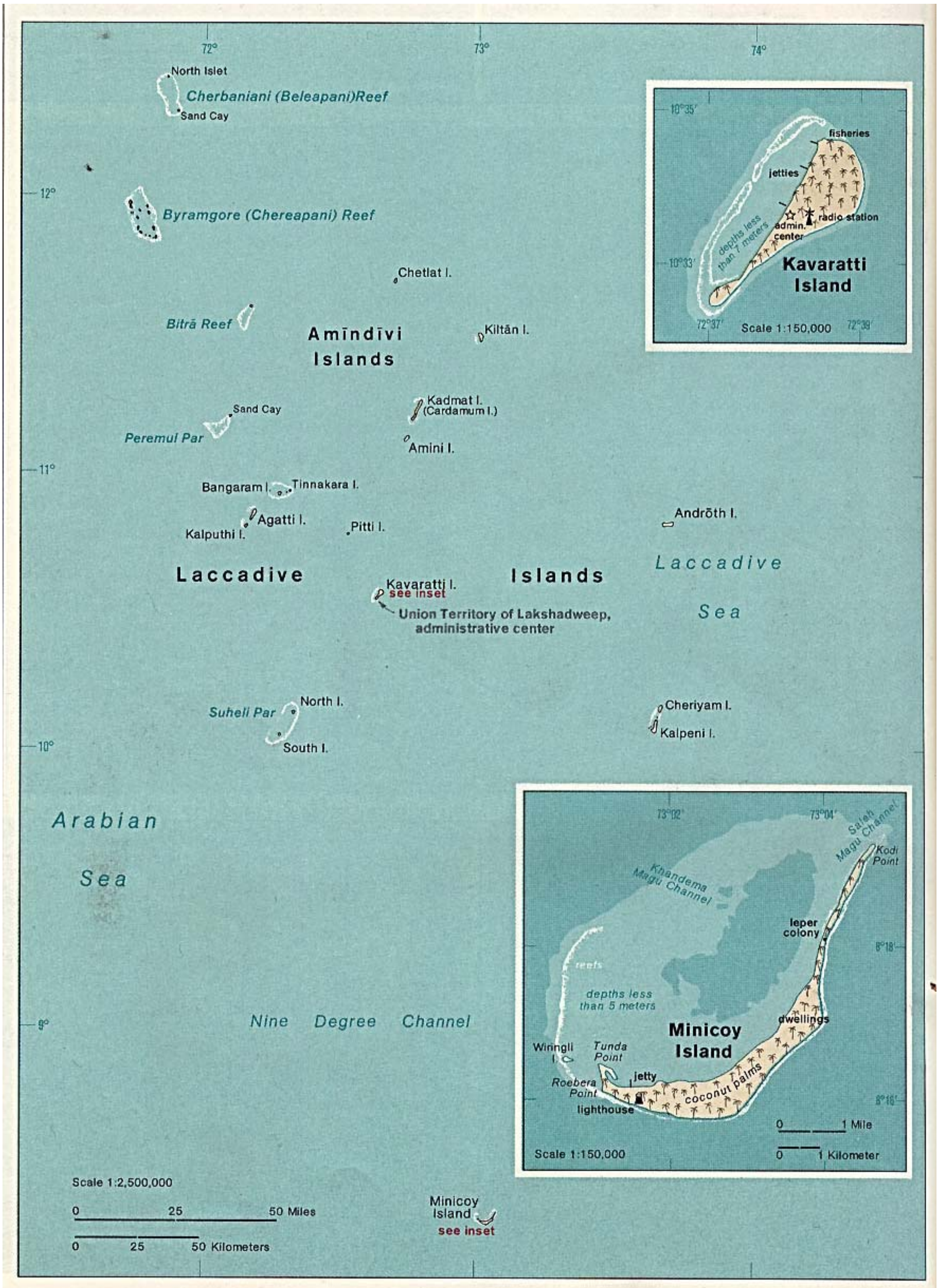


6. Study Site
6.1 Lakshadweep Archipelago

The project is based in Lakshadweep Islands, the smallest Union Territory of India measuring 32 km^2 of land spread over 36 islands (11 inhabited with a population of circa 60,000), 12 atolls and 5 submerged sand banks. They lie scattered in the Arabian Sea about 225 to 445 km from the Kerala coast between 80 and 12^0 North latitude and between 71^0 and 74^0 East longitude. Though the land area is small, with a lagoon area of about 4200 sq. km, Lakshadweep is a substantial territory with an economic zone of 400,000 sq. km and 20,000 sq. km of territorial waters

Tuna fishing, coconut and tourism are the main economic activities in Lakshadweep. Tuna fishing however, has been under threat over the last decade after the baitfish population in the reef lagoons began to decline. Project Giant Clam team therefore works closely with island community to establish management regimes to restore the baitfish populations which are closely linked with the islands' overall economy and livelihood. To sustain these management practices a marine conservation reserve – the first of its kind in India – will be created during this project.

The traditionally strong local communities and the unique cultural characteristics of these islands – following matrilineal Muslim traditions where women have significant status in the community – provide a supportive social environment for community-based natural resource management.



72°
73°
74°
North Islet
Cherbaniani (Beleapani)Reef
Sand Cay
12°
Byramgore (Chereapani) Reef
Chetlat I.
Bitrā Reef
Amīndīvi Islands
Kiltān I.
Kadmat I. (Cardamum I.)
Sand Cay
Peremul Par
Amini I.
11°
Bangaram I.
Tinnakara I.
Agatti I.
Kalputhi I.
Pitti I.
Andrōth I.
Laccadive
Islands
Laccadive Sea
Kavaratti I.
see inset
Union Territory of Lakshadweep, administrative center
Suheli Par
North I.
South I.
Cheriyam I.
Kalpeni I.
10°
Arabian Sea
9°
Nine Degree Channel
Scale 1:2,500,000
0 25 50 Miles
0 25 50 Kilometers
Minicoy Island
see inset
fisheries
jetties
radio station
admin. center
depths less than 7 meters
Kavaratti Island
Scale 1:150,000
Khandema Magu Channel
Saleh Magu Channel
Kodi Point
leper colony
reefs
depths less than 5 meters
dwellings
Minicoy Island
Wiringli I.
Tunda Point
jetty
Roebera Point
coconut palms
lighthouse
0 1 Mile
0 1 Kilometer
Scale 1:150,000

6.2 Islands under Survey

6.2.1 Kavaratti

Latitude: N 10^0-33'30"
Longitude: E 72^0-36'.30"
Land Area: 865.5 Acres (350.25 Hect or 4.22. Sq. Km)
Lagoon area: 4.96 Sq. Km.
Local population: 10113 (2001 Census)

6.2.2 Kalpeni

Islands within Kalpeni lagoon
Kalpeni, Kalpeni Pitti 1, Kalpeni Pitti, Tillakkam 2, Tillakkam 1, Cheriyam, Kalpeni, Koddithala

Latitude: N 10^0-04'
Longitude: E 73^0-38'
Land Area: 649 Acres (262.64 Hect or 2.79 Sq. Km)
Lagoon area: 25.6 Sq. Km.
Local population: 4319 (2001 Census)

6.2.3 Bangaram

Bangaram lagoon encloses four islands namely Bangaram, Tinnakara, Parali 1 and Parali 2

Bangaram
Latitude: N 10^0-55'.30"
Longitude: E 72^0-16'.30"
Land Area: 115 Acres (46.53 Hect)
Lagoon area: 46.25 Sq. Km.
Local population: 61 (1991 census)

Tinnakara
Latitude: N 10^0-56'
Longitude: E 72^0-18'
Land Area: 77 Acres (31.16 Hect)

Parali
Latitude: N 10^0-56'.20"
Longitude: E 72^0-18'.40"
Land Area: 10 Acres (4.47 Hect)

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6.2.4 Agatti

Agatti lagoon encloses two islands namely Agatti and Kalpetti

Latitude: N 10^0-51'
Longitude: E 72^0-11'
Land Area: 716 Acres (289.75 Hect or 3.84 Sq. Km)
Lagoon area: 17.50 Sq. Km.
Local population: 7072 (2001 Census)

6.2.5 Kadmat

Latitude: N 11^0-13'
Longitude: E 72^0-46'
Land Area: 748 Acres (302.70 Hect or 3.12 Sq. Km)
Lagoon area: 37.50 Sq. Km.
Local population: 5319 (2001 Census)

6.2.6 Amini

Latitude: N 11^0-07'
Longitude: E 72^0-44'
Land Area: 622 Acres (251.71 Hect or 2.59 Sq. Km)
Lagoon area: 1.50 Sq. Km.
Local population: 7340 (2001 Census)

6.2.7 Bitra

Latitude: N 11^0-35'.30"
Longitude: E 72^0-09'.30"
Land Area: 26 Acres (10.52 Hect)
Lagoon area: 45.61 Sq. Km.
Local population: 225 (1991 census)

6.2.8 Chetlat

Latitude: N 11^0-41'
Longitude: E 72^0-41'
Land Area: 255 Acres (103.19 Hect or 1.14 Sq. Km)
Lagoon area: 1.6 Sq. Km.
Local population: 2553 (2001 Census)

6.2.9 Kiltan

Latitude: N 11^0-29'
Longitude: E 73^0-00'
Land Area: 397 Acres (160.66 Hect or 1.63 Sq. Km)
Lagoon area: 1.76 Sq. Km.
Local population: 3664 (2001 Census)

6.2.10 Suheli

Suheli lagoon encloses two islands and one sand bar namely Suheli Veliakara**,** Suheli Cheriyakara and Suheli Pitti

Vallyakara
Latitude: N 10^0-08'
Longitude: E 72^0-18'20"
Land Area: 120 Acres (48.56 Hect)
Lagoon area: 78.96 Sq. Km.
Local population: Nil

Cheriyakara
Latitude: N 10^0-02'
Longitude: E 72^0-15'.20"
Land Area: 81.75 Acres (33.08 Hect)
Local population: Nil

6.2.11 Minicoy

Minicoy lagoon encloses two islands namely Viringili and Minicoy

Latitude: N 8^0-16'
Longitude: E 73^0-03'
Land Area: 1120 Acres (453.25 Hect or 4.93 Sq. Km)
Lagoon area: 30.60 Sq. Km.
Local population: 9495 (2001 Census)

6.2.12 Pitti

A tiny island lies between Kavaratti and Agatti. The island has no lagoon; however, is it surrounded by shallow water. It is declared as bird sanctuary and four species of terns nest on this uninhabited island.

The Lakshadweep reef is divided in lagoon reef and open reef. The lagoon is shallow in most islands with maximum depth of 5 m. However, in Bitra, Suheli, Minicoy and Bangaram, in some parts of lagoon depth can reach up to 15m. The reef crest is narrow and gets exposed during low tides. Beyond reef crest however, the depth increases rapidly and can reach up to 3000 m. Continental shelf is virtually absent and open reef is mostly on reef wall.

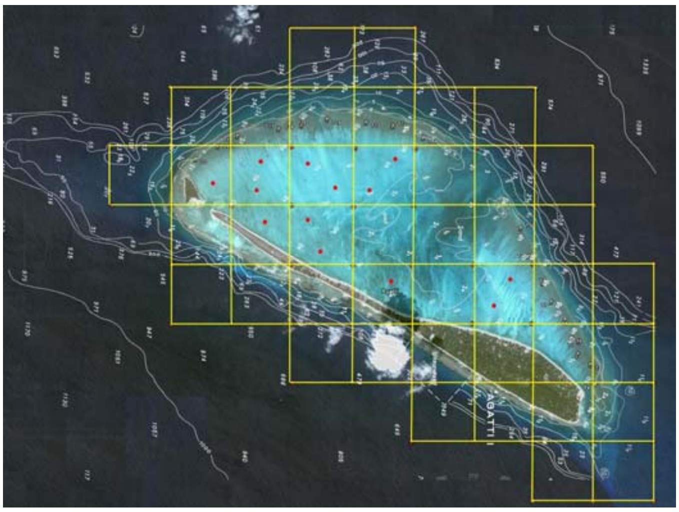
7. Methodology

7.1 Fixed Width Line Transect for *T. maxima*

Line transects[5] are based on the theory of walking/swimming along a pre-determined route to record the species on or near the line. The method requires great care; any line transect study should be designed such that the basic assumptions are not violated. Line transects are well suited for open habitats and flat areas, but they have also been successfully tested in hilly areas.

Once an area has been selected for population estimates, the next step is to lay transects in randomly selected habitats. As the line transect is based on a strict assumption of a straight line, it is imperative that the marked transect is more or less straight, so that there is no error in estimation of perpendicular distances and sighting of objects. Transects should be well spaced out; distances between two parallel transects should not be less than 200m. Transects can be placed in random or stratified (according to habitat) or a combination of both.

For counts of *T, maxima* we have used fixed width line transects or belt transect of 100m x 10m. The islands lagoon was divided in 1 sq. km grid and transects were randomly placed. For each transect start point and end point was marked with permanent markers as well as GPS locations. This was helpful in monitoring the same transects for three consecutive years from 2005 to 2008. Transects were sampled by a team of field workers comprised of researchers and assistants. Corresponding to each sighting of a giant clam, the length and height of the individual, perpendicular distance from the line, age class, status (in the 2nd and 3rd sampling years), substrate, nature of placement on the substrate, mantle colour, height from the sea floor and nearest adult neighbour distance were recorded. Photographic documentation of each individual was also maintained. Altogether, 165 transects were sampled in 2005-06, 134 in 2006-07 and 50 in 2007-08.



Lagoon divided in 1 sq.km grid for laying random line transects. Transects are marked by flags and red dots indicate transects for benthos studies (Image: www.googleearth.com)

[5] Field Methods for Bird Surveys Salim Javed & Rahul Kaul, published by Bombay Natural History Society, 2002

7.2 Point intercept line transect for coral cover

To assess the benthic communities in the potential giant clam area the line and point intercept transect method (English *et al*, 1997) was used. Transects were laid along the substratum, data was collected along the transects as the number of 0.5 meter points intercepted by benthic components under the line. Data on corals was collected at the genus and live form levels.

Statistical analyses

Density of giant clam T. maxima was estimated through the software DISTANCE 5.0[6], vital rates like mortality and recruitment were estimated from successive samplings. Age specific growth was calculated from length measurements of individuals in successive recounts and simulated for the entire population. Population projections were modelled through age structured Leslie transition matrix (ref), using the software POPTOOLS[7]. Details of the analytical procedures have been provided in each of the concerned sections.

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[6] http://www.ruwpa.st-and.ac.uk/distance/

[7] Poptools: http://www.cse.csiro.au/CDG/poptools/index.htm

8 Mantle

Mantle is the most obvious, visible and one of the most attractive parts of the giant clam body. It shows a range of colour variations. The reasons for such variations are still not known. Presence of zooxanthellae is likely to play some role in the colour of the mantle. It might as well be a defence strategy by giant clams. To find out the mantle colour preference by *T. maxima*, a detailed data on its colour was collected under various ecological conditions from 11 lagoons.

Corresponding to each giant clam *T. maxima* sighting along the 100m transects, data on the primary mantle colour, associated pigments (if any), height from the sea floor and age class of the clam were recorded. The mantle colour was classified in basic four colour forms such as brown, green, blue and cream colour. Irrespective of colour, the mantle is always profusely spotted with various shades. The four colour forms are illustrated as below.

Green

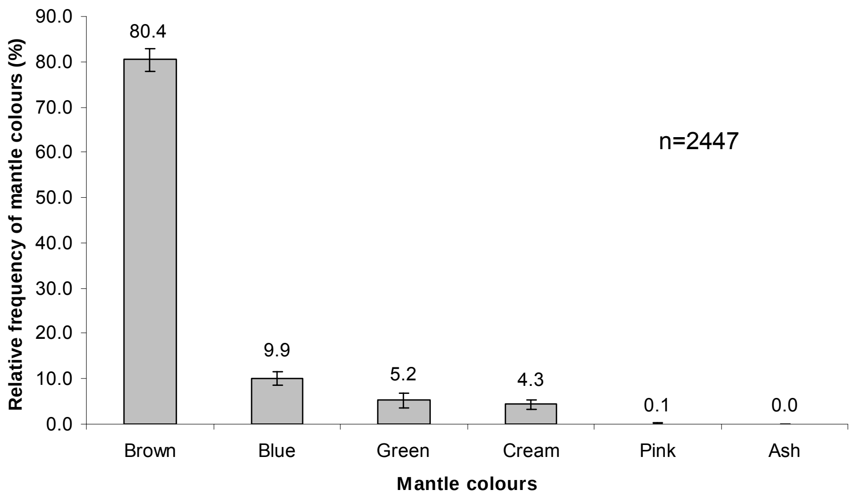
Blue

Cream

Brown

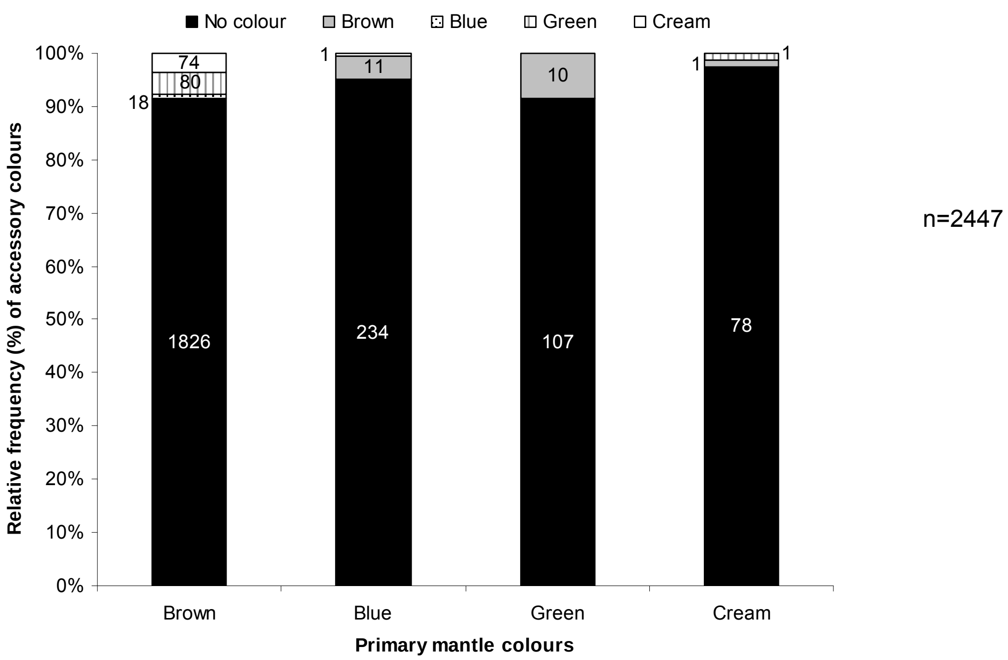
Among the several colour morphs, brown is the most common (80%) followed by blue (10%), green (5%) and cream (4%). The other colour morphs (ash, pink etc.) are extremely rare (figure 8.1). 92 % of mantles in the population exhibit unique colouration (only the primary colour) while the remaining posses accessory colours in various forms (figure 8.2). Brown pigment again accounts for the majority of the accessory colours. The brown colour blends well in the background of *Porites lutea* (the most preferred substrate), encrusting sea weed *Turbinaria ornata* and green algae *Caulerappa racemosa* (most common associate species). Thus camouflage seems to be the most important driver for colour of mantle. Whether variation in mantle colour is genetic or an ecological adaptation is yet not known. Although the naturally occurring pigmentation of the mantle is brown, analysing the causes of chromatic variation was expected to provide valuable information on the biology of the species.

Figure 8.1. Primary mantle colours of *T. maxima* in Lakshadweep Archipelago



Error bars are Standard errors

Figure 8. 2. Various colour composition in the mantle of *T. maxima* in Lakshadweep Archipelago

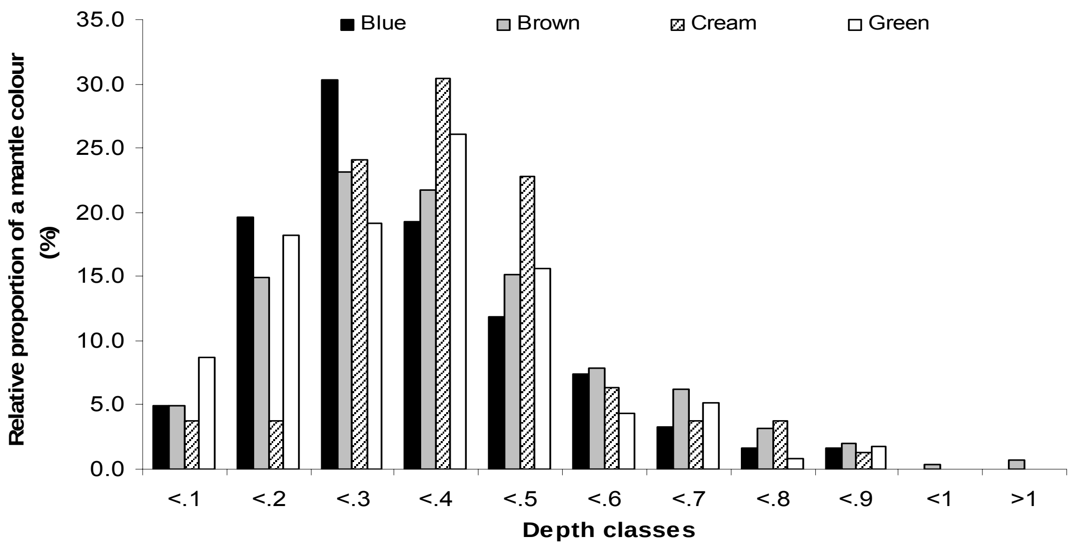


The following ecological aspects of mantle colouration were investigated in our study.

1. Is mantle colouration related with the water depth?

Water depth was classified as ≤ 0.1 m, ≤ 0.2 m … ≥ 1m from sea floor. Frequency of clams with a particular primary mantle pigment in each depth class relative to the total number of clams with that pigment was tested for randomness of pigment distribution across depth classes through G-test. Pigmentations such as brown (G = 1.6, p = 0.99), green (G = 9.4, p = 0.31) and blue (G = 14.6, p = 0.07) were randomly distributed but cream colouration revealed non random distribution (G = 16.1, p =0.04) across water depth (figure 8.3).

Figure 8.3. Distribution of each primary mantle colour in *T. maxima* across the water depth gradient in Lakshadweep Archipelago

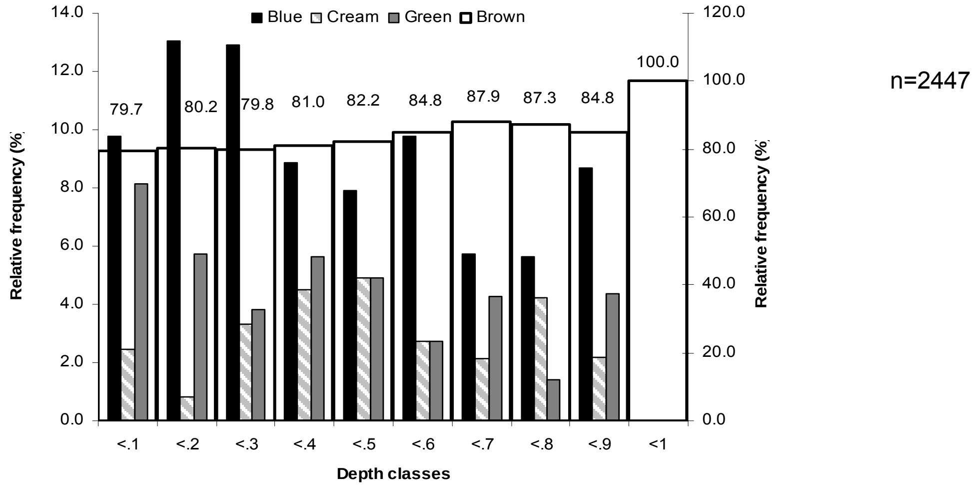


Frequency of a primary mantle pigment relative to the number of clams in each depth class did not reveal any striking pattern of chromatic distribution across the depth gradient but there was a trend of increasing brown (primary) pigmentation and decreasing other pigmentation(s) with increasing height from the sea floor (figure 8.4).

Considering brown as the dominant primary pigment, relative frequencies of accessory pigments were calculated across the gradient of water depth. Occurrence of exclusive brown pigmentation diminished and accessory pigmentation became more common with increasing height from the sea floor (figure 8.5).

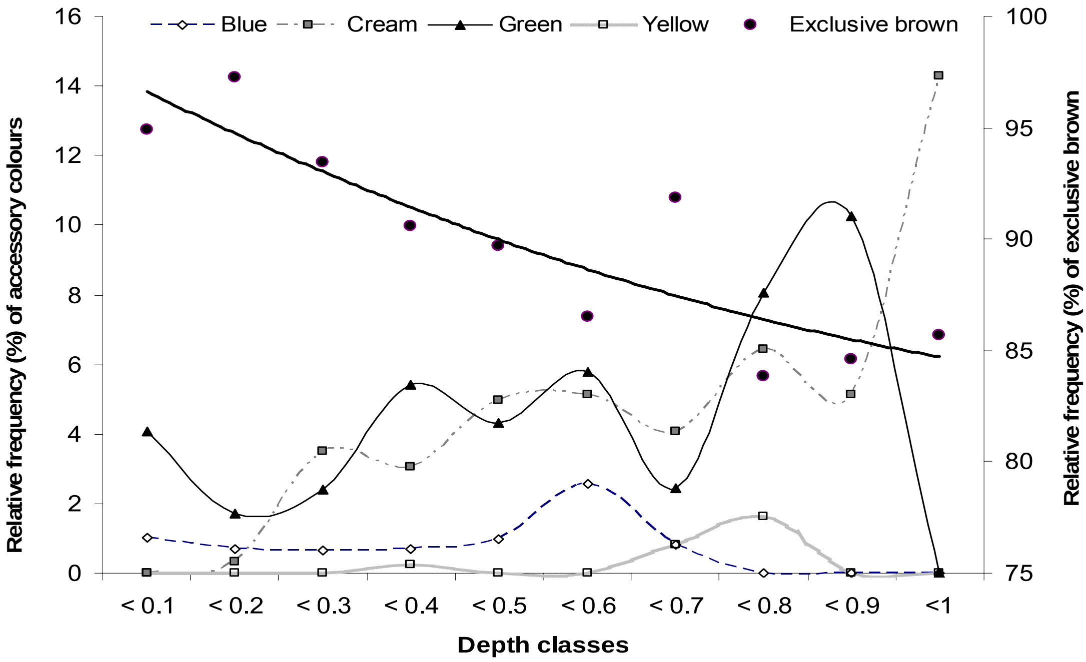
Thus, we would expect exclusive brown followed by blue primary mantle colours in deeper waters, whereas, brown mantle with accessory pigmentation of cream and green are relatively more probable in shallower waters.

Figure 8.4. Occurrence of various primary mantle colours in *T. maxima* across a gradient of water depth in Lakshadweep Archipelago



Relative frequency of brown pigmentation plotted along secondary Y axis and all other pigments along primary Y axis

Figure 8.5. Occurrence of accessory pigmentation with dominant brown primary mantle colour of *T. maxima* in Lakshadweep Archipelago

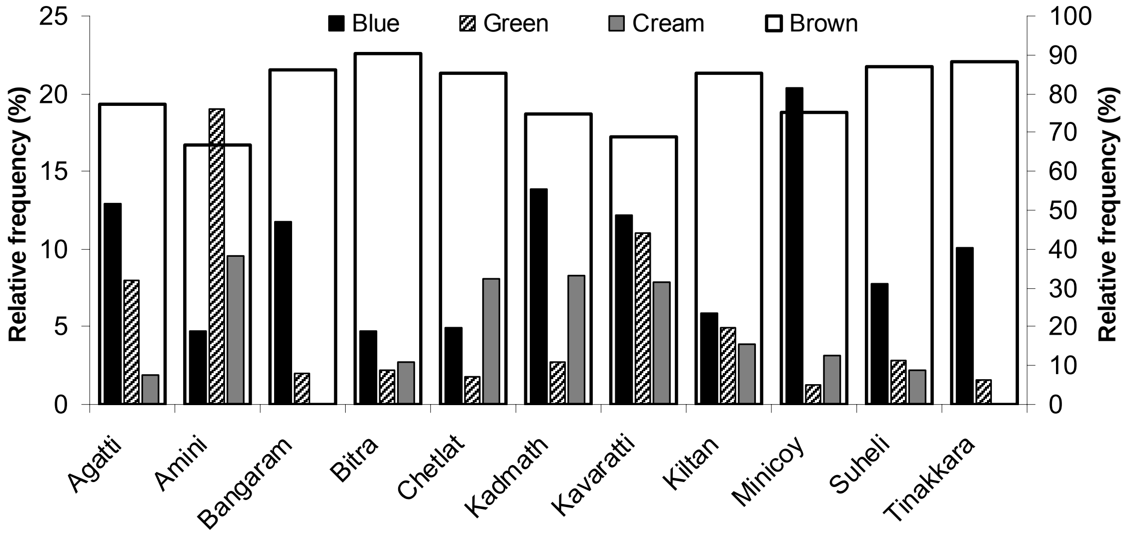


Relative frequency of brown pigmentation plotted along secondary Y axis and all accessory pigments along primary Y axis

2. Does mantle colour composition vary among islands?

Relative proportions of various primary mantle pigments in the *T. maxima* population of each island were tested against the overall relative frequencies of different pigments for any general pattern, through G-test (figure 8.6). Results did not reveal any general trend and islands were varying among each other in the mantle colour distribution except the fact that brown pigment was universally dominant over other pigments (Table 8.1).

Figure 8.6. Relative proportions of various primary mantle colours in *T. maxima* across islands in Lakshadweep Archipelago



Relative frequency of brown pigmentation plotted along secondary Y axis and all other pigments along primary Y axis

Table 8.1. Results of G-test for testing any generality in the relative proportions of mantle colours in *T. maxima* across islands in Lakshadweep Archipelago

Island	G	p value
Agatti	25.44	0.000
Amini	6.75	0.080
Bangaram	6.54	0.088
Bitra	31.87	0.000
Chetlat	21.36	0.000
Kadmat	2.42	0.491
Kavaratti	25.44	0.000
Kiltan	2.29	0.514
Minicoy	20.77	0.000
Suheli	5.94	0.115
Tinakkara	7.64	0.054

Shaded rows show significant variation from the general pattern (Brown : Blue : Green : Cream = 251 : 31 : 15 : 10)

3. Does mantle colour vary with age?

Moderate intensity brown pigment was consistently dominant across age classes but relative frequencies of various mantle colours showed increasing trend of green, cream and brown pigments, and decreasing trend of blue pigment from juvenile to adult stages. If mantle colour is persistent through the clam life, then there might be a gradual shift of mantle colour distribution in the giant clam population through time (figure 8.7). The plausible causes should be investigated further. Moreover, relative proportion of dark mantles in the population increased from juveniles to adults (figure 8.8).

Figure 8.7. Distribution of various mantle colours across age classes of *T. maxima* in Lakshadweep Archipelago

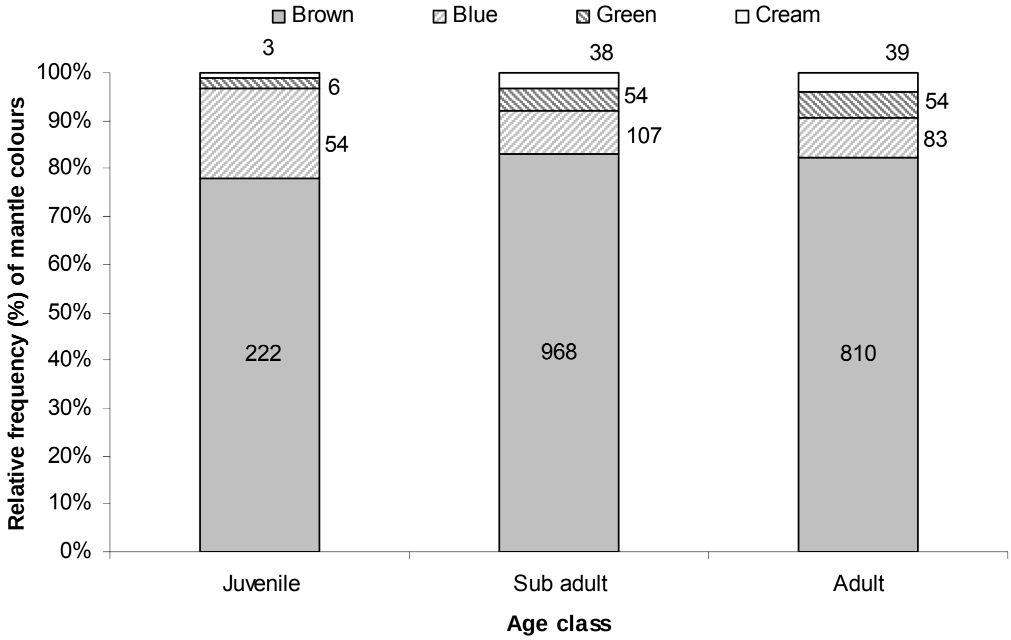
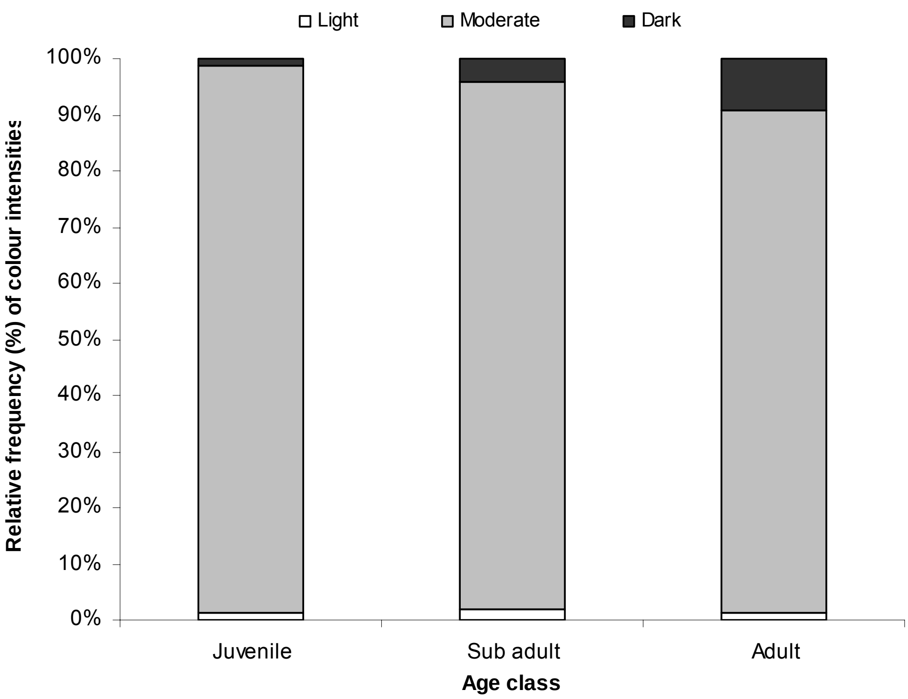


Figure 8.8. Distribution of colour intensities in the mantle of *T. maxima* across age classes in Lakshadweep Archipelago



Thus, moderate intensity brown pigment is super dominant in *T. maxima* population of Lakshadweep Archipelago but other primary and accessory colours showed variations across islands and to some extent with age and water depth. Photo-documentation of *T.*

maxima revealed evidences that mantle colour patterns frequently resemble the surrounding substrate. The general substrate in Lakshadweep archipelago being comprised of *Porites lutea*, encrusting sea weed and green algae, creates a greenish brown environment; and the dominant pigmentation in *T. maxima* mantle is quite similar to such a background. The occasional exceptions from brown mantles were observed in non-brown environments similar to the mantle pigment. The plausible explanation to such phenomenon might be that a suitable camouflage reduces mortality of this otherwise easy prey, thereby permitting natural selection to drastically eliminate individuals appearing conspicuous against the environment. Analysis of proximal factors behind the chromatic variation of *T. maxima* mantle suggested that pigmentation is an ecological artifact of a genetic character.

Mantle colour patterns frequently resemble the surrounding substrate

9. Reproduction and Growth

Giant clams are functional protandrous hermaphrodites but can soon transform into simultaneous hermaphrodites (Wada, 1952). In giant clams male phase of the gonad develops first followed by female phase.

9.1 Spawning

Sperms are released first followed by eggs. Spawning is induced by the chemicals associated with eggs. Fecundity is prodigious. Heslinga and Watson (1985) reported spawning behaviour of three species of giant clams. They noted that *T. gigas* and *T. deresa* spawns through out year, however, not all clams spawn every time. *T. gigas* spawns usually during second and fourth quarters of lunar month (Heslinga *et al*, 1984).

Larvae settlement happens on fifth day post fertilization. Beckvar (1981) reported possibility of lunar spawning in *T. gigas*, *T. deresa* and *H. hippopus*. Most of the spawning observations however, are based on induced spawning (Beckvar, 1981; Wada, 1952; LaBarbera, 1975; Jameson, 1976).

Rosewater (1965) reported spawning of *T. squamosa* from February to March at Eniwetok while as LaBarbera (1974, 1975) reported it in July in Fiji and Hardy and Hardy (1969) in March in Palau. Yamaguchi (1977) suggested that *T. squamosa* has a peak spawning season in winter.

Jameson (1976) observed that water current is an important stimulus to induce spawning in giant clams. He also noted that *H. hippopus* of size 249 mm is capable of releasing 25 x 10^6 eggs. LaBarbera (1975) also noted effects of changing tide in stimulating spawning of giant clams in Fiji.

In the present study we have not observed spawning behaviour of *T. maxima* in Lakshadweep. It may be spawning in winter month from November to March. However, it is completely speculative and based on traditional knowledge of locals. Further studies are required to decide the peak spawning season in Lakshadweep.

9.2 Growth

It is well known that among bivalves, giant clams grow very fast during early years of recruitment. As the clams grow, the growth rates slow down significantly. However, this is not applicable universally as several factors influence growth. Bonham (1965) and Rosewater (1965) studied annual growth rate in *T. gigas* at Bikini Atoll and Eniwetok respectively and fount it to be 50 mm per year. McMichael (1974) studied growth rate of *T. maxima* and found that early stages of clams shows rapid growth and there after the growth is very slow. This may be the case of all other species of giant clams. It is also interesting to note that fecundity is directly proportional to the body mass. Thus the variations in the fecundity are great among the adult (Yamaguchi, 1977). In other terms, small size adults may not yield sufficient number of gametes thereby affecting recruitment. Therefore it is imperative to have sufficient density of adults to achieve substantial recruitment. Though the optimal level of densities of adults are not known, over-harvesting of adults in fragmented areas or island system like Lakshadweep Archipelago, can have catastrophic impacts on its populations. Beckver (1981) reported annual growth of 80 to 120 mm in *T. gigas*, while *T. deresa* grows 30 to 60 mm and *Hippopus hippopus* grows 30 to 50 mm annually. *T. squamosa* however, grows with slightly slow at 20 to 40 mm annually. During induced spawning and laboratory studies on *T. gigas* he found that, Trochophores hatched 16 hrs after fertilization and at 20 hrs larvae were in transition stage between Trochophore and veliger. Pediveligers settles after seven days and by tenth day metamorphosis is complete. The similar pattern was observed in *T. deresa* metamorphosis happened on 11th day. Beckver (1981) observed faster growth rates in *T. squamosa* in lagoon reared population (0.85 cm in two months) as compared to laboratory reared (0.31 cm in two months).

Growth of giant clam *T. maxima* in Lakshadweep Archipelago

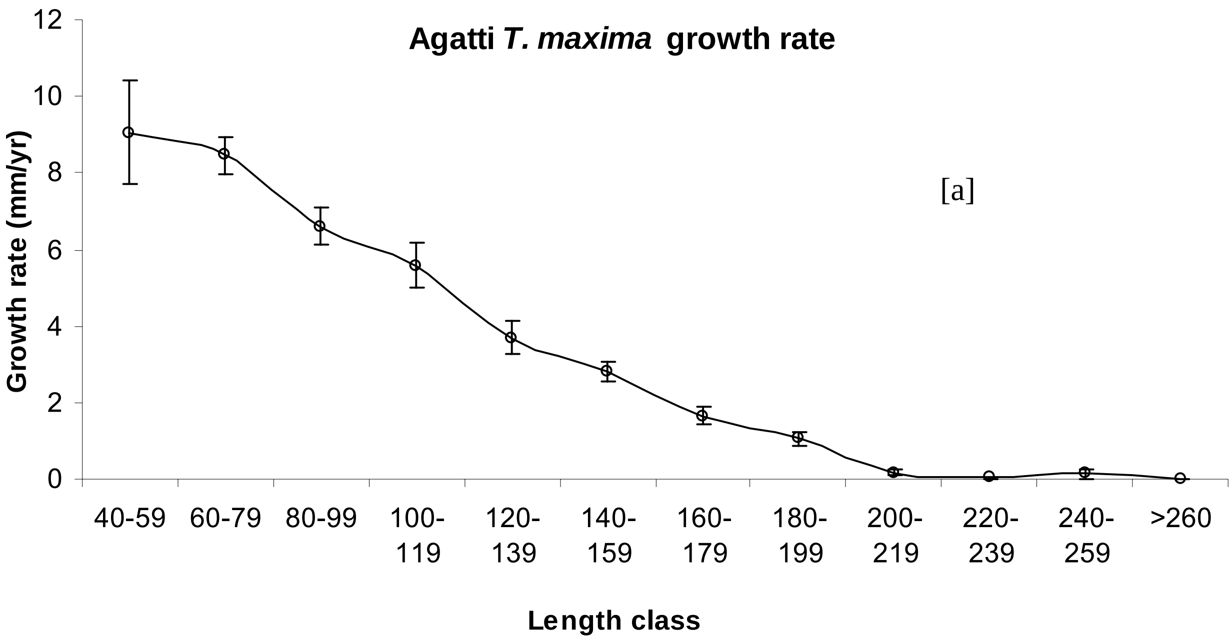
Growth of individual *T. maxima* was obtained from repetitive measurements of the tip-tip shell length in a gap of 2 years from 55 transects across the islands of Agatti, Bangaram, Tinnakkara and Kavaratti. Annual growth rate of each length class (<40, 40-

59, 60-79…..240-259, >260) was estimated from the average growth of clams belonging to that length class for each island (figure 9.2.1). Inter-island variation in growth rates of *T. maxima* was tested for significance through ANOVA (p=0.06, F=2.7, df=3). Annual growth rate in Kavaratti was considerably dissimilar from the other three islands (figure 9.2.2).

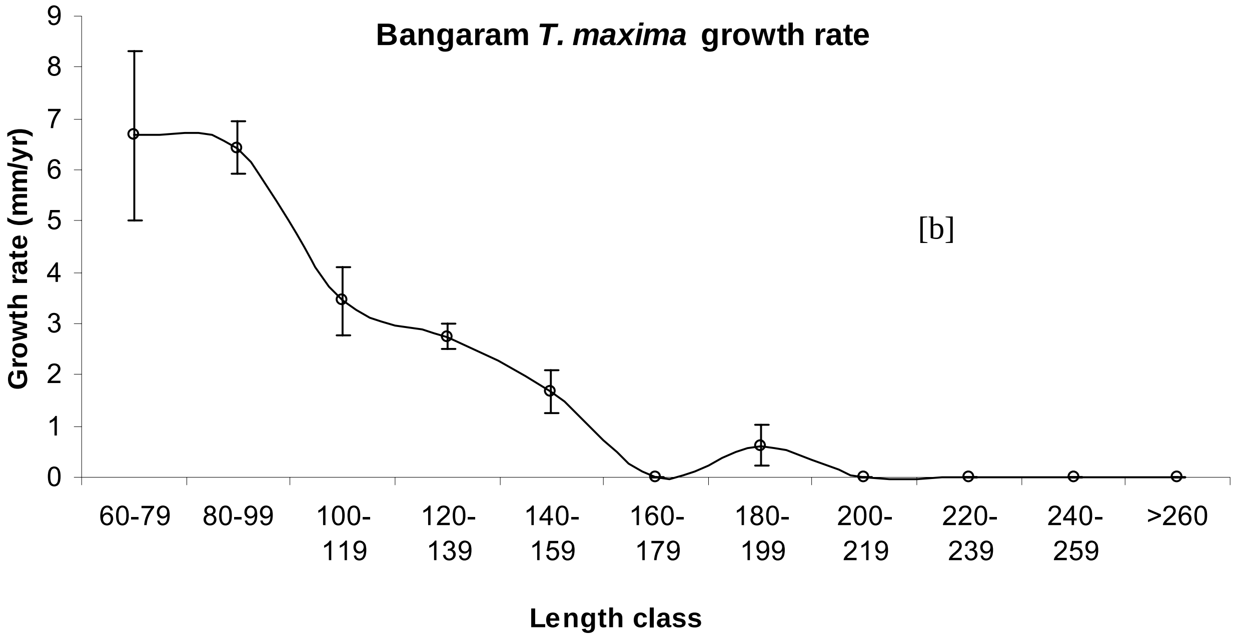
Generalized length specific annual growth rate of typical *T. maxima* was then pooled across islands (excluding Kavaratti from the analysis). Annual growth rate of *T. maxima* showed non-linear trend of decline with increasing length (figure 9.2). However, giant clams > 160mm in size showed high variation in growth among individuals (CV% >100) with even higher variations among adults, >200mm in size (CV% 300 – 742). This indicates that growth becomes extremely stochastic with adulthood (figure 10.2.3). Adult clams probably wait for favourable conditions and only 2% of the adult population grows at a rate of 2 - 5 mm / year.

Growth of typical *T. maxima* with age was then simulated for 100 years from length specific annual growth rates assuming growth rate to be constant within a length class. The asymptotic growth curve revealed that a typical recruit would attain sub adulthood in 8 years and thereafter require > 50 years to attain the size class of 200mm and above. As a result of the slow and stochastic growth, an adult *T. maxima* is expected to show a stair-case growth pattern, the exact nature of which requires long term studies to get revealed (figure 9.2.4).

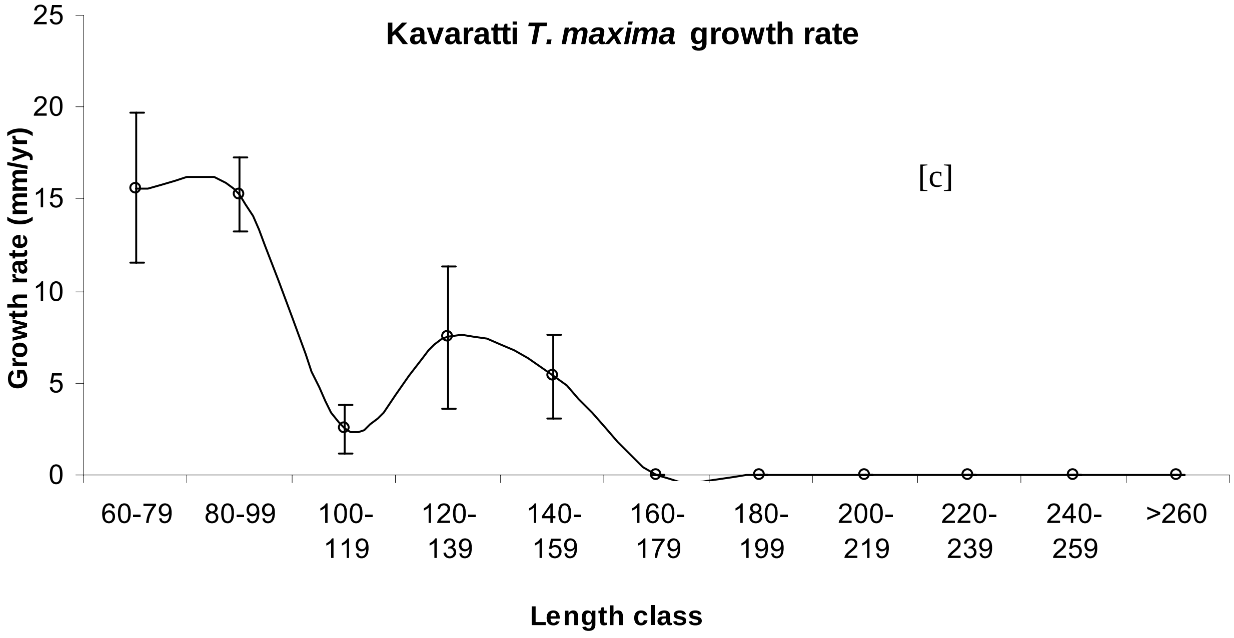
Figure 9.2.1. Annual growth rates of giant clam *T. maxima* across length classes in the surveyed islands ([a] Agatti, [b] Bangaram, [c] Kavaratti & [d] Tinnakkara) of Lakshadweep Archipelago



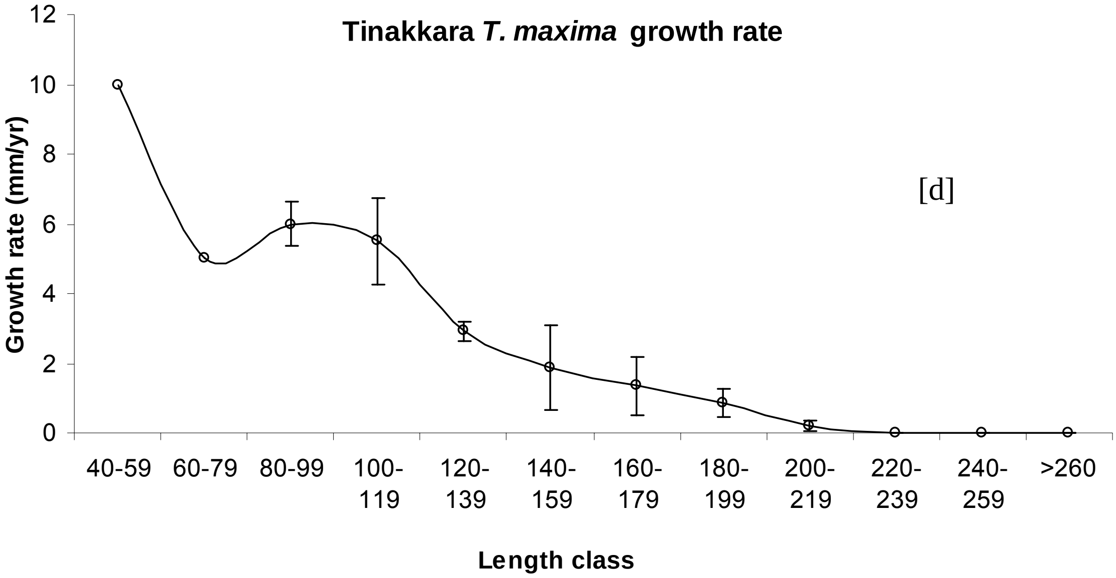
Error bars are Standard Errors



Error bars are Standard Errors

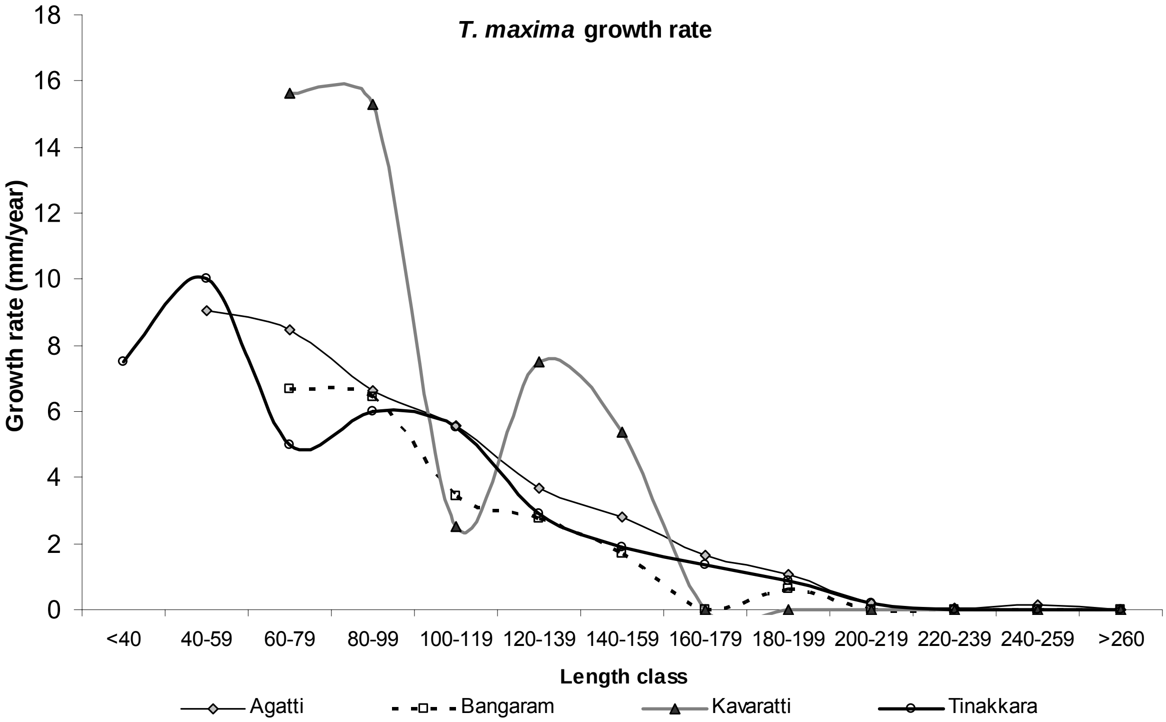


Error bars are Standard Errors



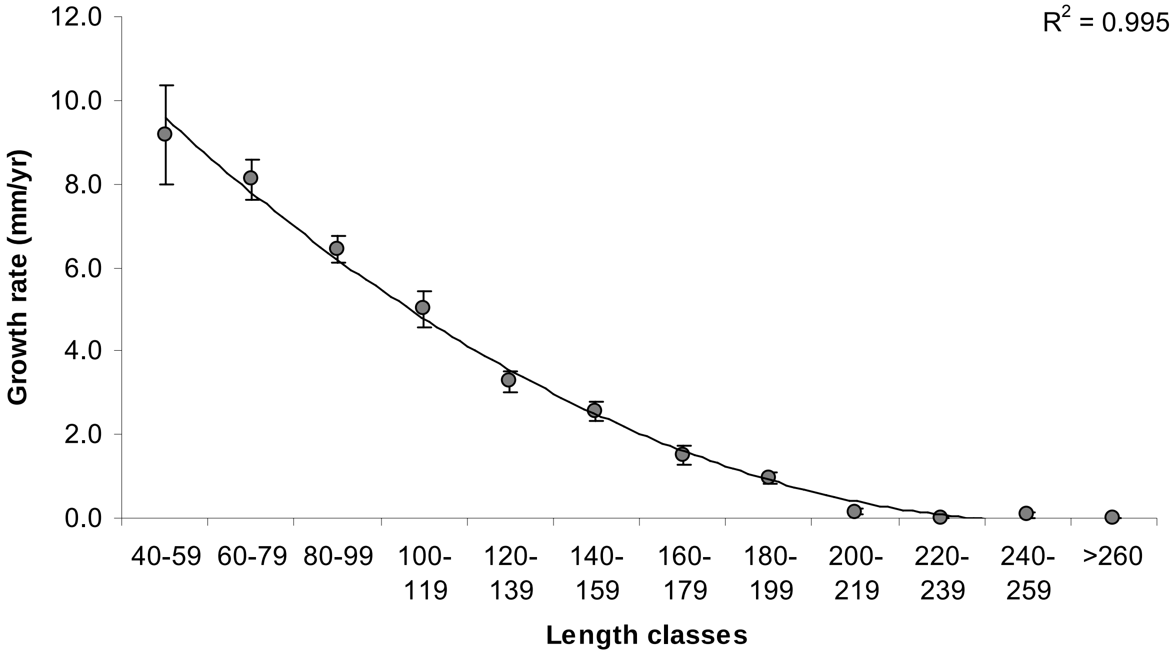
Error bars are Standard Errors

Figure 9..2.2. Variation in annual growth rates of giant clam *T. maxima* across length classes among the surveyed islands of Lakshadweep Archipelago



Error bars are Standard Errors

Figure 9.2.3. Generalized annual growth rate of giant clam *T. maxima* across length classes in Lakshadweep Archipelago



Error bars are Standard Errors

Figure 9.2.4. Intraspecific variation in growth of giant clams (estimated as CV% of growth rates) across length classes in Lakshadweep Archipelago

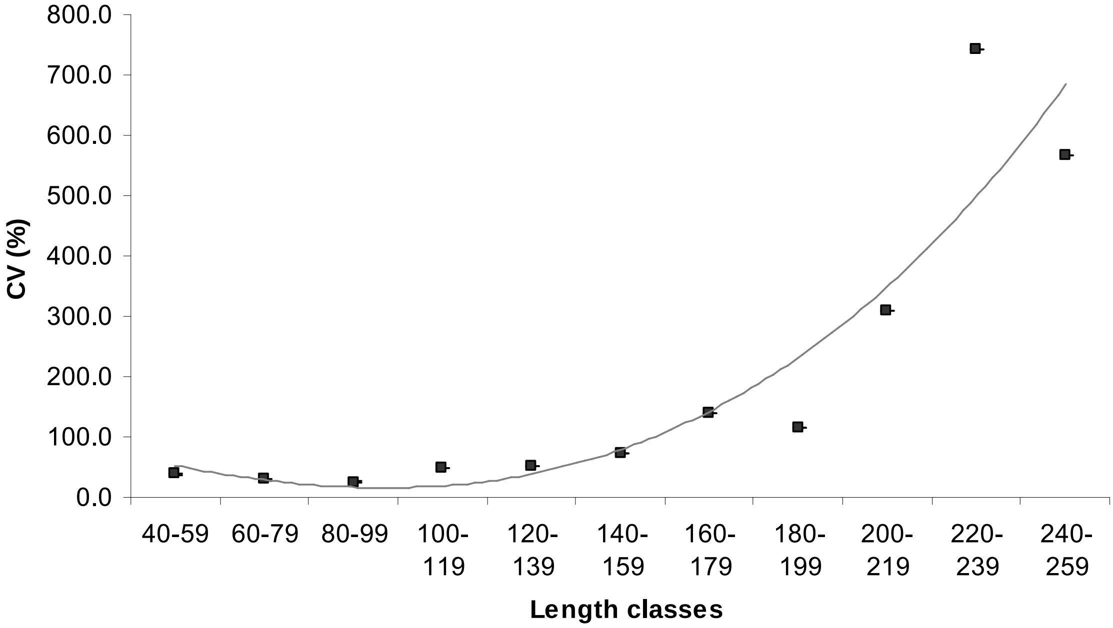
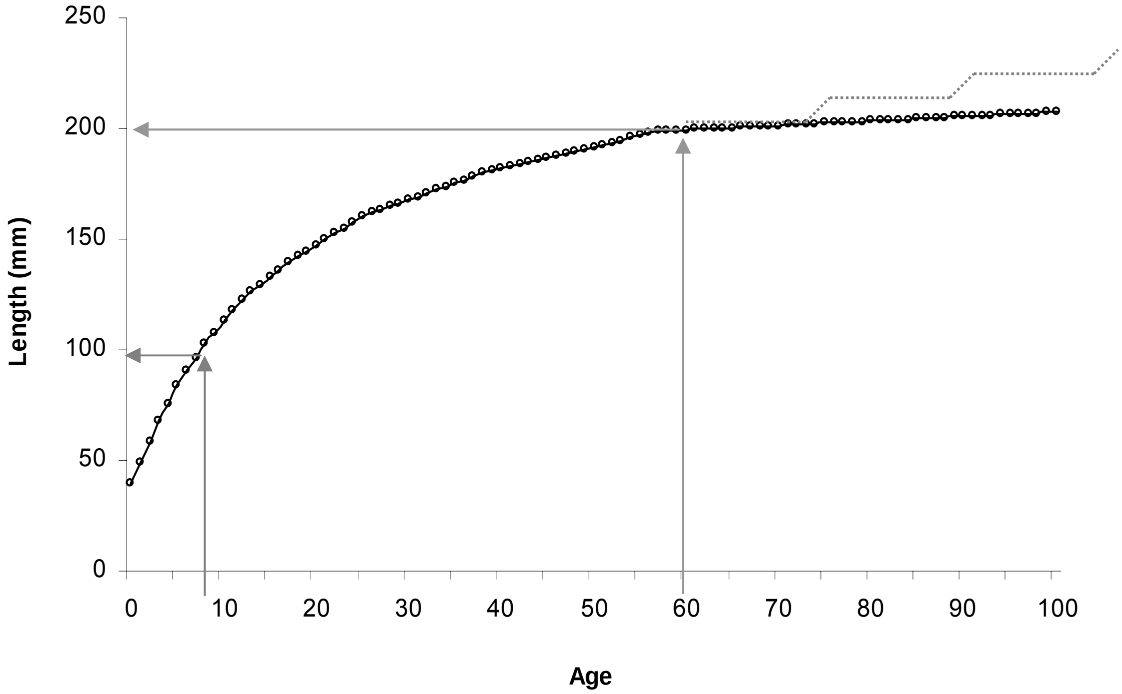


Figure 9.2.5. Growth of a typical giant clam *T. maxima* with age in Lakshadweep Archipelago



Approximation of the stair-case growth pattern of adult *T. maxima* represented by dotted line; attainment of sub-adult hood and adult-hood marked by arrow marks.

Thus, our study suggested that giant clam *T.* maxima in Lakshadweep archipelago grows at a slow annual rate of 8 – 11 mm in the juvenile stage with growth becoming slower and stochastic with age. Growth rates might vary to some extent among certain islands.

9.3 Size

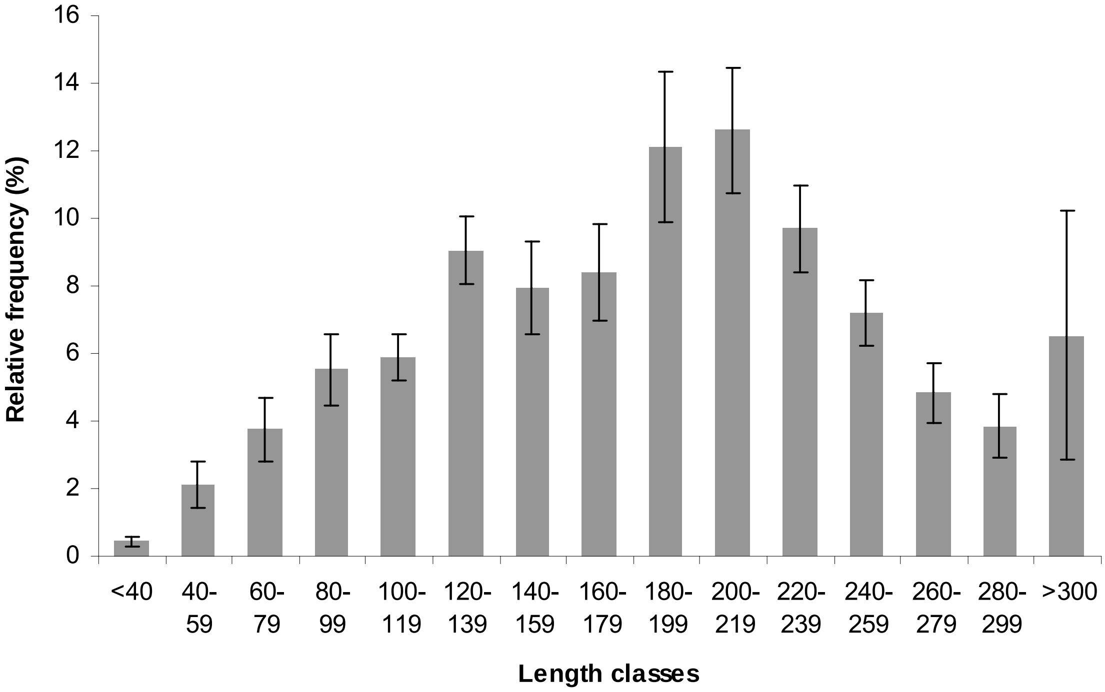
Basker (1991) reported size of *T. squamosa* up to 540 mm and *T. maxima* up to 250 mm. In Lakshadweep we have reported *T. maxima* individuals over 400 mm. The size class data of various islands clearly shows large size *T. maxima* to occur, though in small number.

Population structure of giant clam *Tridacna maxima* in Lakshadweep Archipelago

Giant clam *Tridacna maxima* follows an asymptotic growth curve and tip to tip shell length can be considered as a surrogate of the clam age. Individuals were classified into 20 mm interval size classes (<40mm, 40-59mm, 60-79mm…280-299mm, >300mm) and the age/size structure of the population was studied from 165 transects across 24 islands (within 11 lagoons) in 2005, 121 transects across 22 islands (within 11 lagoons) in 2006, and 55 transects across 4 islands (within 3 lagoons) in 2007. Proportion of each size class in the giant clam population of every island was averaged over the study years to compare the age/size structures across islands (figure 9.3.1). Data was pooled over all islands to obtain the overall age/size structure in Lakshadweep archipelago. Population structure was skewed from normal distribution towards greater size classes (figure 9.3.2) probably due to the rapid growth of juveniles (<160mm) and extremely slow growth of adults (>200mm) leading to higher proportions of mid-sizes. Variations in age/size structure of *T. maxima* population in each island from the overall, pooled over all islands in Lakshadweep archipelago was tested for significance by the G-test. Age/size distribution varied considerably across islands, with Bangaram, Tinakkkara, Minicoy and Amini (but not Agatti, Bitra, Chetlat, Kadmat, Kalpeni, Kavaratti, Kiltan and Suheli) showing age/size structure similar to the typical population (table 9.3.1).

Proportions of different size classes in the population of each island were compared across the study years and the annual fractional change in the relative proportion of each size class between successive years was calculated (figure 9.3.3). A chi-square test of significance for variation in size class frequencies between 2005 and 2006 revealed unstable distribution in Kadmat and Amini populations between the study years (table 9.3.2). Data was pooled over all islands studied every year to obtain the dynamics of the overall age/size structure of giant clam *T. maxima* population in Lakshadweep archipelago (figure 9.3.4). Relative frequency of juveniles was on an increasing trend from 2005 to 2007 but this is not universal as Agatti, Tinakkara, Kalpeni and Kadmat populations were not corresponding to such trend.

Figure 9.3.2. Overall size class distribution of giant clam *Tridacna maxima* in Lakshadweep Archipelago during 2005-2007



Error bars are Standard Errors

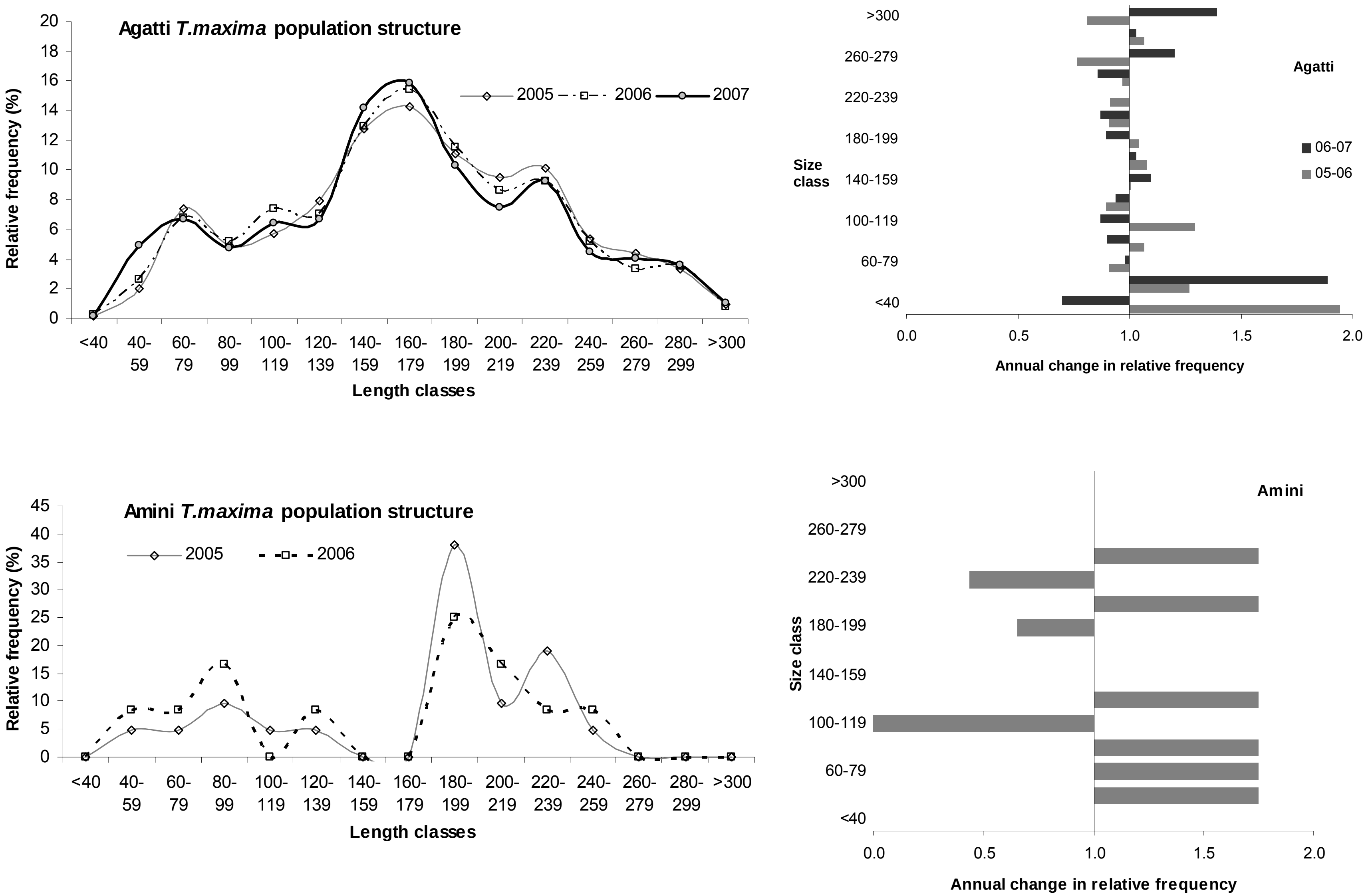
Table 9.3.1. Results of G-test for the significance of variation in age/size structure of *T. maxima* population in each island against the overall (typical) population in Lakshadweep archipelago

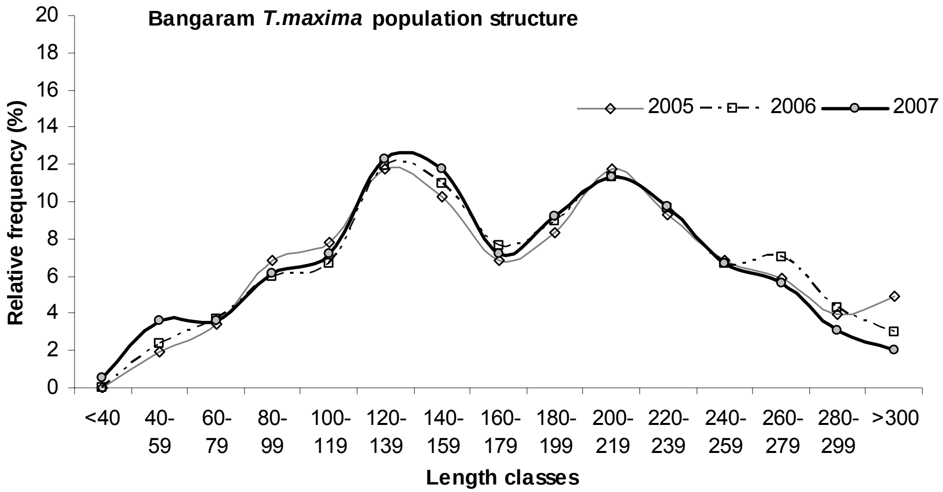
Island	G-statistic	p-value
Agatti	45.44	0.000
Bitra	43.14	0.000
Chetlat	62.86	0.000
Suheli	42.01	0.000
Bangaram	7.95	0.892
Kalpeni	784.62	0.000
Tinakkara	19.94	0.132
Kavaratti	52.61	0.000
Kiltan	37.99	0.001
Minicoy	11.73	0.628
Kadmat	31.7	0.004
Amini	11.23	0.668

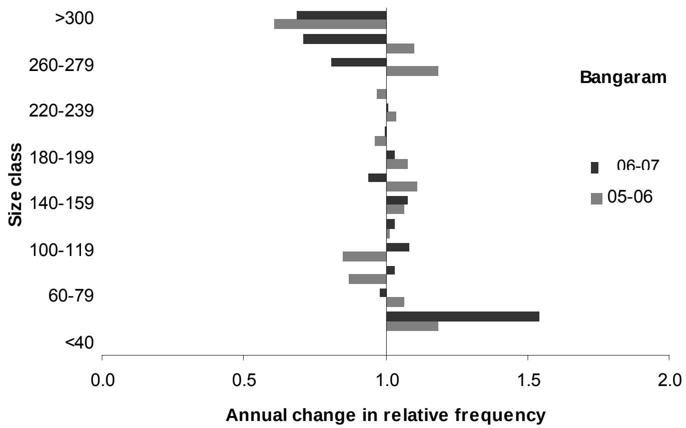
Islands arranged in descending order of *T. maxima* densities

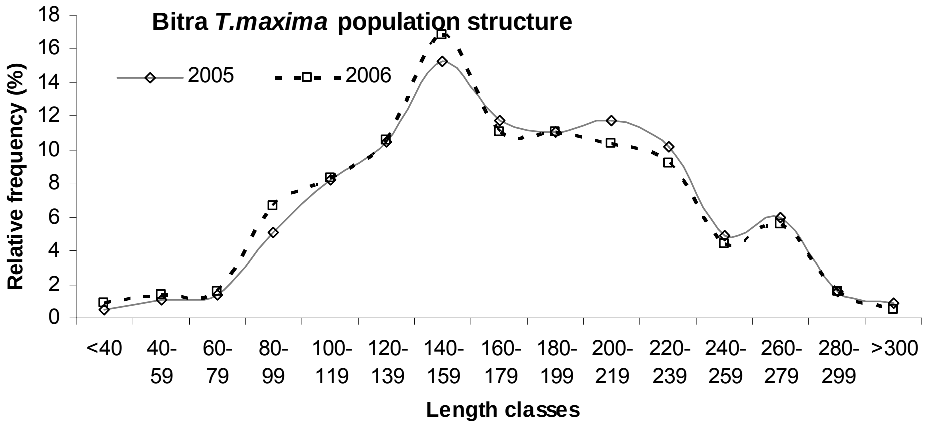
Any change greater or lesser than 1.00 in the annual fluctuation in relative frequency of different size classes (see the graphs on the right column of fig 9.3.3) corresponds respectively and in exact magnitude to an increment or decline of that size class relative to the population size between successive years. Thus, Kalpeni shows relative decline of the younger age classes without any increment in the older age classes, Kavaratti shows consistent decline in the older age classes with a mixed pattern in the younger ones, Agatti shows a haphazard pattern altering between reproductive pulses, and so on.

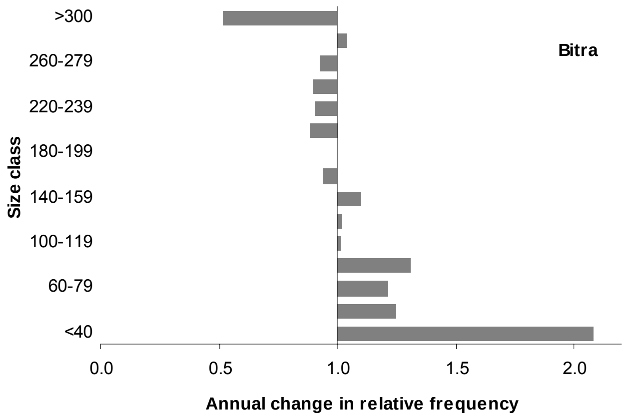
Figure 9.3.3. Size class distribution of giant clam *Tridacna maxima* in different islands of Lakshadweep Archipelago across the study years, 2005-2007

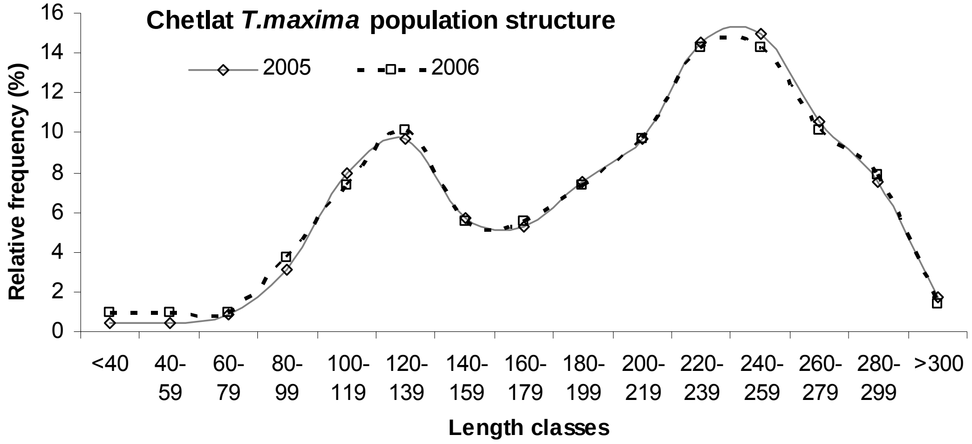


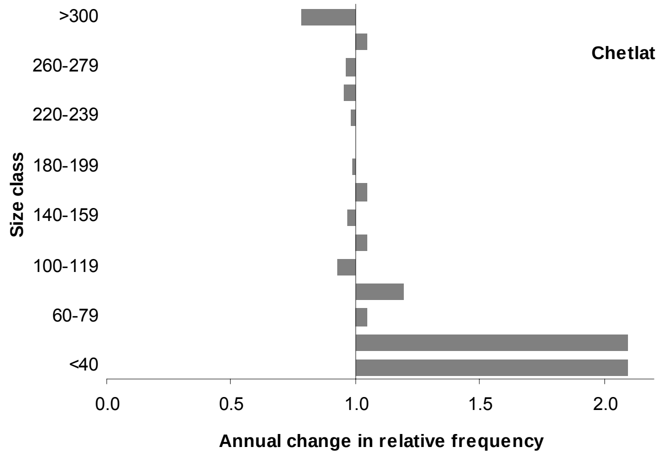

Bangaram *T.maxima* population structure
2005
2006
2007
Relative frequency (%)
0
2
4
6
8
10
12
14
16
18
20
<40
40-59
60-79
80-99
100-119
120-139
140-159
160-179
180-199
200-219
220-239
240-259
260-279
280-299
>300
Length classes

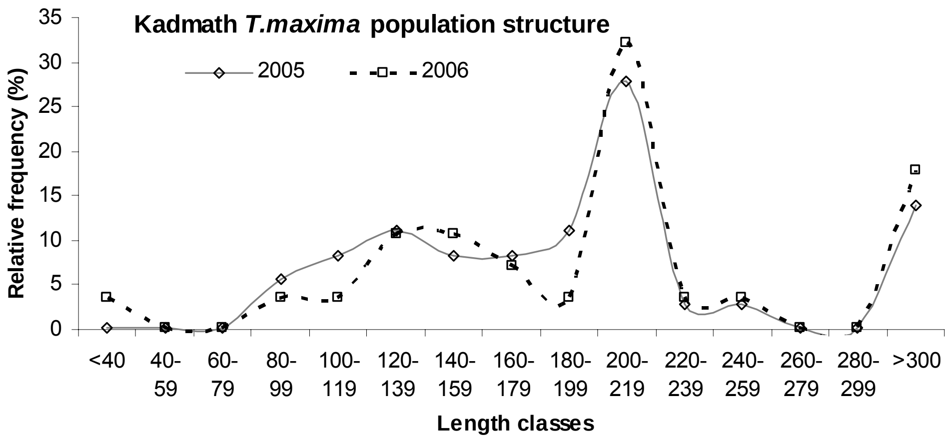

Bangaram
06-07
05-06
Size class
>300
260-279
220-239
180-199
140-159
100-119
60-79
<40
0.0
0.5
1.0
1.5
2.0
Annual change in relative frequency

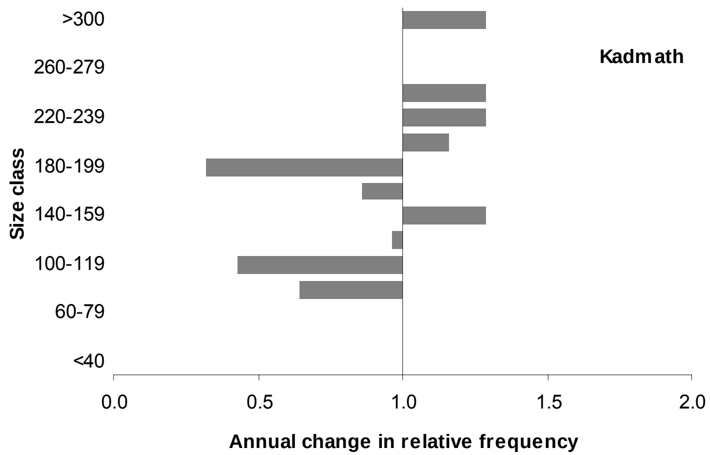

Bitra *T.maxima* population structure
2005
2006
Relative frequency (%)
0
2
4
6
8
10
12
14
16
18
<40
40-59
60-79
80-99
100-119
120-139
140-159
160-179
180-199
200-219
220-239
240-259
260-279
280-299
>300
Length classes

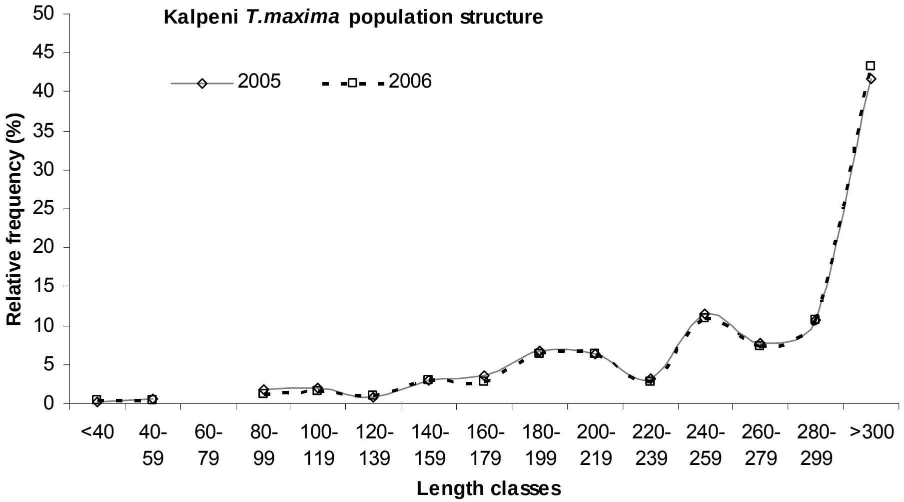

Bitra
Size class
>300
260-279
220-239
180-199
140-159
100-119
60-79
<40
0.0
0.5
1.0
1.5
2.0
Annual change in relative frequency

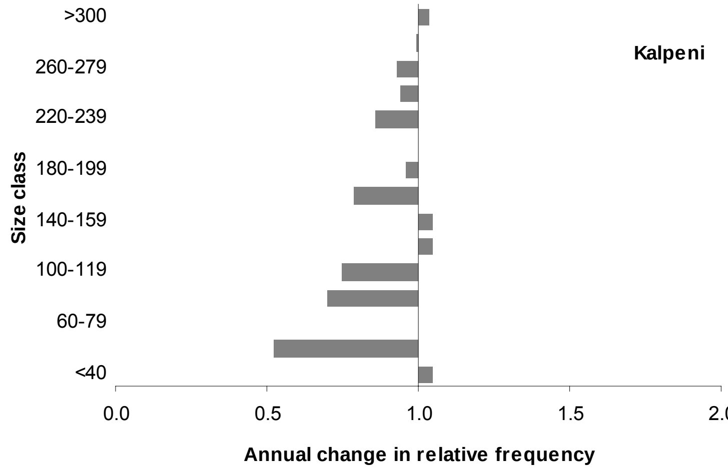

Chetlat T.maxima population structure
2005
2006
Relative frequency (%)
Length classes
<40
40-59
60-79
80-99
100-119
120-139
140-159
160-179
180-199
200-219
220-239
240-259
260-279
280-299
>300

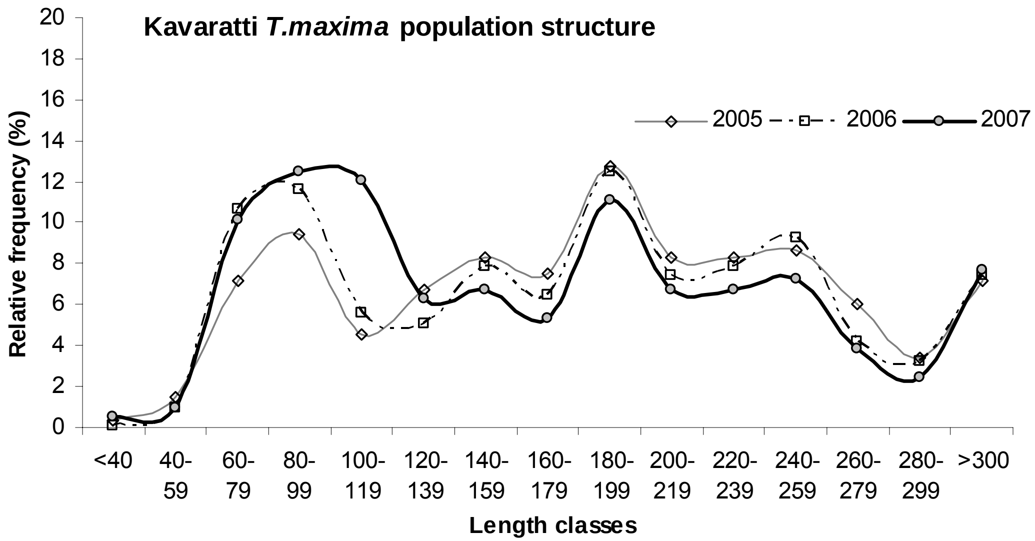

Chetlat
Size class
>300
260-279
220-239
180-199
140-159
100-119
60-79
<40
Annual change in relative frequency

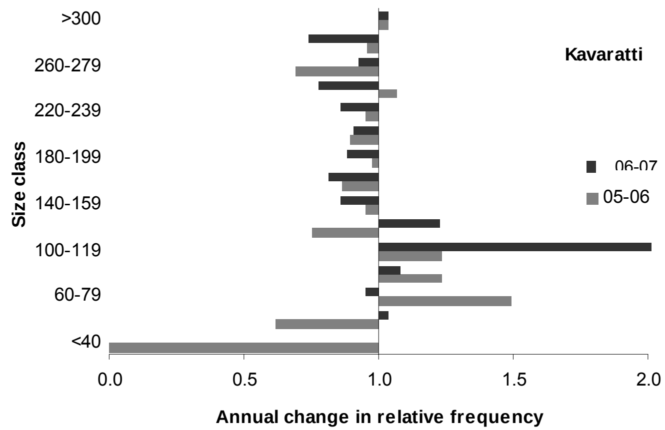

Kadmath T.maxima population structure
2005
2006
Relative frequency (%)
Length classes
<40
40-59
60-79
80-99
100-119
120-139
140-159
160-179
180-199
200-219
220-239
240-259
260-279
280-299
>300

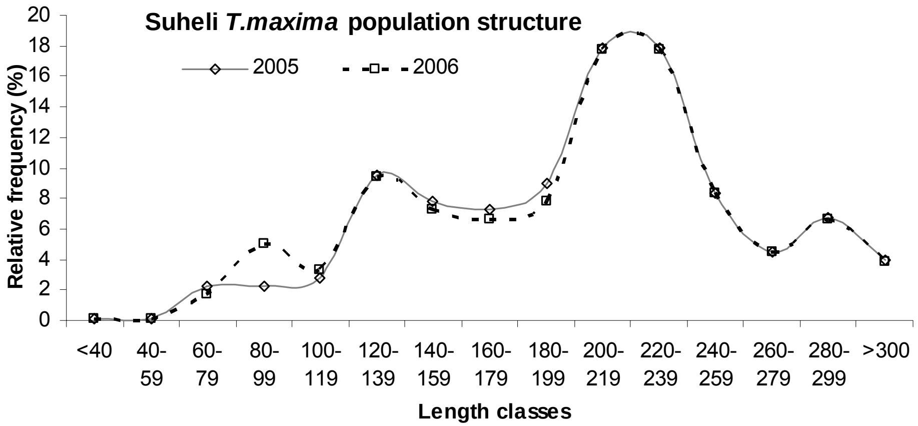

Kadmath
Size class
>300
260-279
220-239
180-199
140-159
100-119
60-79
<40
Annual change in relative frequency

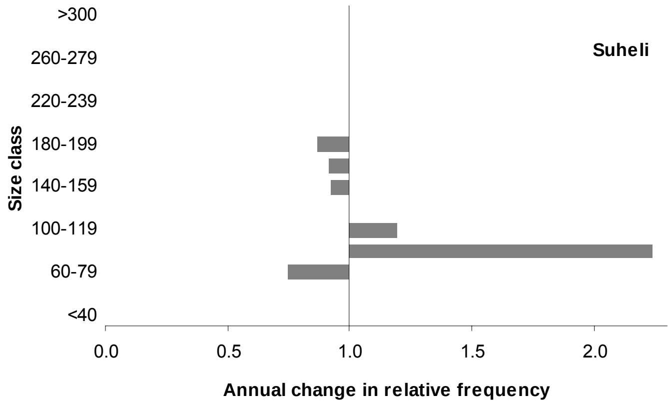

Kalpeni T.maxima population structure
2005
2006
Relative frequency (%)
Length classes
<40
40-59
60-79
80-99
100-119
120-139
140-159
160-179
180-199
200-219
220-239
240-259
260-279
280-299
>300

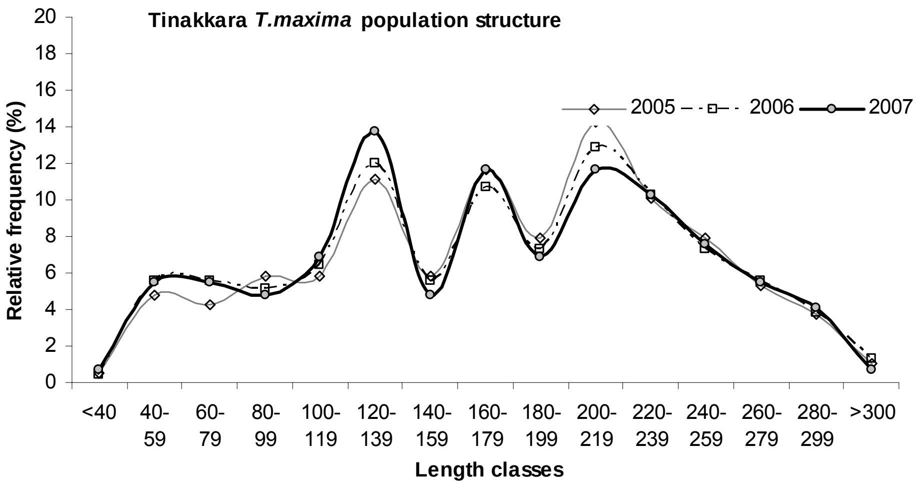

Kalpeni
Size class
>300
260-279
220-239
180-199
140-159
100-119
60-79
<40
Annual change in relative frequency


Kavaratti T.maxima population structure
2005
2006
2007
Relative frequency (%)
Length classes
<40
40-59
60-79
80-99
100-119
120-139
140-159
160-179
180-199
200-219
220-239
240-259
260-279
280-299
>300


Kavaratti
06-07
05-06
Size class
>300
260-279
220-239
180-199
140-159
100-119
60-79
<40
Annual change in relative frequency


Suheli T.maxima population structure
2005
2006
Relative frequency (%)
Length classes
<40
40-59
60-79
80-99
100-119
120-139
140-159
160-179
180-199
200-219
220-239
240-259
260-279
280-299
>300


Suheli
Size class
>300
260-279
220-239
180-199
140-159
100-119
60-79
<40
Annual change in relative frequency


Tinakkara T.maxima population structure
2005
2006
2007
Relative frequency (%)
Length classes

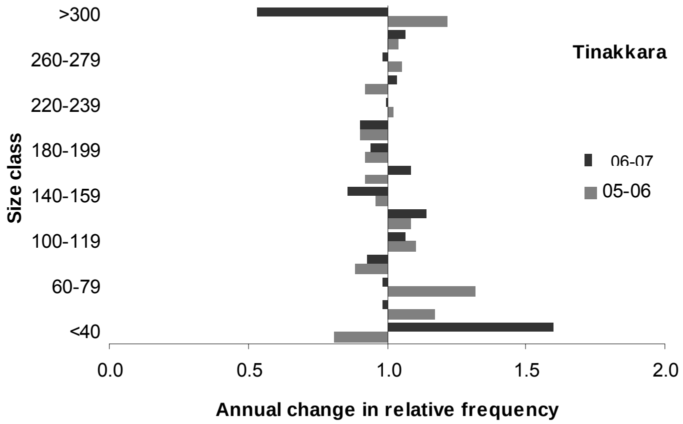
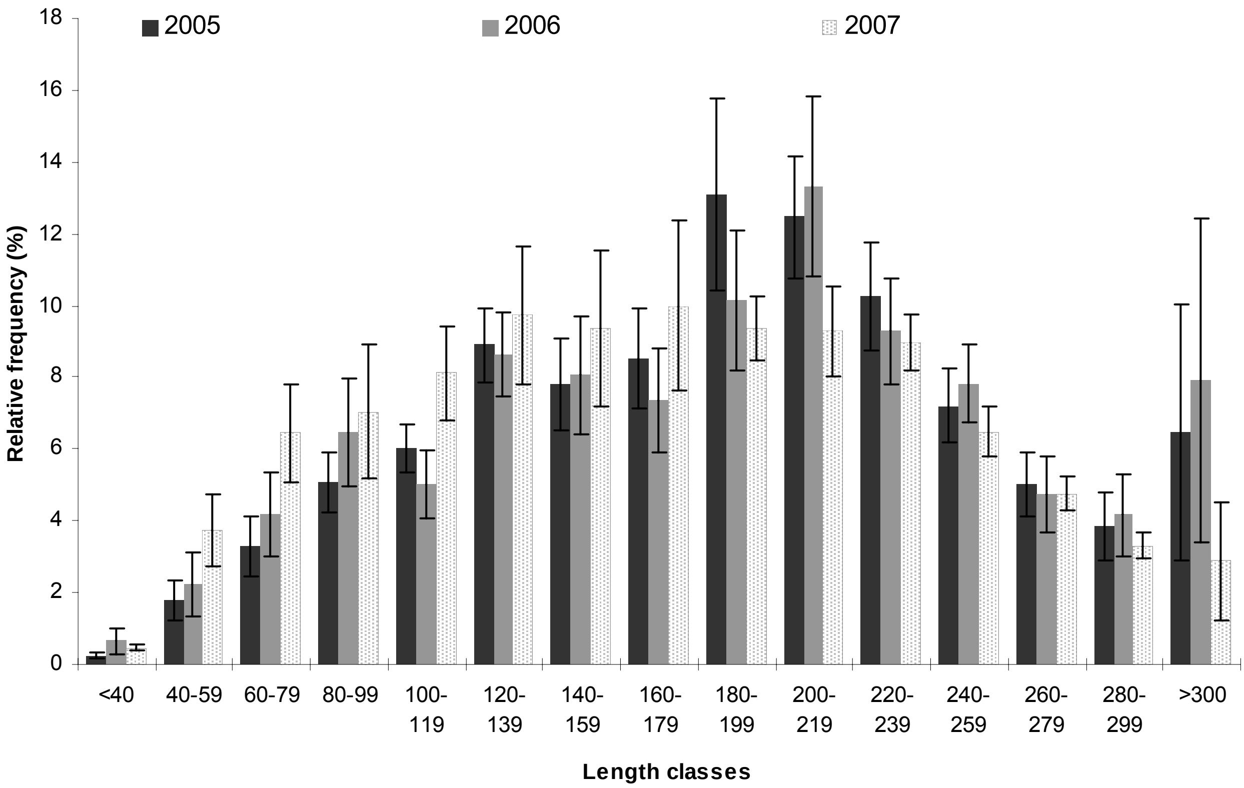

Tinakkara
06-07
05-06
Size class
Annual change in relative frequency

Table 9.3.2. Results of Chi-square test of significance for variation in age/size structure of *T. maxima* population between 2005 and 2006 across islands

Island	Chi-square	p-value
Agatti	1.53	1.000
Bitra	1.88	1.000
Chetlat	1.40	1.000
Suheli	3.92	0.996
Bangaram	1.59	0.999
Kalpeni	0.78	1.000
Tinakkara	1.21	1.000
Kavaratti	4.36	0.993
Kadmat	132.19	0.000
Amini	36.70	0.001

Islands arranged in descending order of *T. maxima* densities

Figure 9.3.4. Overall size class distribution of giant clam *T. maxima* in Lakshadweep Archipelago across the study years, 2005-2007



The large sized individuals in the *T. maxima* population is an interesting finding of the present study. It is not an individual instance and large size clams are not an uncommon sight especially at Cheriyam, Bangaram, Bitra and Suheli. Besides this we have also notices exceptionally large clams. However, since they are deeply embedded inside massive corals, it is difficult to classify them. Never the less these clams exceed all known records of either *T. maxima* or *T. squamosa* which are known from Lakshadweep. Only genetic studies could reveal its identity. Some images of these exceptionally large clams have been provided below


T. maxima 580 mm

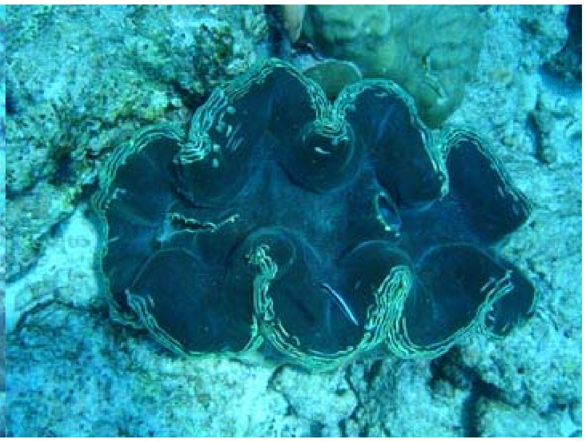

T. squamosa 577 mm


T. squamosa 600 mm


T. Squamosa 570 mm

Besides these we have encountered two specimens which have not been classified into any species as their proper identification was not possible. The specimens measure 890 mm and 902 mm respectively. These were recorded at the depth of 30 m. Only genetic studies will help solve the mystery of these large individuals.


Unidentified giant clam 902 mm


Unidentified giant clam 890 mm

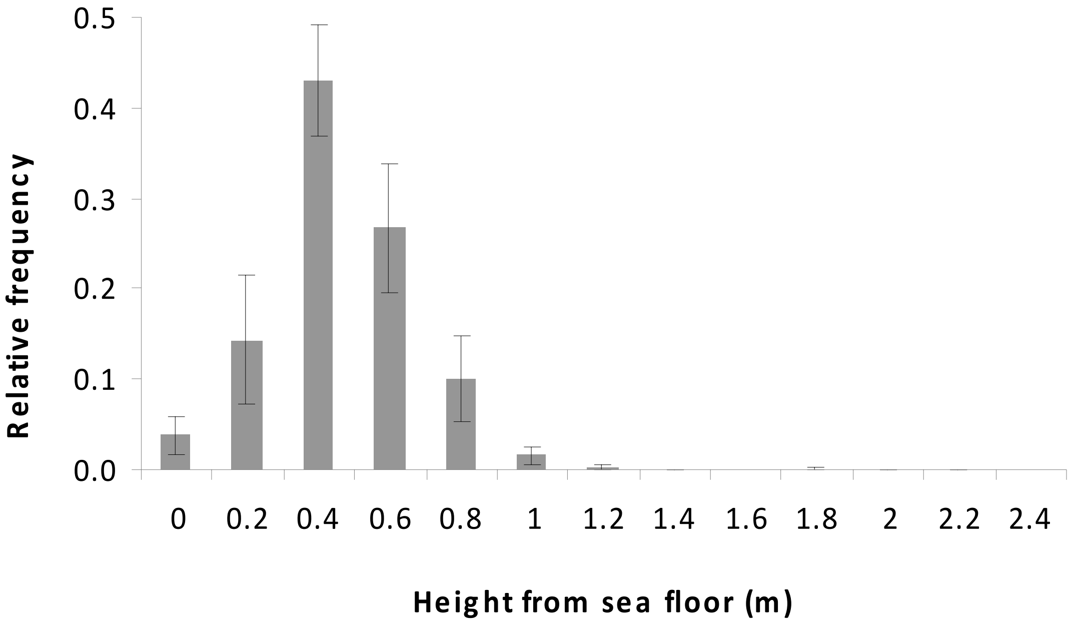
10. ECOLOGY of *T. maxima*

10.1 Reef Canopy Distribution

To assess the niche selection of *T. maxima*, data was collected along 165 transects from 24 islands within 11 lagoons in Lakshadweep during the first year of sapling. Frequency of individuals in each 'height from sea floor' class was calculated relative to the total clam count for each island, and averaged across islands (figure 10.1.1). The data was analysed separately for Kalpeni and Amini as the water column at low tide is 1m as compared to 2.5 m in all other islands (figure 10.1.2).

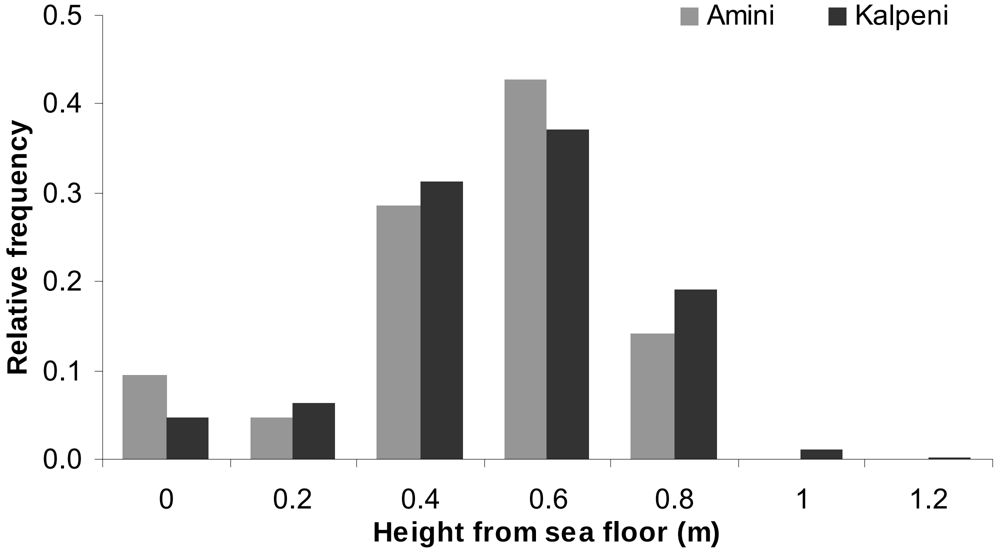
Frequencies of *T. maxima* in different height classes from the sea floor were calculated across islands as relative proportions of the total counts, and averaged for entire Lakshadweep archipelago. It was found that *T.* maxima utilize a narrow range of 0.2 – 0.8 m out of the available 2.5 m water depth in a typical lagoon, with the exception of Kalpeni where individuals occurred between 0.4 – 0.8 m in the lagoon of 1.5m depth (figure 10.1.2).

Figure 10.1.1. Distribution of giant clam *T. maxima* (expressed as relative frequency) on the reef canopy in Lakshadweep archipelago during 2005-07



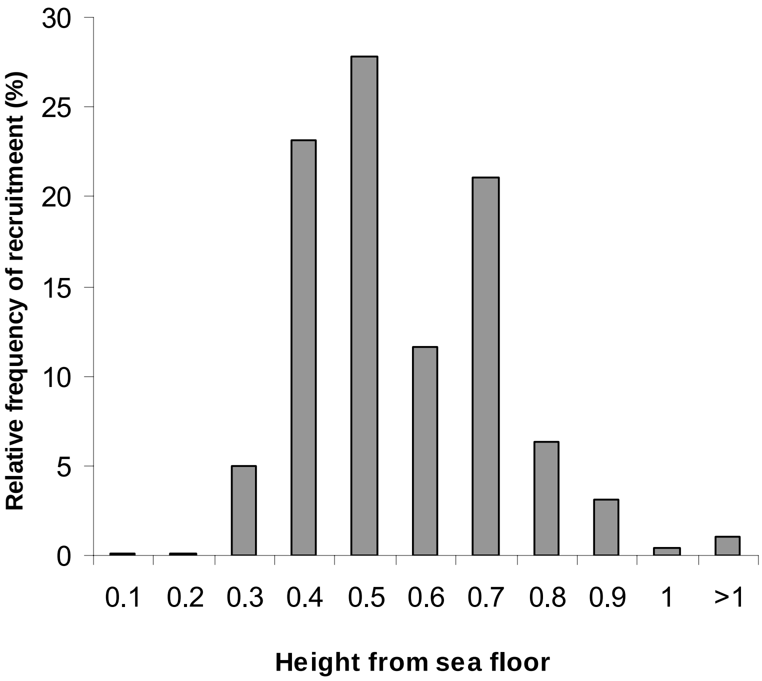
Error bars are Standard errors

Figure 10.1.2. Distribution of giant clam *T. maxima* (expressed as relative frequency) on reef canopy in Kalpeni and Amini islands during 2005-07



It is clearly evident that *T. maxima* are specialized to a narrow range of reef canopy with ~ 90% of the population utilizing a range of 0.2-0.6 m from the sea floor. Successful recruitment is also restricted between 0.4 and 0.7 m (figure 10.1.3).

Figure. 10.1.3. Recruitment in giant clam *T. maxima* population expressed as relative frequency (%) across different heights from sea floor in some islands of Lakshadweep Archipelago



Giant clam *T. maxima* prefer an optimal depth of 1.5 m at low tide or the lower strata of reef canopy. In other words, the species is clearly avoiding higher reef canopy probably to avoid the wave surge. Within lagoon waters, this seems to be the best strategy adopted by recruits. The reef crest has very intense wave action. In high wave surge, the juveniles who are yet to find right anchor location are vulnerable to dislodging. Giant clams are also avoiding the zone proximal to the sea floor as sand particles can easily clog their gills. Thus by selecting a super specialized niche between 0.2 m to 0.8 m, they are successful in avoiding high wave surge as well as sedimentation. Juveniles of giant clams up to few days of its early life cycle are known to move and find right anchor location, and substrate availability in the lower reef canopy is likely to be one of the factors influencing the recruitment success.

In case of Kalpeni lagoon, the situation is almost the same. This lagoon is much shallower and during low tide the average water depth is just 1-1.5 m. Amini on other hand, has a small lagoon and *T. maxima* can be seen only in deeper pools on reef crest. With in Kalpeni lagoon however, Cheriyam Island has depth of about 2-3 m during low tide. Recruitment is very poor in both Kalpeni and Amini, probably due to the lack of suitable habitat below the surf zone. The existing population is old with extremely low recruitment, and giant clam *T. maxima* population seems to be at a critical state in this lagoon. This aspect demands further investigation.

As a consequence of the lower reef specialisation, lagoon sedimentation due to various means such as cyclones, dredging and changes in flow regimes can influence *T. maxima* recruitment and thereby, threaten the viability of its population.

10.2 Microhabitat
Role of Herbivory

Herbivory is one of the most visible and intense activity in coral reefs. Composition of herbivore greatly influences the algal community in a coral reef ecosystem (Birkeland, 1977; Bak & van Eys, 1975; Doty, 1959; Earle, 1972; Hiatt & Strusburg, 1960; Hughes *et al*, 1987; Lewis, 1986; Stephenson & Scarles, 1960; Bakus, 1966; Randall, 1961; Van Den Hock, 1969; Vine, 1974). In general algal biomass and micro algal abundance is low in highly grazed reef system. In such cases filamentous algae dominate the substrate along with encrusting algae[8]. Large scraping herbivores such as parrotfishes, surgeonfishes and sea urchins have great impact on algal community structure and play vital role in reef ecosystem.

High algal biomass can adversely affect coral recruitment (Birkeland, 1977). Algal assemblages are generally classified as turf, microalgae and crustose algae. An algal turf primarily consists of filamentous algae with 1-10 mm (Neuschul, 1967; Randall, 1967; Dahl, 1972; Carpenter, 1986; Lewis, 1986; Foster, 1987). Microalgae includes larger, more rigid and complex algal forms (Adey *et al*, 1977; Steneck, 1988). Crustose algae include encrusting, calcareous as well as non calcareous algae.

Herbivores are grouped according to their functional impact on algal communities. Deep grazing parrotfishes and urchins have greatest impact on algal assemblages (Bakus, 1966; Brock, 1979; Borowitzka, 1981; Steneck, 1988). Acanthurids, blennies and damselfishes are commonly called as denuding herbivores and can significantly reduce fleshy algal biomass (Lewis, 1985; Steneck, 1988). However, this group can not feed on crustose corallines (Steneck, 1983a, 1985). Larger acanthurids such as *Naso sp*. can however, feed on leathery microalgae. Heslinga and Watson (1985) reported various species of parrotfishes, surgeonfishes and rabbitfishes as main herbivores in open ocean nursery beds of giant clams.

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[8] Steneck, 1988

Beckvar (1981) suggested introduction of *Trochus niloticus* as algal grazer in controlling algal growth in giant clams hatcheries.

Despite the large diversity of herbivores, parrotfishes, acanthurids and sea urchins are by far the most abundant (Randall, 1961; Hay, 1981a; Hay, 1984). In shallow reefs (up to 10 m), these groups play important role of herbivore.

Role of herbivore in maintenance of habitat for *T. maxima* in Lakshadweep Archipelago

Series of observation were made on the role of herbivore in maintenance of *T. maxima* and *T. squamosa* habitat. Frequent browsing of algae on table tops of *P. lutea* is the most important requirement primarily for the recruits. The browsing episodes are counted only in Kavaratti and following species were found to play most important role in maintenance of top surface of *P. lutea*.

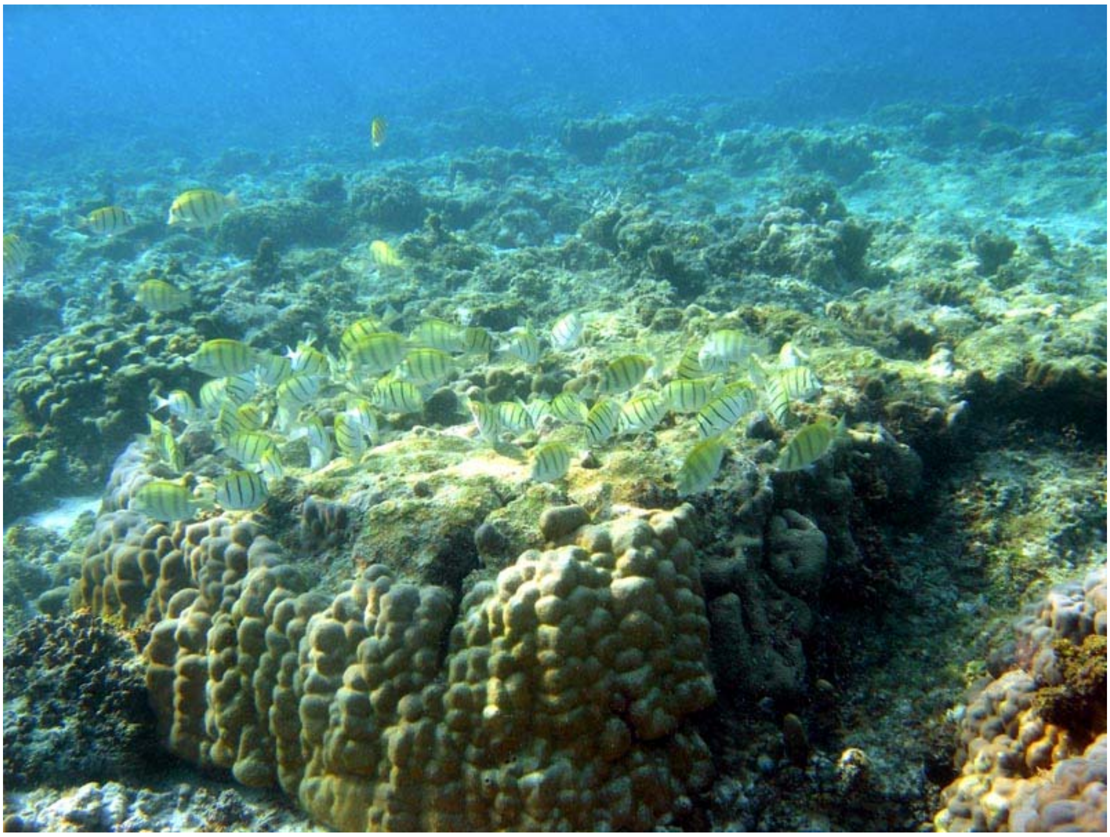
All important recruitment sites have complete overlap with active browsing episodes there by confirming its role in maintenance of microhabitat for *T. maxima.*

Table 10.2.1 Common herbivore species in Lakshadweep

Sr. No	Species	Image
1	Black Surgeonfish *Acanthurus gahhm*	
2	Striped Surgeonfish (*Acanthurus lineatus*)	
3	Convict Surgeonfish (*Acanthurus triostegus*)	

4	Powder-blue Surgeonfish (*Acanthurus leucosternon*)	

Convict Surgeonfish (*Acanthurus triostegus)* found to be the most important browser within lagoon remains active during the day time. They form huge shoals exceeding 50,000 individuals. They prefer *P. lutea* coral tops for browsing there by clearing these coral tops of all filamentous and other encrusting algae. This creates suitable habitat for young recruits of *T. maxima*. Black Surgeonfish *Acanthurus gahhm* and Striped Surgeonfish (*Acanthurus lineatus*) also are main browser within lagoon. However, the data is not sufficient to assess its role as herbivory for *T. maxima* recruitment. Besides this few species of juvenile parrotfishes were also use these tops for browsing. However, identification and estimations of the parrotfish species was not possible within existing time frame. Outer reef slopes are usually used by large congregations of multiple species such as Black Surgeonfish *Acanthurus gahhm*, Palelipped Surgeonfish (*Acanthurus leucocheilus*) and Powder-blue Surgeonfish (*Acanthurus leucosternon*). In present study we have not assessed the browsing activity on the outer reef as our studies were exclusively for lagoon population of *T. maxima*. However, the *T. maxima* population on outer reef is very small.



Convict Surgeonfish (*Acanthurus triostegus*) is the single most dominant browser inside lagoon waters. Thus, role of this species in maintaining microhabitat for new recruits is most crucial part of *T. maxima* life cycle.

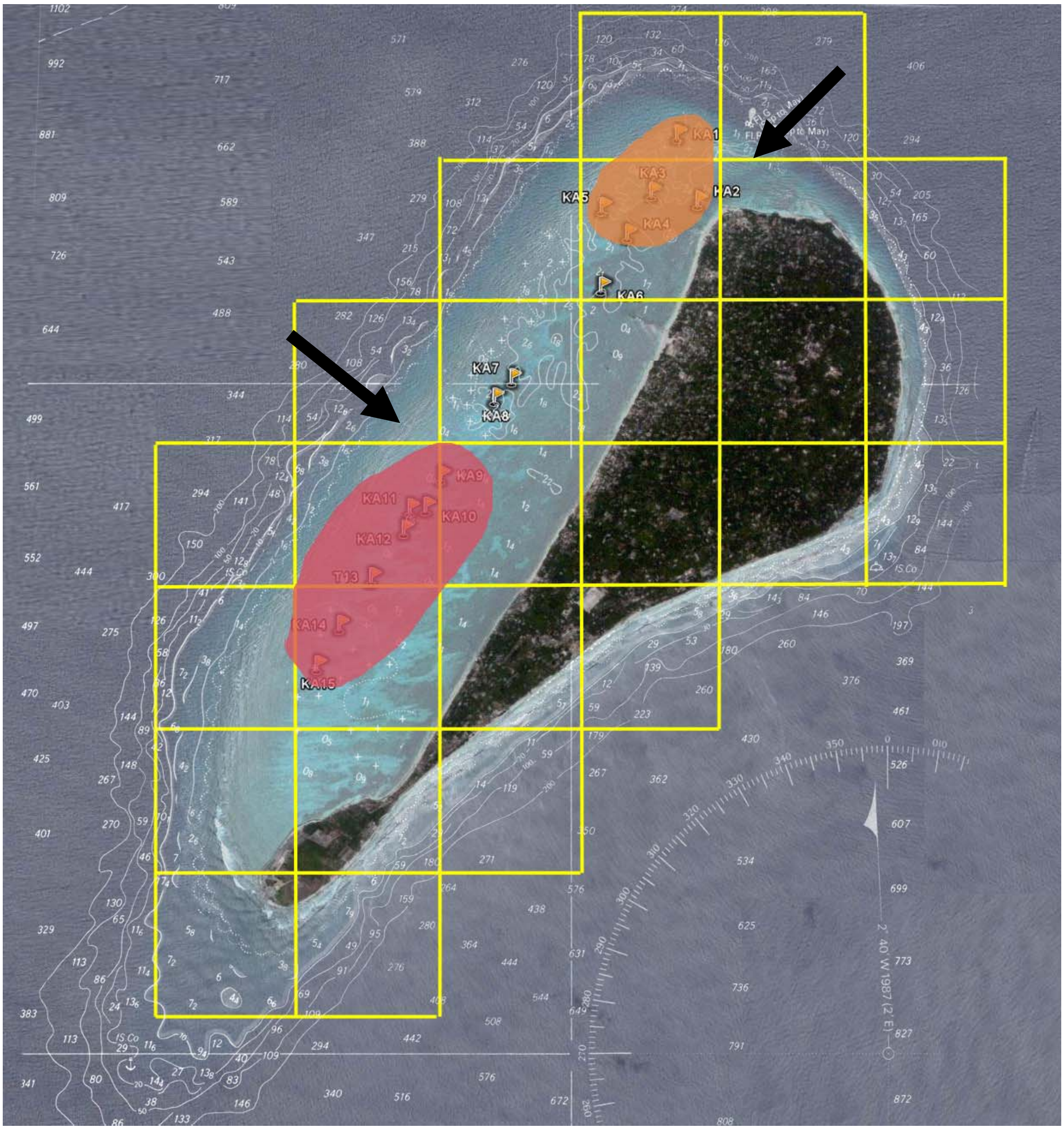
Table 10.2.2 *T. maxima* count at Kavaratti with juvenile and new recruits with browsing activity

Transect No.	*T. maxima* count	Juvenile (2005) and Recruitment 2006, 2007			Browsing activity
		2005	2006	2007	
1	7	2	3	0	+
2	10	3	1	1	+
3	20	1	0	1	+
4	19	0	4	3	+
5	11	1	0	1	-
6	12	2	0	0	-
7	11	3	0	0	+
8	6	0	0	NT	-
9	6	0	0	7	-
10	47	14	2	4	+++++
11	14	7	2	2	+++++
12	21	9	3	4	+++++
13	28	1	0	7	++++
14	11	2	0	0	+++
15	43	11	3	6	+++++

+ = low browsing activity
+++ = Medium browsing activity
++++ = High browsing activity
+++++ = Very high or intense browsing activity
- = No browsing activity observed
NT = Transect not located

Low browsing activity	Shoal size of *Acanthurus triostegus* less than 500 individuals
Medium browsing activity	Shoal size of *Acanthurus triostegus* is more than 500 but less than 1000 individuals
High browsing activity	Shoal size of *Acanthurus triostegus* is between 5000 to 10000 individuals
Very high or intense browsing activity	Shoal size of *Acanthurus triostegus* is above 10000 individuals

Map 10.2.1 Active Browsing Sites at Kavaratti



Transact 10-15 showed high to intense browsing activity. It clearly overlaps with healthy *T. maxima* population and recruitment. Transect 1 to 5 also showed medium to low browsing activity. Both the areas are close to the mouth or entrance of the lagoon (marked by arrows). Browsing episodes were always observed with incoming high tide. The active browsing sites have a complete overlap with recruitment sites. Thus, the role of herbivores in maintenance of microhabitat is essential for *T. maxima* recruitment. The browsing sites lie close to lagoon entrance there by suggesting the requirement of strong or medium currents for both the movement of browsing species as well as the recruitment of *T. maxima*.

Figure 10.2.1. Recruitment and adult densities of giant clam *T. maxima* across a gradient of browsing activity by herbivorous fishes in Kavaratti Island

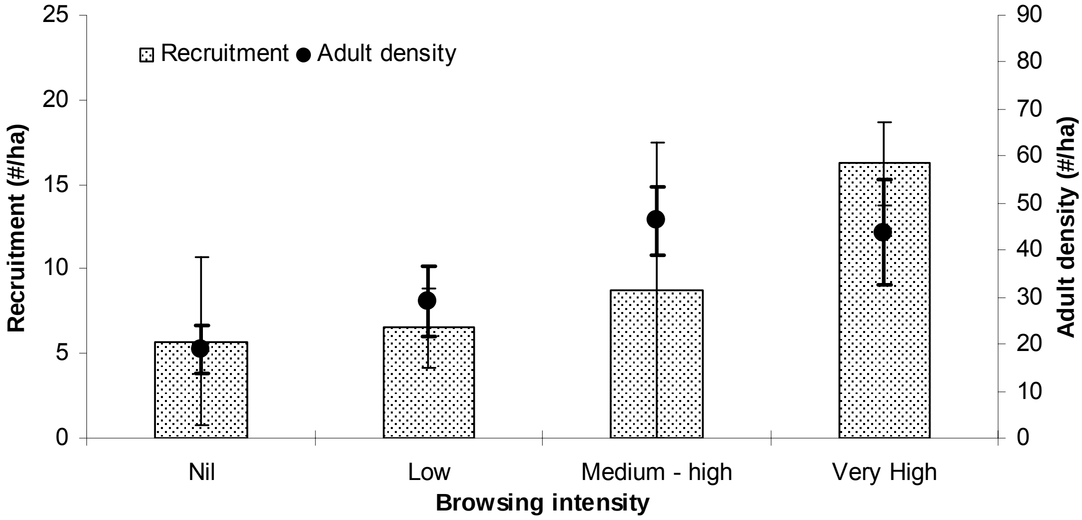


Table 10.1 Pearson's coefficient to test the bivariate correlation among the following variables

	Recruitment	Adult density	Browsing intensity
Recruitment		0.25 (0.19)	0.42 (0.02)
Adult density			0.42 (0.02)
Browsing intensity			

Assessing population of *Acanthurus triostegus*

Since *Acanthurus triostegus* is an important species for the microhabitat maintenance for *T. maxima*, studies are required to asses its population. This species is edible and locals consume it on regular basis. Fishing of *Acanthurus triostegus* is tuned to the incoming high tide inside lagoon. It is a shoal forming species and thus the fishing is mostly timed with incoming tide near lagoon mouths and thus a single net can pick up the entire shoal. Thus harvesting of this species is bound to have impact on its population. Therefore studies on its population dynamics are essential.

Conclusion

- Sites of intense browsing and recruitment of *T. maxima* showed total overlap.
- Both recruitment and intense browsing is seen near entrance or mouth of lagoon there by suggesting requirement of strong to medium currents of tides.
- Convict Surgeonfish (*Acanthurus triostegus*) is the single most dominant browser inside lagoon waters. Thus role of this species in maintaining microhabitat for new recruits is most crucial part of *T. maxima* life cycle.
- Detailed studies on population of *Acanthurus triostegus* are necessary.

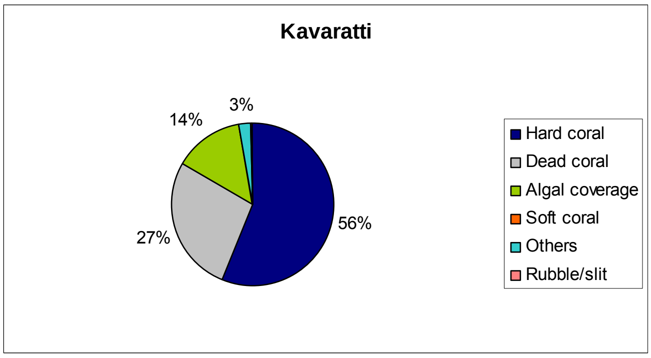
10.3 Benthos studies at Agatti and Kavaratti

To assess the benthic communities in the potential giant clam area, point intercept transect method was used. Transect was laid out along the substratum, data collected along transect as the number of 0.5 meter point intercepted by benthic component under the line. Data was collected on coral at genus level and live form levels. Table 10.3.1 shows the detailed live form classification method used for the surveys.

The data obtained for each island was used to look at abundance and composition of benthos in relation with giant clam population.

Benthos was grouped under 6 main categories: Hard corals, dead corals, total algae, soft corals other invertebrates and rubble. The observed benthic cover under transects were averaged for each island and are presented in Table 10.3.2. Figure 10.3.1 shows the percentage cover of each category at Kavaratti and Agatti.

Figure 10.3.1: Percentage coral cover of 6 major categories at Kavaratti and Agatti



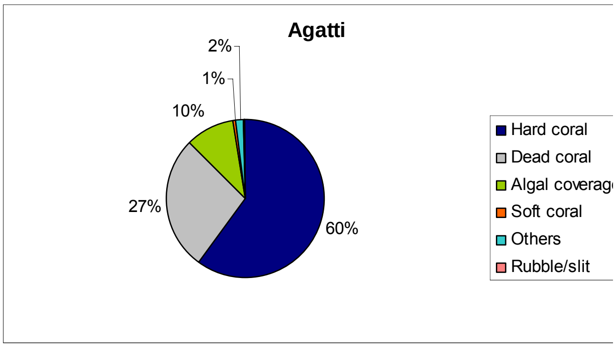


Figure 2 Coral fauna at Kavaratti and Agatti shows both tabular and branching *Acropora* sp. dominance. Highest coralline algal coverage was also recorded at Kavaratti (10.3%).

Acropora sp. dominated Agatti while as *Porites* sp. Dominated Kavaratti lagoon. This was followed by other major coral species from genus *Fungia, Monitpora, Pavona, Goniopora, Favities, Favia, Astreopora, Pocilliopora, Stylopora*, etc. Table 3 shows coral genus observed in survey areas of Kavaratti and Agatti.

Discussion and analysis

Total coral cover at Kavaratti and Agatti shows that the corals are healthy and has rapid growth**.** Agatti showed higher cover of branching *Acropora* (30%) than massive coral cover (12.2%), while Kavaratti shows higher cover of massive corals (14.2%) and less cover of branching Acropora (11.8%). Arthur (2000) reported 57.95% *Porites* sp. cover in Kavaratti. However, present study found massive and sub-massive forms to be up to 20%.

This clearly indicates that the substrate available for *T. maxima* as anchor i.e. massive corals *Porites lutea* and sub-massive corals is less than 20%. Thus any impact on it will have impacts on *T. maxima* populations as well.

Figure 10.3.2: Major benthic categories at Kavaratti and Agatti

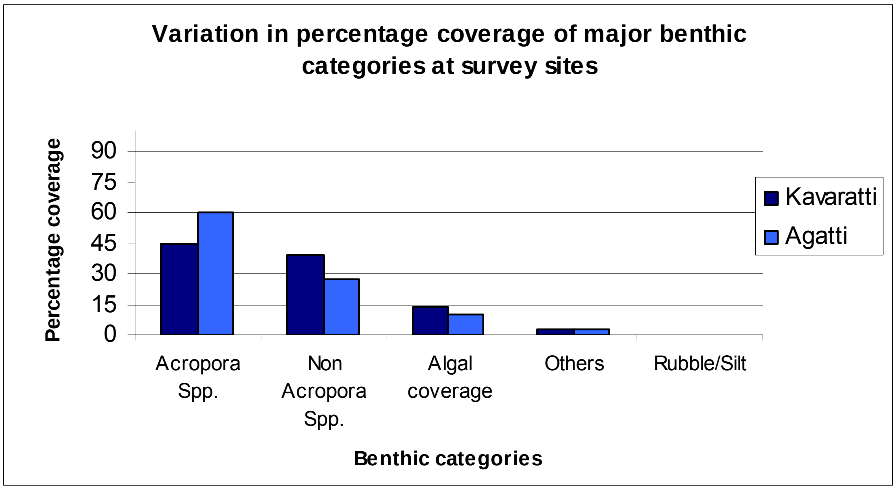


Table 10.3.1 Classification of benthic communities used for survey

Benthic forms	Codes
***Acropora* Spp.**	
Branching	ACB
Encrusting	ACE
Sub-massive	A SM
Digitate	ACD
Tabular	ACT
Non Acropora	
Branching	BR
Encrusting	EN
Foliose	FOL
Massive	MA
Submassive	SB
Mushroom	MUS
Heliopora	HELI
Milliepora	MILLI
Others	
Sponges	SPONGE
Soft corals	SC
Zoanthids	ZO
Algae	
Coralline algae	CA
Macro algae	MA
Turf algae	TRA
Algal assemblage	AA
Halimeda	HA
Rubble/silt	RU
Sand	SA
Rock	RCK
Dead Coral with Algae	DCA

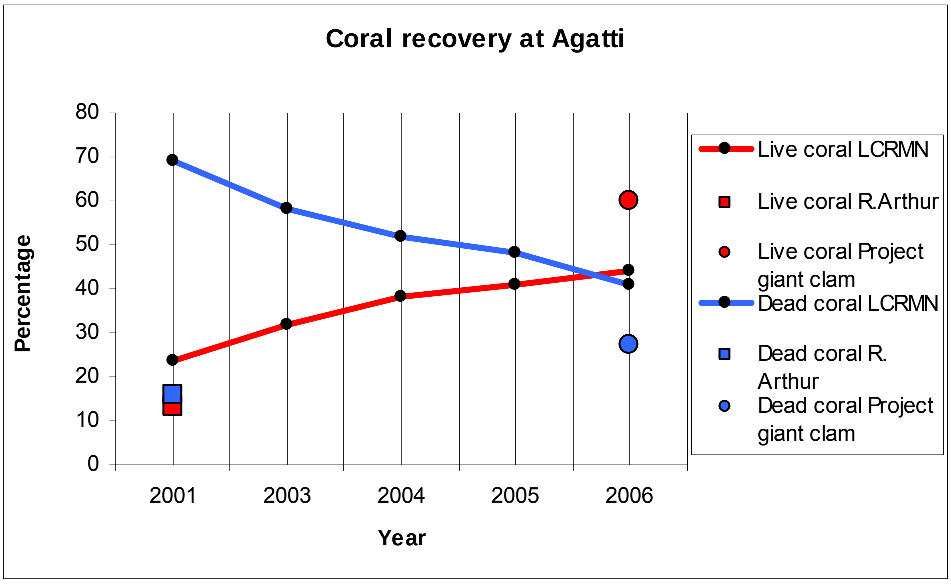
Table 10.3.2: Summary of observed benthic coverage (mean % cover) by site

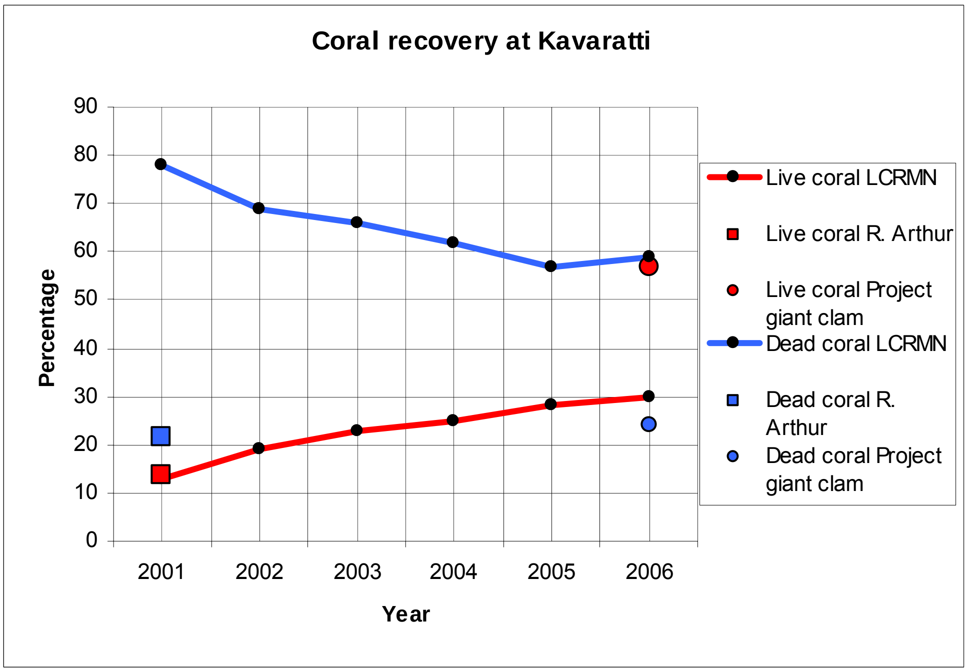
Site details and benthos	**Kavaratti**	**Agatti**
No of transects	19	10
Area surveyed (sq km)	0.038	0.02
Depth (m)	2- 4	2.5 - 4
***Acropora* Spp.**		
Branching	11.8	30
Encrusting	3	5.5
Submassive	8	6
Digitate	7.5	8
Tabular	14	10.5
Total *Acropora* Coverage	44.3	60
Non Acropora spp.		
Branching	2	2.5
Encrusting	16.6	10.3
Foliose	0.3	0.1
Massive	14.2	12.2
Submassive	4.2	0.2
Mushroom	1.5	0.4
Heliopora	0.2	1.2
Milliepora	0.1	0.5
Total Non Acropora Coverage	39.1	27.4
Total Coral Coverage	83.4	87.4
Others		
Sponges	1.3	0.6
Soft corals	0	0.5
Zoanthids	1.2	1.2
Total others	2.5	2.3
Algae		
Coralline algae	10.3	8.4
Macro algae	2	1.1
Turf algae	0.5	0.3
Algal assemblage	1	0.1
Halimeda	0.1	0.2
Total Algal Cover	13.9	10.1
Rubble/silt/sand	0.2	0.2

Table 10.3.3: Coral species observed at Kavaratti and Agatti

Genus	Kavaratti	Agatti
Acropora Branching	x	x
Acropora Tabular	x	x
Acropora Digitate	x	x
Acropora Encrusting	x	x
Acropora Submassive	x	x
Acanthastrea	x	x
Astreopora	x	x
Echinopohora	x	x
Favia	x	x
Favites	x	x
Fungia	x	x
Galaxea	x	x
Goniopora	x	x
Goniastrea	x	x
Heliopora	x	x
Lobophyllia	x	x
Miliepora		x
Montipora	x	x
Pavona	x	x
Platygyra	x	x
Porities	x	x
Pocillopora	x	x
Stylophora	x	x
Turbinaria	x	x

Reef recovery at Agatti and Kavaratti after 1998 El Niño





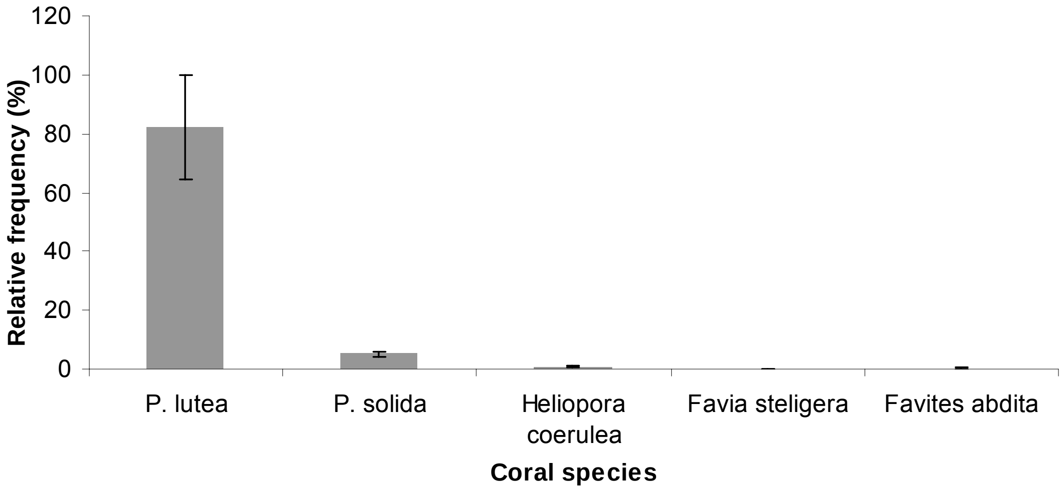
10.4 Habitat requirements of *T. maxima* in Lakshadweep archipelago

It is known that *T. maxima* prefer massive corals as main substrate for anchorage. It was however, not known which species of massive corals they prefer. To assess the substrate preference, a detailed account of corals on which *T. maxima* anchor was maintained for each island under study. Data on the substrate type, placement, associated coral species and height of *T. maxima* from sea floor were collected along 165, 100mX20m transects from 24 islands of Lakshadweep archipelago in 2005.

Substrate preference by *T. maxima*

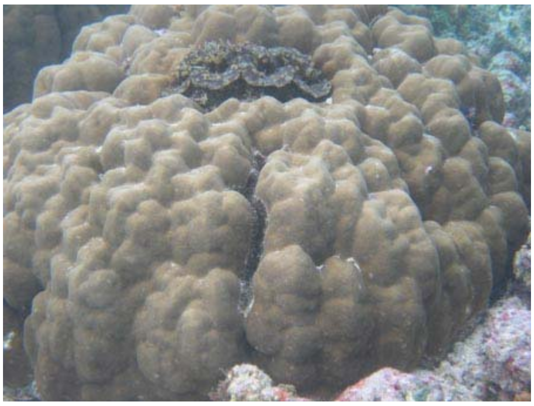
Frequencies of coral species to which *T. maxima* were attached, were calculated relative to the total *T. maxima* counts across 24 islands (within 11 lagoons) and averaged for entire Lakshadweep archipelago. It revealed an exclusive use of *Porites lutea* (>80% relative use) followed by *P. solida* (figure 11.4.1). Therefore, it will be imperative to assess the threats to *P. lutea* for the management and conservation of *T. maxima*.

Figure 10.4.1. Coral species preference of giant clam *T. maxima* expressed as relative frequency (%) in Lakshadweep archipelago during 2005-07



Error bars are Standard errors

Besides *P. lutea* and *P. solida*, *Hydrophora microconos, Favia steligera, Favites abdita* and *Heliopora coerulea* are also used for anchorage. However, *H. coerulea* being fragile could not hold adult size clams. Thus in Minicoy, which is dominated by *H. coerulea* species, *T. maxima* density is very poor.



Porites lutea is the most preferred coral species used by *T. maxima* for anchorage

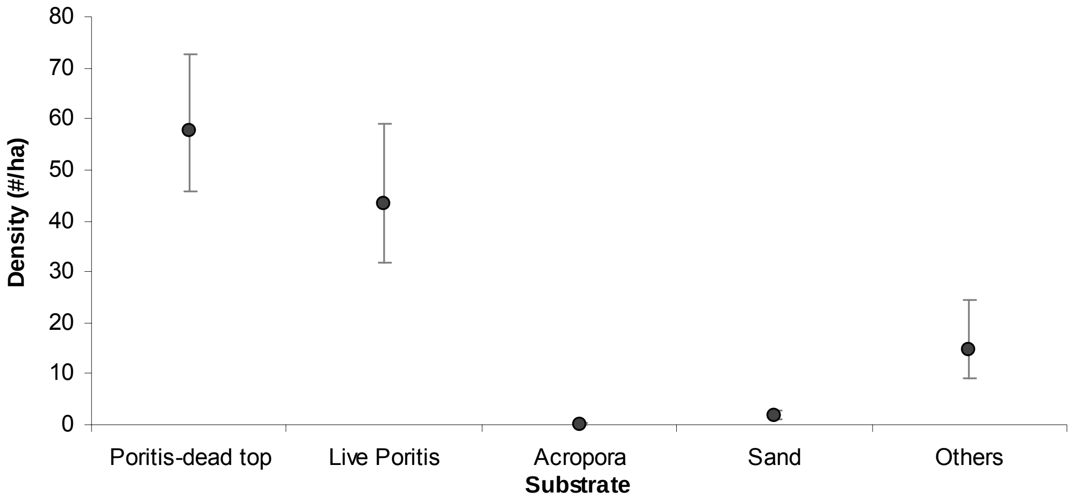
Porites solida is second in preference after *P. lutea* as anchor substrate for *T. maxima*

Heliapora corulea is not a suitable substrate for *T. maxima*

Uncommon association of *T. maxima* with *Goniopora stokesi*

T. maxima densities in different substrate types (as discussed above) were estimated by the conventional distance sampling analysis with default settings of the software DISTANCE 5.0[9]. Densities were distinctly high on the massive *Porites* substrate with dead top followed by the live ones. Other substrates were rarely occupied (figure 10.4.1). Most of the individuals were found on the flat coral tops, fewer on the coral walls and the embedded ones were rare (figure 10.4.2).

Figure 10.4.2. Giant clam *T. maxima* densities on different substrates in Lakshadweep Archipelago during 2005-07



Error bars are 95% Confidence intervals

11.5 Anchorage site selection

The detailed account of anchorage provided vital insights to the ecology of *T. maxima*. To understand the anchorage of juveniles through site selection, detailed notes of each clam along transects were maintained.

T. maxima are boring clams. Thus, settlement of larvae on appropriate substrate is important for its successful growth. Thus, the site selection for anchorage is an important aspect of life cycle of *T. maxima*. Based on the observations, two types of anchorage and three types of placement were observed as follows:-

Attachment
1. Flat: Embedded on *Porites* tops (also called massive coral tops)
2. Wall: Partially embedded in *Porites* walls

[9] http://www.ruwpa.st-and.ac.uk/distance/

1. *Porites* flat: Dead coral flat with live coral wall

2. *Porites* flat: live coral flat with live coral wall

Placement

3. Embedded: Fully embedded inside *Porites*
4. Sand/floor: Present on lagoon floor
5. Detached: Detached from substrate

Flat: Embedded on dead *Porites lutea* tops with partial live coral cover

Wall: Partially embedded in *Porites solida*

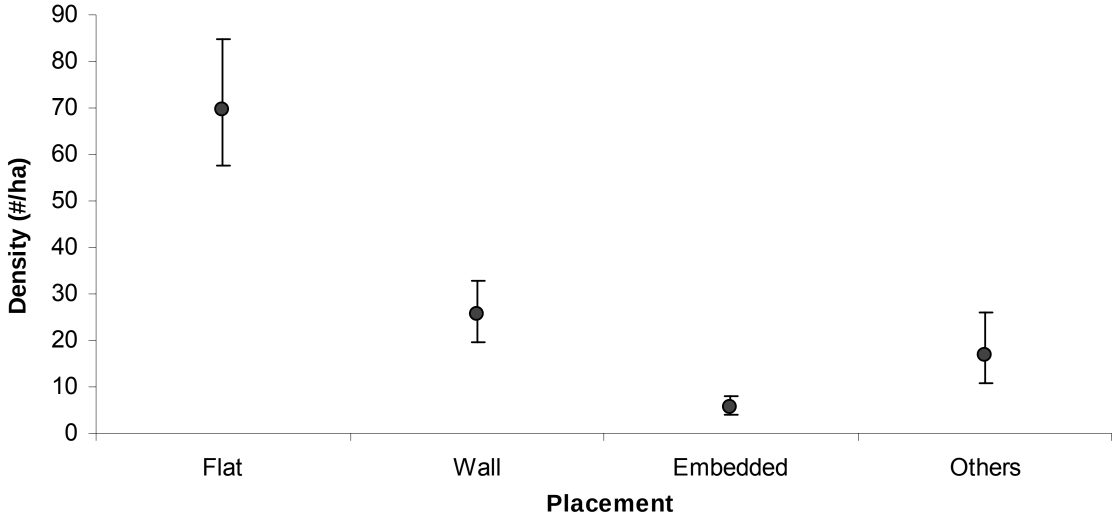
Embedded: Fully embedded in *Porites lutea*

Sand floor: loosely anchored in sand bed

Detached: dislodged from substrate and lying on sand floor

T. maxima densities in different placement types (as discussed above) were estimated by the conventional distance sampling analysis with default settings of the software DISTANCE 5.0[10].

Figure 10.5.1. Giant clam *T. maxima* densities in different attachment and placement types in Lakshadweep Archipelago during 2005-07



Error bars are 95% Confidence intervals

The data clearly indicates that *T. maxima* prefer the flat tops and walls of *Porites* for placement on substrate across islands. Among these two dominant microhabitats, *Porites* flats are the most favoured site for the recruitment of juveniles (as discussed in the later chapter). The *Porites* flat is usually of two types, live with abundant live corallites and dead with algal growth.

Basker (1991) however reported that giant clams are found in areas dominated by *Acropora* sp in Maldives. He also reported *T. maxima* boring massive corals of *Porites sp*. Similar trend was seen however, only in Agatti where *Acropora* is dominant coral form among all islands in Lakshadweep.

10.6 Habitat Use Vs Availability

Agatti, one of the well studied lagoons was selected for the habitat selection studies of *T. maxima*. Coral and other substrate counts at 0.5 m interval along 15, 100m transects in Agatti were used to estimate the proportion availability of various coral and non-coral substrates (figure 10.6.1). Proportional use of various substrates by the giant clam *T. maxima* in Agatti was compared against their proportional availability by the Ivlev's selectivity index[11] (figure 10.6.2). It was found that *Porites* which is essential for the *T. maxima* attachment is present in <10% of the potential lagoon area in Agatti.

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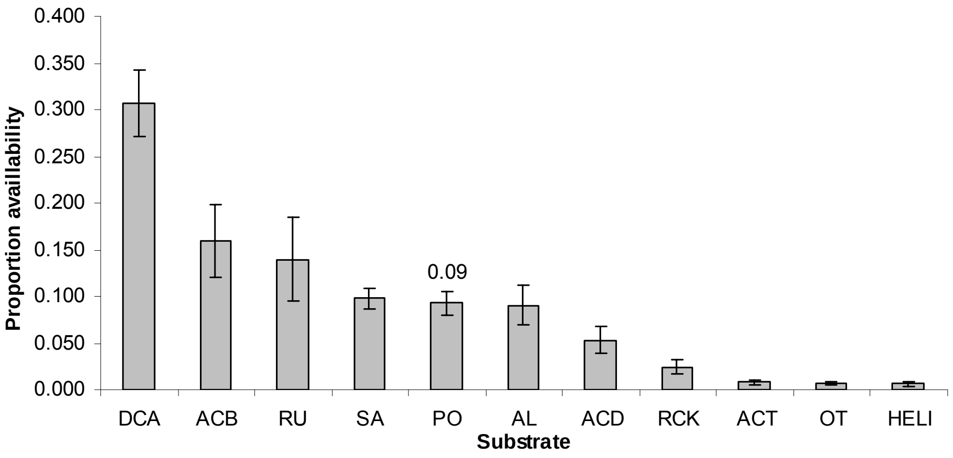
[10] http://www.ruwpa.st-and.ac.uk/distance/
[11] Ivlev, V. S. 1961. Experimental ecology of the feeding of fishes. Yale Univ. Press, New Haven. 302 p.

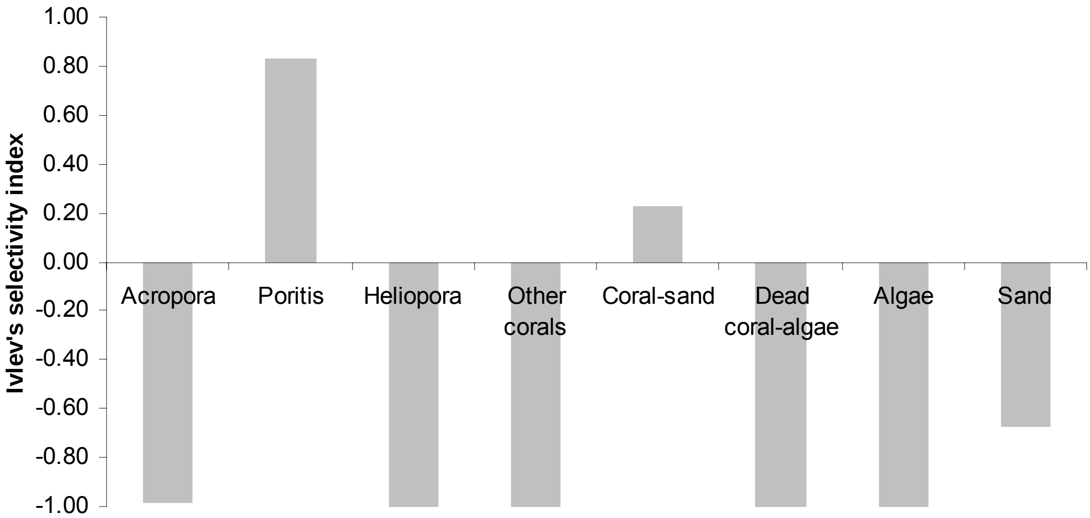
Figure 10.6.1. Availability of different substrates (expressed in relative frequency) for the attachment of giant clam *T. maxima* in Agatti island during 2005-07



Error bars are Standard errors

DCA: Dead coral – algae, ACB: *Acropora* branched, ACD: *Acropora* digitate, ACT: *Acropora* tubular, Po: *Porites*, Heli: *Heliopora*, Al: Algae, SA: Sand, RU: Rubble, RCK: Rock, OT: Others.

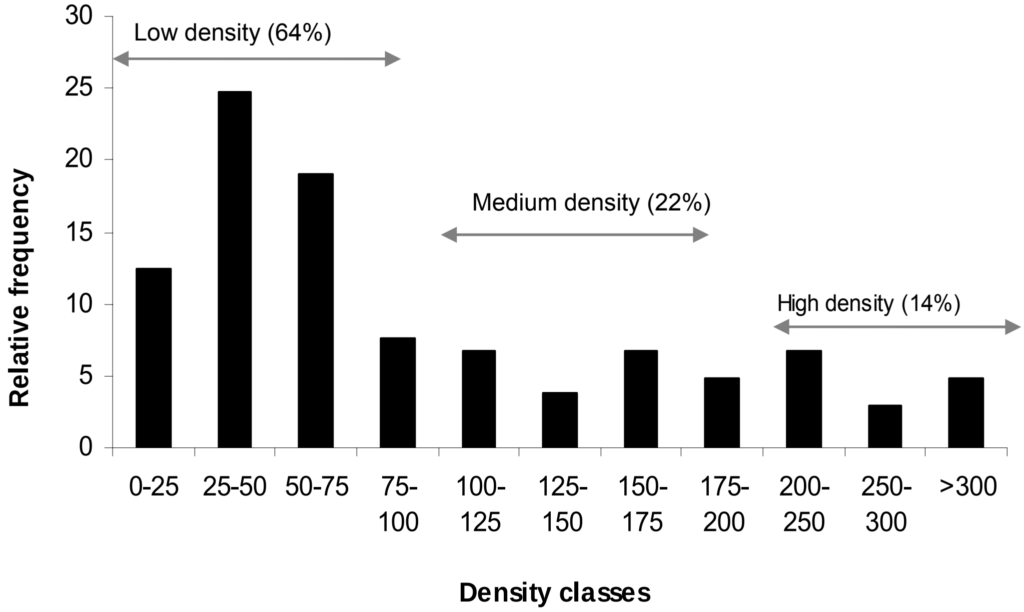
Figure 10.6.2. Substrate use versus availability of giant clam *T. maxima* estimated through Ivlev's selectivity index[12] in Agatti Island during 2005-07



Sample (transect) densities of giant clam *T. maxima* in 2005 across 165 transects spread over 12 islands of Lakshadweep were classified into discrete density classes (0-25/ha, 25-50/ha… 250-300/ha, >300/ha) and relative frequency of each density class was calculated. 64% of the samples fell into the low density class (90-100/ha), 22% in the medium density (100-200/ha) and only 14% in the high density class (>300/ha), indicating that bulk of the habitat available for the species is sub-optimal, and optimal habitats are scarce.

[12] Ivlev, V. S. 1961. Experimental ecology of the feeding of fishes. Yale Univ. Press, New Haven. 302 p.

Figure 10.6.3. Relative frequencies of different giant clam *T. maxima* density classes in Lakshadweep archipelago during 2005-2007



Conclusion: Giant clam *T. maxima* prefers the dead flat tops (with live coral on all sides) and to lesser extent, the walls of the coral *Porites lutea* within a narrow range of water depth (0.2 - 0.8m) in the lagoon. Such specific habitat requirements leave very little potential space (~ 3 % crude estimation) for the species in the lagoon.

10.7 Anchorage profile of *T. maxima*

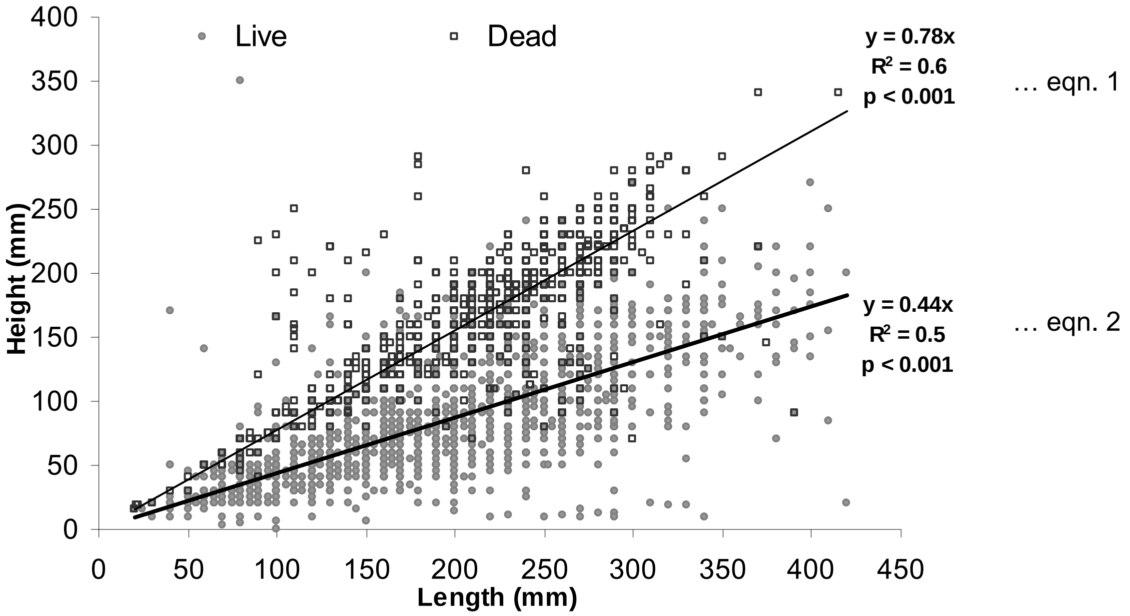
T. maxima are a boring species. After successful settlement of larvae it grows as juveniles which then bore deep inside the substrate which is mostly *P. lutea*. As the clam grows, so do the coral and thus the clams get deeply embedded inside the coral, primarily due to the growth of coral around the clams. To assess the anchorage of *T. maxima* in *P. lutea* and other substrate and its role in *T. maxima* population and ecology was studied in detail.

For this purpose, the data on height and length of live clams was collected on various transects. Besides this, height and length of 1000 dead *T. maxima* valves was measured. The dead *T. maxima* valves are commonly available in the lagoon. The data was then analyzed to assess the embedment of *T. maxima* in *P. lutea*. This data was then compared with recruitment and mortality profile of *T. maxima*.

Height of *T. maxima*, coral anchorage and mortality in *T. maxima* population

Height of *T. maxima* was linearly related with their length. Length to height relations of dead (eqn. 1) and live (eqn. 2) clams followed different slopes and the difference between the two lines of best fit resulted from the growth of the coral around the clam (figure 10.7.1). The portion of clam embedded in the coral or the anchorage (Z) at any size/length class (X) was calculated by subtracting eqn. 2 from eqn. 1 to obtain: Z = 0.34X (eqn. 3). Considering length of the giant clam as a surrogate of its age, anchorage was found to increase in a constant proportion with age.

Figure 10.7.1. Height - length relationship of dead and live *T. maxima* in Lakshwadeep Archipelago

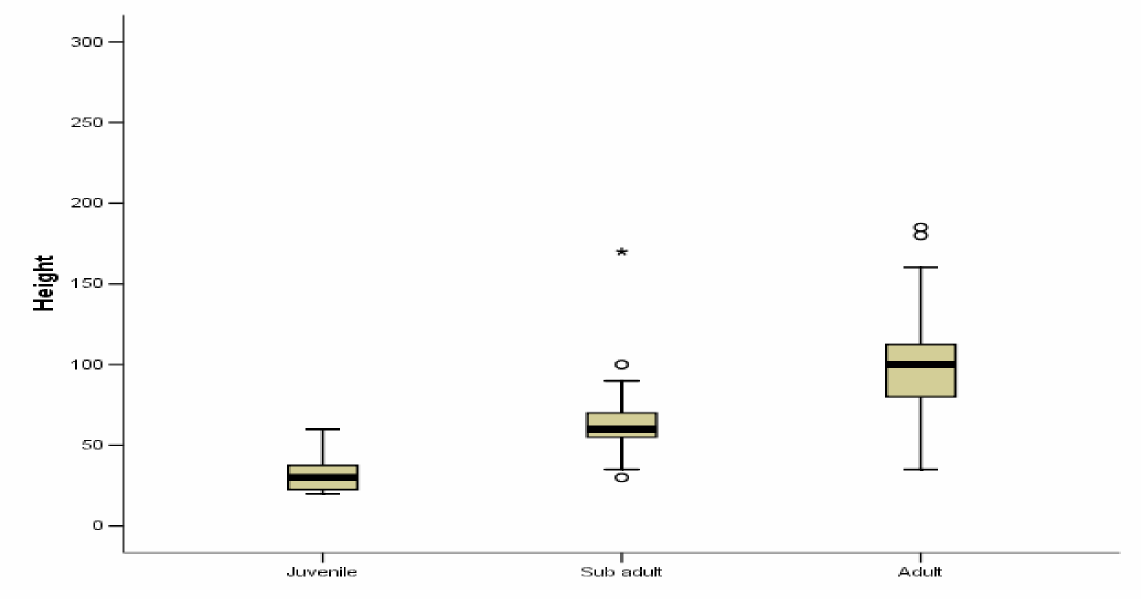


As expected from the linear relation between length and height of clams, average clam height increased with age but with diminishing precision of estimate (figure 10.7.2). Adult clam heights ranged from 0 to 350mm with an average of 107mm (SD = 44.4, n = 904). The frequency distribution of adult clam heights was not normal (Konglomorov –

Smirnov Z = 2.67, p < 0.001) and was skewed towards lower height classes (figure 10.7.3). This revealed that clams were varying considerably in coral anchorage and anchorage might have some significance in clam survival.

Observed heights of individual *T. maxima* were subtracted from the predicted heights of corresponding individuals calculated from the length – height relationship of dead clams (eqn. 1), to obtain the actual coral anchorage. Expected coral anchorage was predicted from the length – anchorage relation (eqn. 3) and an anchorage index (AI) was developed by dividing the actual anchorage by the expected anchorage. Frequency distribution of population and mortality rates were tested across a gradient of anchorage index and no definite pattern could be revealed (figure 10.7.4). Mortality rates were not uniform across the gradient of anchorage index (Konglomorov – Smirnov Z = 1.63, $p < 0.01$) and grossly followed the population distribution curve ($X^2 = 6.3$, p = 0.99, df = 22). However, there were unexpected spikes of mortality rates at the extremes of the anchorage index gradient.

Figure 10.7.2. Height differences among *T. maxima* of different age classes in Lakshwadeep Archipelago



Error bars are 95% Confidence intervals

Figure 10.7.3. Frequency distribution of height in adult *T. maxima* population of Lakshwadeep Archipelago

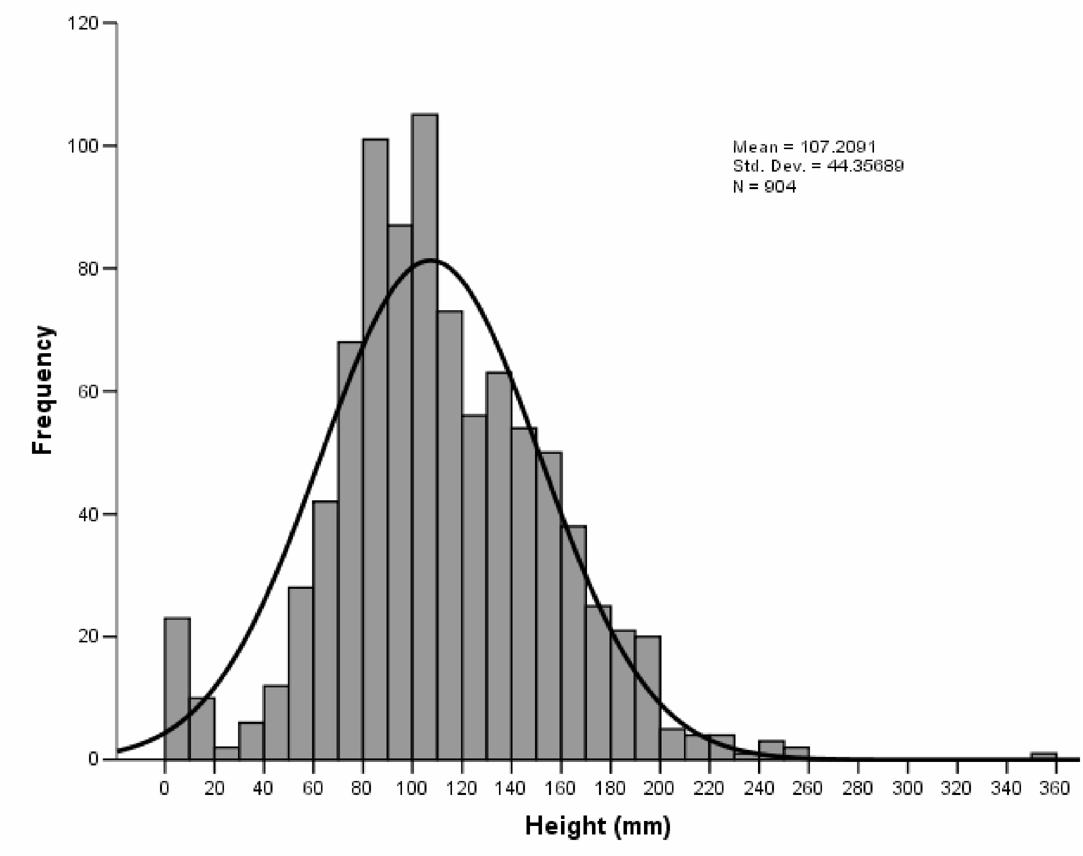
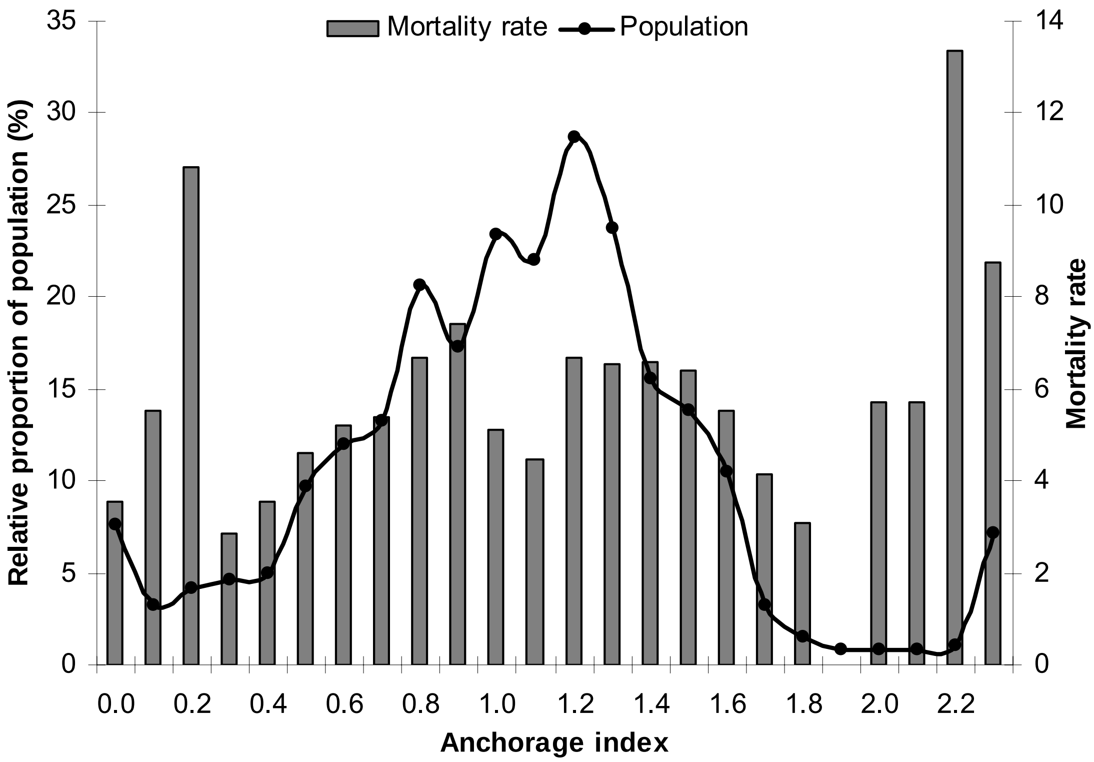


Figure 10.7.4. Mortality rates and population distribution of *T. maxima* across a gradient of coral anchorage index



Conclusion: The data clearly reveal that the anchorage though plays significant role in *T. maxima* ecology, it has a weak influence on mortality. The data clearly shows that *T. maxima* prefer live *P. lutea* with dead coral tops for anchorage. This part of the coral has to face severe wave action especially in monsoon. Thus *T. maxima* growing on these coral tops are always vulnerable for high wave surge. Thus the deeper embedment helps *T. maxima* to hold its substrate even in high wave surge. Rate of coral growth is an important factor behind the survival of *T. maxima*.

11. Population Dynamics of *T. maxima*

Quantification of population parameters like mortality and recruitment, and monitoring of their dynamics are imperative to the understanding of the population ecology of a species and its conservation. Population dynamics of a species would depend on the intrinsic growth rate which would vary with the stochasticity of the environment.

11.1 Density

Planes *et al* (1993) observed that on barrier reef, there is a close relationship between live coral cover and clam density. In contrast clam density was poor on fringing reef even with good coral cover. This is primarily due to easy access of foot by people to fringing reefs which lie adjacent to land mass. He also observed low density of adult *T. maxima* along with low mean size (75 mm) on fringing reefs as compared to 89 mm on barrier reef.

Basker (1991) studies giant clam densities in Maldives. He observed density of *T. maxima* in fished water as 29.9 clams/ha while as 39.6 clams/ha in unfished waters (Raa atoll). The Shaviyani and Lhaviyani reefs showed density of *T. maxima* varying between 2.8 to 171.9 clams/ha.

T. squamosa densities were much lower with 3.4 clams/ha and 10.6 clams/ha in fished and unfished waters respectively (Raa atoll). However, this varies significantly among various islands. The Shaviyani and Lhaviyani reefs on other hand showed density of *T. squamosa* varying from 2.8 to 65.6 clams/ha.

Richard (1977) reported densities of *T. maxima* from Tuamotu Atoll, French Polynesia up to 60,000 clams/ha. Munro (1986) reported 100 *T. maxima*/ha from Abiang Atoll (Kiribati). Braley (1988) reported 63-101 *T. maxima*/ha from Tuvalu. Salvat (1967, 1971, 1972) estimated about 11 million *T. maxima* in Reao Atoll with 40,000 clams/ ha. Preston *et al* (1995) reported *T. maxima* density at Palmerston Atoll of Cook Island as 2900 clams/ha. Green and Craig (1999) reported 5000 *T. maxima/* ha in Rose Atoll in Samoa. Richard (1982) reported 4.6 clams/m^2 from Moorea Island. Kinch (2002) reported density of 17.9 clams/ha from Milne Bay in Papua New Guinea. Gilbert *et al* (2005) reported 544 *T. maxima*/m^{-2} in Tatakoto lagoon of French Polynesia. Andrefouet *et al* (2005b) reported 23.6 million *T. maxima* in 4.05 sq. km Fangatau atoll of French Polynesia. Gilbert *et al* (2006) reported 88.3 and 47.5 million *T. maxima* in Tatakoto (11.46 sq. km) and Tubuai (16.3 sq. km) lagoons of French Polynesia. Fangatau and Tatakoto are the world's highest density localities for *T. maxima*.

Hammer and Jones (1976) reported over 100 *T. crocea* /m^2 at Great Barrier Reef.

T. squamosa densities from these areas were very low and were 0.68 and 1.4 clams/ha from Tuvulu and Tokelau respectively (Braley, 1988; Braley, 1989).

Motoda (1938b) reported very low recruitment and juvenile density of *T. gigas* despite abundant adult population in Palau.

Size distribution of *T. maxima* as reported by Asano, 1937; Motada, 1938b; Hester and Jones, 1974 and McMichael, 1974 indicates that recruitment of juvenile is either erratic or poor. This also suggests the high mortality at larval or post metamorphic stage.

Richard (1977) reported density of *T. maxima* in Takapoto lagoon of French Polynesia which stands to 1440 clams/ha.

***T. maxima* populations in Takapoto lagoon over time (as reported by Andrefouet *et al*, 2005b)**

Year	Author	Population
1977	Richard, 1982	9 million
1986	Richard, 1989	6.9 million
1993	Richard and Duval, 1993	3.7 million
1998	Adessi, 1999	0.59 million
2001	Laurent, 2001	0.63 million

The above table clearly indicate the impact of El Niño Southern Oscillation of *T. maxima* population in this lagoon.

Density estimation of *T. maxima* in Lakshadweep Archipelago, 2005-2006

Such density of adult *T. maxima* is rare sight in Lakshadweep

Density estimation of giant clams in Lakshadweep archipelago, 2005-2007

Data on population parameters were collected from 100m x 20m belt transects from 24 islands (within 11 lagoons) in 2005, 22 islands (within 11 lagoons) in 2006 and 4 islands (within 3 lagoons) in 2007. Sample (transect wise) densities obtained in 2005 were randomized and adequacy of sample size for the correct estimation of giant clam *T. maxima* density in Lakshadweep was estimated post hoc from stagnation of the mean density curve (figure 11.1.1 & table 11.1.1). Sampling efforts in 2005 and 2006 were more than the minimum required.

Figure 11.1.1 Determination of sample size adequacy in estimating density of giant clam *T. maxima* population in Lakshadweep Archipelago

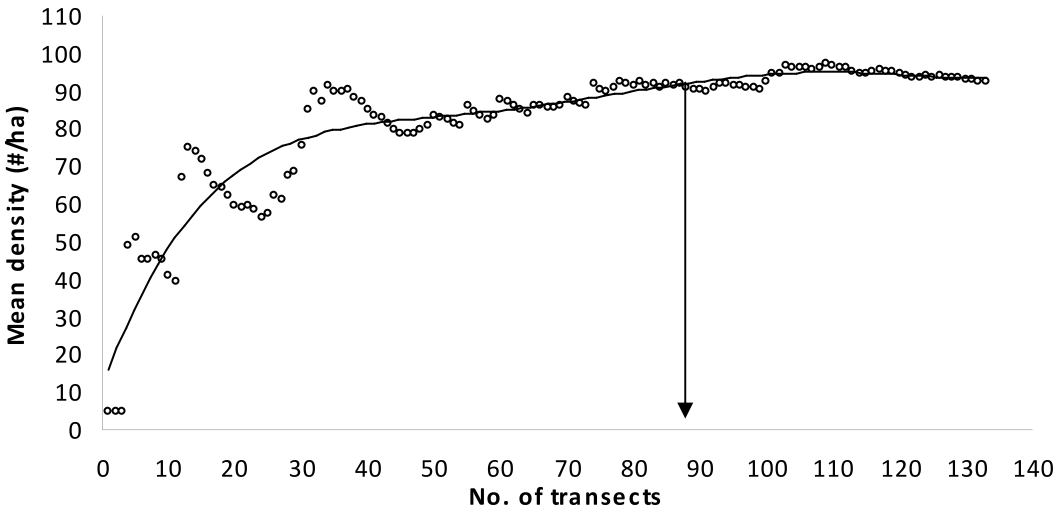


Table 11.1.1 Sampling efforts for population estimation of giant clam *T. maxima* in Lakshadweep Archipelago

Island	**Potential area (ha)**	**2005**	**2006**	**2007**
Agatti	525	20	20	19
Amini	150	8	7	
Bangaram & Tinnakara	1388	18	18	17
Bitra	1369	18	18	
Chetlat	48	10	10	
Kadmat	1125	12	11	
Kalpeni	768	21	21	
Kavaratti	149	15	15	14
Kiltan	53	10		
Minicoy	918	19		
Suheli	2369	14	14	
Lakshadweep		**165**	**134**	**50**

Although belt transect count was selected as the sampling method, it was realized that under-water visibility which might depend on weather conditions, coral complexity and physical conditions of the lagoon, water depth, the observer(s), and even the size of the clam would impair the assumption of complete detection. To arrive at robust density estimation, detection probabilities were incorporated in the analysis assuming transects to be open-width and truncating all observations at perpendicular distance of >10m on either side. Density was thereafter estimated by the software DISTANCE 5.0[13]. Transect data was structured as islands and years.

In the first step, giant clam *T. maxima* density for entire Lakshadweep was estimated by the default settings of the conventional distance sampling engine for the year 2005 and 2006. Extrapolation of global density was not done for the year 2007 due to paucity of sampling efforts. Density estimates were found to be 141.2/ha (n = 2748, 95% CL 118.17 - 168.74) in 2005 and 122.7/ha (n = 1948, 95% CL 103.60 - 145.37) in 2006. Detection probability and effective strip width were 0.59 (0.55 - 0.64) and 5.9m

[13] http://www.ruwpa.st-and.ac.uk/distance/

respectively in 2005, and 0.69 (0.67 - 0.72) and 6.9m respectively in 2006 (table 11.1.2 & figure 11.1.1).

With the assumption that factors affecting visibility in a lagoon would remain unchanged through successive sampling years, detection probability of giant clam *T. maxima* in each island/lagoon was pooled over the study years during 2005-2007, and island wise density for each year was estimated through post stratification. Such an adjustment provided adequate number of sightings (60-80) for reliable density estimates in case of all the islands except Amini. In the case of Amini, detection probability was pooled across all islands and density was estimated by post stratification (table 11.1.3). Age class was used as factor covariate in the multicovariate distance sampling analysis using the half-normal detection function model with cosine and polynomial series expansions. Models were selected on the basis of minimum Akaike Information Criteria.

Lastly, to estimate separate densities of juvenile, sub-adult and adults in each island/lagoon, age classes were selected as different layers; detection probability was estimated globally over the study years, and density estimation was post stratified for each year. Half-normal and uniform models with cosine and polynomial series expansions were used in the conventional distance sampling analysis and model selection was based on the minimum Akaike Information Criteria. Adjustments were made in the cases where number of sightings was unreliably low, and these included pooling of detection probability across islands or age classes (table 11.1.4).

Table 11.1.2. Model information & findings of distance sampling analysis of giant clam *T. maxima* population in Lakshadweep Archipelago, 2005-06

Year	Parameter	Estimate	%CV	Df	95% CI	
2005	f(0)	0.169	3.8	2744	0.157	0.183
	P	0.589			0.547	0.635
	ESW	5.897			5.47	6.35
	AIC	12317				
2006	f(0)	0.144	1.86	2276	0.139	0.149
	P	0.692			0.667	0.718
	ESW	6.92			6.67	7.18
	AIC	10205				

Figure 11.1.2. Detection probability curves of giant clam *T. maxima* population in Lakshadweep Archipelago for the years 2005 & 2006

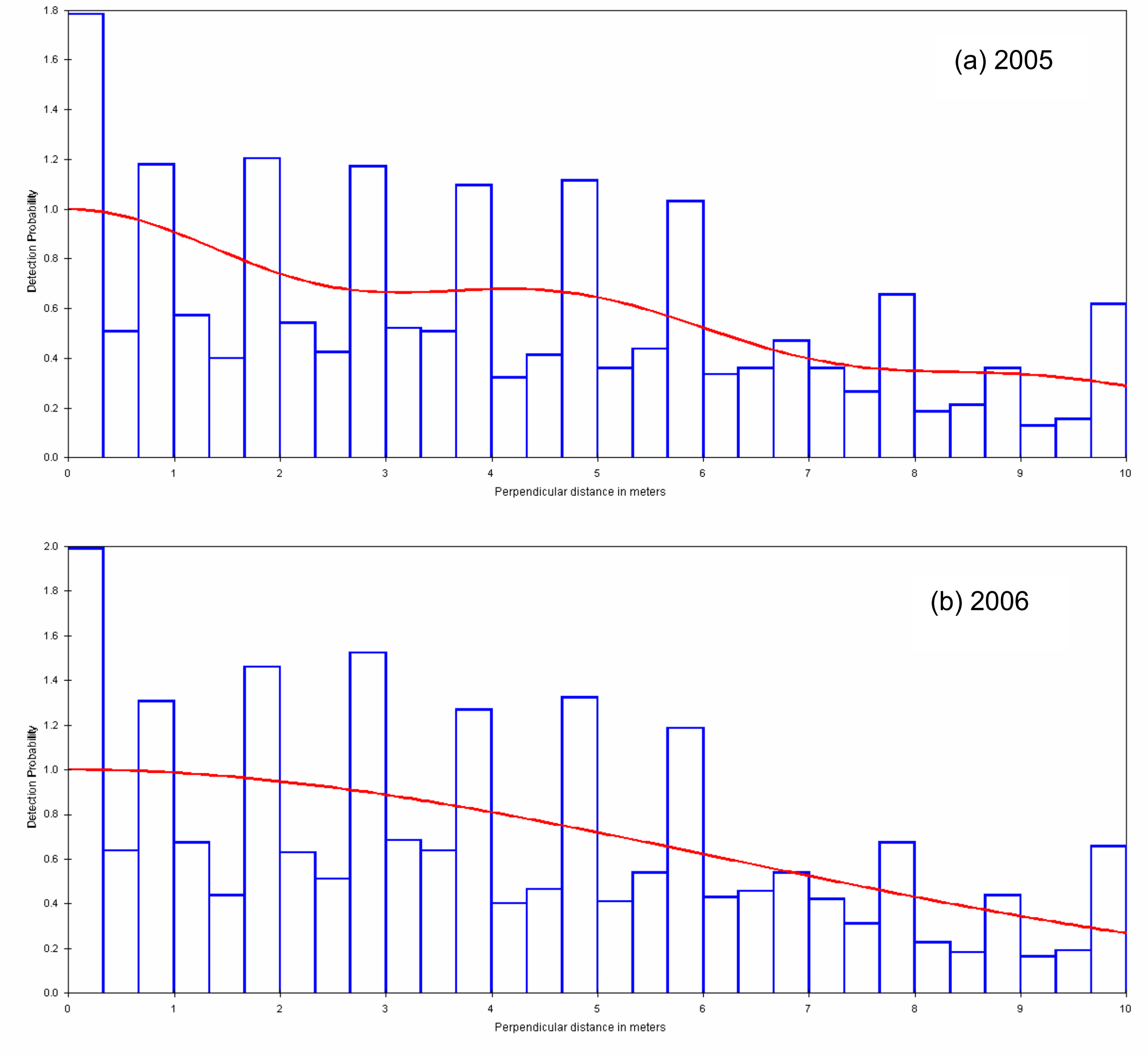


Table 11.1.3. Model information, detection probability and density estimates (#/ha) of giant clam *T. maxima* population in different islands of Lakshadweep Archipelago during 2005-2007

Island	Year	Model	p	**Estimate**	CV	LCL	UCL	n
Agatti	2005	Half-normal/Cosine	0.686	**227.84**	16.30	162.40	319.65	625
	2006			**187.01**	16.35	133.15	262.66	513
	2007			**188.42**	17.49	130.89	271.22	491
Amini	2005	Half-normal/Polynomial	0.62983	**20.84**	53.95	6.32	68.72	21
	2006	Half-normal/Polynomial	0.62733	**13.66**	60.80	3.47	53.74	12
Bangaram	2005	Half-normal/Cosine	0.83342	**137.14**	21.53	83.03	226.52	180
	2006			**132.57**	21.61	80.12	219.36	174
	2007			**132.57**	21.83	79.71	220.50	174
Bitra	2005	Half-normal/Cosine	0.62841	**198.47**	23.28	122.31	322.06	449
	2006			**190.52**	22.30	119.76	303.08	431
Chetlat	2005	Half-normal/Cosine	0.62833	**179.84**	34.52	84.34	383.50	226
	2006			**172.68**	35.01	80.16	372.00	217
Kadmat	2005	Half-normal/Cosine	0.41923	**35.78**	26.55	20.94	61.14	36
	2006			**29.27**	25.89	17.34	49.43	27
Kalpeni	2005	Half-normal/Polynomial	0.62733	**130.42**	16.75	92.34	184.21	345
	2006	Half-normal/Polynomial	0.37552	**124.87**	17.14	87.77	177.65	329
Kavaratti	2005	Half-normal/Cosine	0.81246	**105.44**	19.39	69.88	159.10	257
	2006			**97.65**	21.52	61.91	154.02	238
	2007			**98.47**	20.43	63.66	152.30	224
Kiltan	2005	Half-normal/Cosine	0.66	**76.20**	40.49	34.05	170.54	170.54
Minicoy	2005	Half-normal/Cosine	0.6591	**62.29**	28.61	34.63	112.02	156
Suheli	2005	Half-normal/Cosine	0.43004	**148.66**	22.23	92.80	238.15	179
	2006			**148.66**	22.08	93.09	237.39	179
Tinakkara	2005	Half-normal/Cosine	0.796	**109.35**	15.83	76.78	155.74	174
	2006			**99.30**	16.36	68.90	143.11	158
	2007			**93.57**	18.00	62.13	140.93	134

Table 11.1.4. Model information, detection probability and density estimates (#/ha) of different age classes of *T. maxima* population across islands of Lakshadweep during 2005-2007

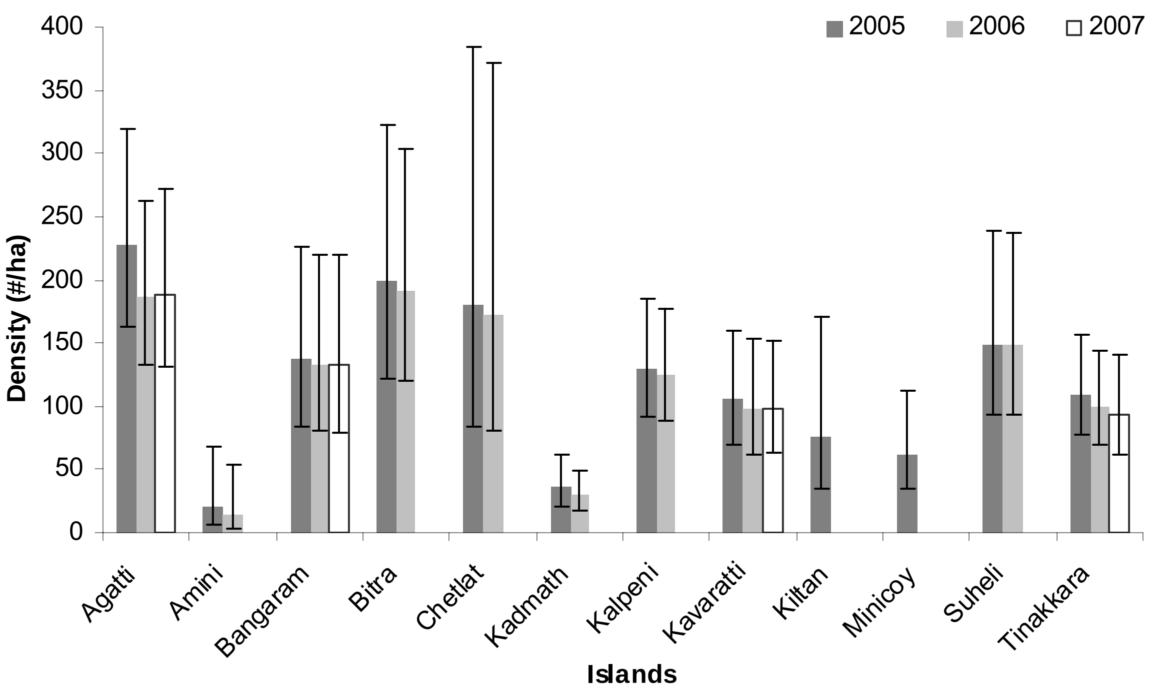
Island		Juvenile							Sub-adult							Adult						
	Year	Model	P	D	CV	LCL	UCL	n	Model	p	D	CV	LCL	UCL	n	Model	p	D	CV	LCL	UCL	n
Agatti	2005	Half-normal/ Cosine	0.69	37.95	21.99	24.18	59.55	92	Half-normal/ Cosine	0.73	107.32	19.33	72.00	159.98	313	Half-normal/ Cosine	0.66	83.01	18.53	56.63	121.67	220
	2006			28.87	25.94	16.99	49.08	70			93.61	18.68	63.64	137.69	273			64.14	18.37	43.91	93.70	170
	2007			32.57	26.61	18.87	56.21	75			94.57	19.30	63.39	141.07	262			61.16	19.51	40.84	91.60	154
Amini	2005	Uniform /Cosine	0.64	4.08	75.72	0.83	20.02	4	Uniform /cosine	0.68	8.22	56.88	2.35	28.73	9	Half-normal/ Polyno mial	0.68	7.34	46.45	2.59	20.82	8
	2006	Uniform /Cosine	0.48	5.92	75.33	1.16	30.33	4	Uniform/ cosine	0.67	4.24	52.13	1.28	14.06	4	Half-normal/ Polyno mial	0.71	4.03	64.69	0.95	17.08	4
Bangaram	2005	Half-normal/ Cosine	0.94	14.01	29.09	7.40	26.54	21	Half-normal/ Cosine	0.80	55.21	25.17	31.09	98.03	71	Half-normal/ Cosine	0.81	67.84	23.74	39.64	116.10	88
	2006			13.34	22.89	8.15	21.85	20			65.31	22.28	39.33	108.46	84			53.96	30.18	27.21	107.05	70
	2007			14.68	24.17	8.70	24.78	22			67.65	22.55	40.48	113.05	87			50.11	31.09	24.75	101.45	65
Bitra	2005	Half-normal/ Cosine	0.60	15.32	20.33	10.10	23.23	33	Half-normal/ Cosine	0.62	115.47	24.28	69.82	190.99	257	Half-normal/ Cosine	0.66	67.39	29.69	36.60	124.09	159
	2006			20.42	20.00	13.56	30.76	44			111.88	24.15	67.83	184.53	249			58.49	27.93	32.91	103.96	138
Chetlat	2005	Half-normal/ Cosine	0.47	11.63	43.41	4.82	28.03	11	Half-normal/ Cosine	0.61	67.18	33.86	32.19	140.21	82	Half-normal/ Cosine	0.66	100.48	38.49	43.58	231.64	133
	2006			14.80	47.32	5.67	38.65	14			64.72	34.15	30.83	135.90	79			93.68	37.77	41.24	212.78	124
Kadmat	2005	Uniform /Cosine	0.64	0.71	100.35	0.11	4.44	1	Uniform /cosine	0.68	6.59	36.05	3.15	13.83	10	Half-normal/ Cosine	0.38	27.73	34.65	13.68	56.23	25
	2006	Uniform /Cosine	0.48	0.94	100.25	0.15	6.03	1	Uniform/ cosine	0.67	6.47	35.81	3.09	13.59	9			20.57	38.03	9.40	45.01	17
Kalpeni	2005	Uniform /Cosine	0.68	3.14	44.57	1.31	7.53	9	Half-normal /Cosine	0.47	28.06	31.98	14.83	53.10	55	Half-normal/ Polyno mial	0.68	98.06	17.54	68.76	139.86	281
	2006			4.88	34.29	2.48	9.63	14			24.49	32.74	12.75	47.04	48			93.18	17.56	65.31	132.94	267
Kavaratti	2005	Half-normal/ Cosine	0.51	36.60	31.05	19.19	69.82	56	Half-normal/ Polynomi al	0.88	35.63	27.16	20.21	62.84	94	Half-normal/ Cosine	1.00	35.67	20.07	23.47	54.21	107
	2006			25.49	35.71	12.17	53.37	39			39.80	26.47	22.90	69.20	105			31.34	22.72	19.50	50.35	94
	2007			21.01	33.70	10.39	42.47	30			46.71	24.12	28.12	77.60	115			28.22	24.21	16.97	46.91	79
Kiltan	2005	Half-normal/ Cosine	0.66	0.76	101.04	0.12	5.02	1	Half-normal/ Cosine	0.66	46.48	48.72	16.80	128.64	61	Half-normal/ Cosine	0.66	28.96	67.31	7.40	113.28	38
Minicoy	2005	Uniform /Cosine	1.00	7.40	54.43	2.54	21.58	27	Half-normal/ Cosine	0.52	34.22	46.62	13.67	85.66	68	Unifor m/Cosi ne	0.50	32.42	23.95	20.09	52.32	61
Suheli	2005	Half-normal/ Cosine	0.29	6.24	101.94	1.02	38.13	5	Half-normal/ Polynomi al	0.43	24.70	52.73	8.54	71.45	30	Half-normal/ Cosine	0.45	114.15	24.35	69.96	186.26	144
	2006			13.73	50.59	5.03	37.48	11			51.05	28.81	28.13	92.65	62			84.03	25.04	50.75	139.11	106
Tinakkara	2005	Half-normal/ Polyno mial	0.61	19.70	25.55	11.43	33.96	24	Half-normal/ Polynomi al	1.00	26.50	25.32	15.08	46.58	53	Half-normal/ Polyno mial	0.75	64.73	18.66	43.25	96.90	97
	2006			20.52	22.47	12.76	33.01	25			32.00	21.37	19.84	51.62	64			46.05	24.08	27.24	77.84	69
	2007			19.15	26.78	10.73	34.20	21			33.33	24.87	18.95	58.65	60			39.30	25.65	22.25	69.41	53

Comparison of density estimates between successive study years

H_0: Population is stationary; there is no significant variation in population size through successive study years.

Paired t-test on temporal replicates of transects showed significant reduction ($t = 5.35$, $df = 79$, $p < 0.0001$) of giant clam *T. maxima* density from 2005 to 2006. But, there was no such reduction in density from 2006 to 2007 ($t = 1.40$, $df = 38$, $p = 0.085$) (fig. 11.1.3).

Figure 11.1.3. Comparison of giant clam *T. maxima* densities across the study years (2005-2007) in different islands of Lakshadweep archipelago



Error bars are 95% Confidence intervals

Comparative study of giant clam *T. maxima* populations in different islands of Lakshadweep archipelago during 2005-2007

1. *H_0: Mean densities of giant clams are equal across islands.*

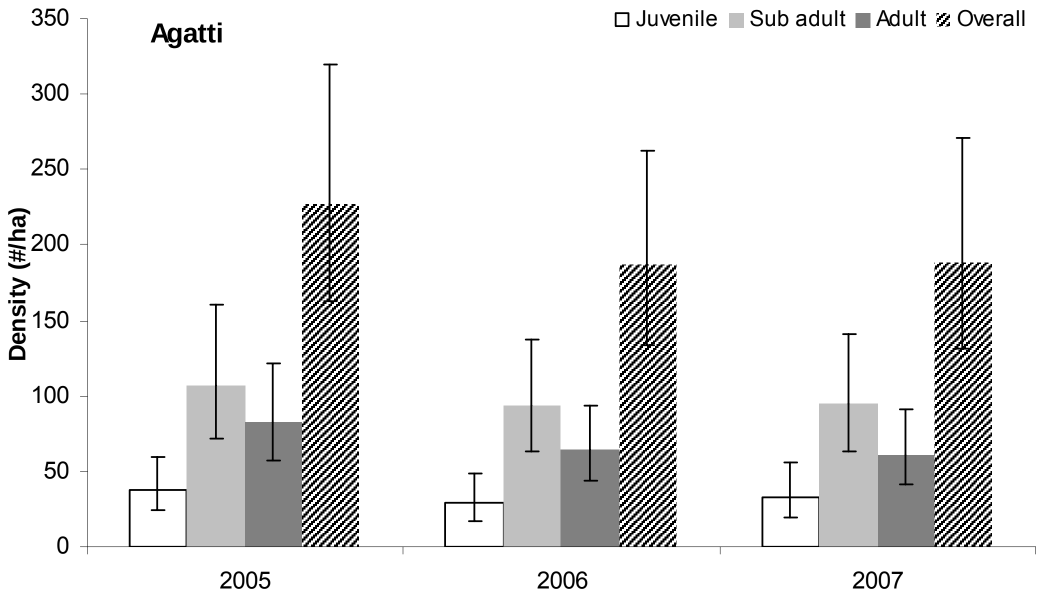
One way anova with post hoc Dunnett C test showed significant difference ($F = 4.39$, $df = 134$, $p < 0.001$) in giant clam densities across islands (figure 3).

2. *H_0: Relative percentages of different age classes in giant clam population are constant across islands.*

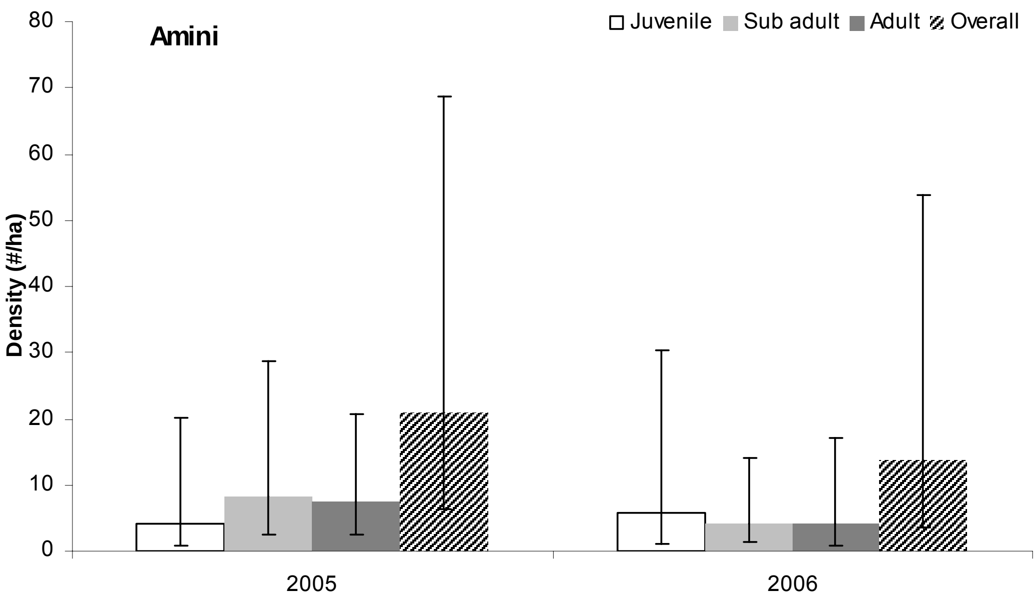
Chi-square goodness of fit test on the relative percentages of different age classes in the giant clam *T. maxima* population across islands in the year 2005 showed significance differences ($\chi^2 = 143.9$, $df = 32$, $p < 0.0001$) resulting to the rejection of the null hypothesis. This indicates that intrinsic and/or extrinsic forces regulating population growth are varying among islands.

To obtain a fine resolution picture of how individual (island) populations are behaving through time, juvenile, sub-adult and adult giant clam *T. maxima* densities in each island were compared across the study years (figure 11.1.4). Amini, Bangaram, Tinakkara and Kavaratti populations were deviating from stable age class distribution through successive years. In general, sub-adults and adults dominated the populations and juvenile densities were low with extremely low records (<10% relative proportion of the population) from Bitra, Chetlat, Kadmat, Kalpeni, Kiltan and Suheli followed by Agatti, Bangaram, Tinakkara and Minicoy (10-20% relative proportion of the population). Kavaratti and Amini populations showed relative healthy status of the juveniles. Adult mortality was considerably high (>30% decline between successive years) in Amini, Tinakkara, Agatti, Bangaram, Kadmat and Suheli. Overall, populations exhibited declining trend between the successive study years, particularly in Amini (33% decline), Tinakkara (33% decline), Kavaratti (22% decline), Kadmat (18% decline) and Agatti (17% decline).

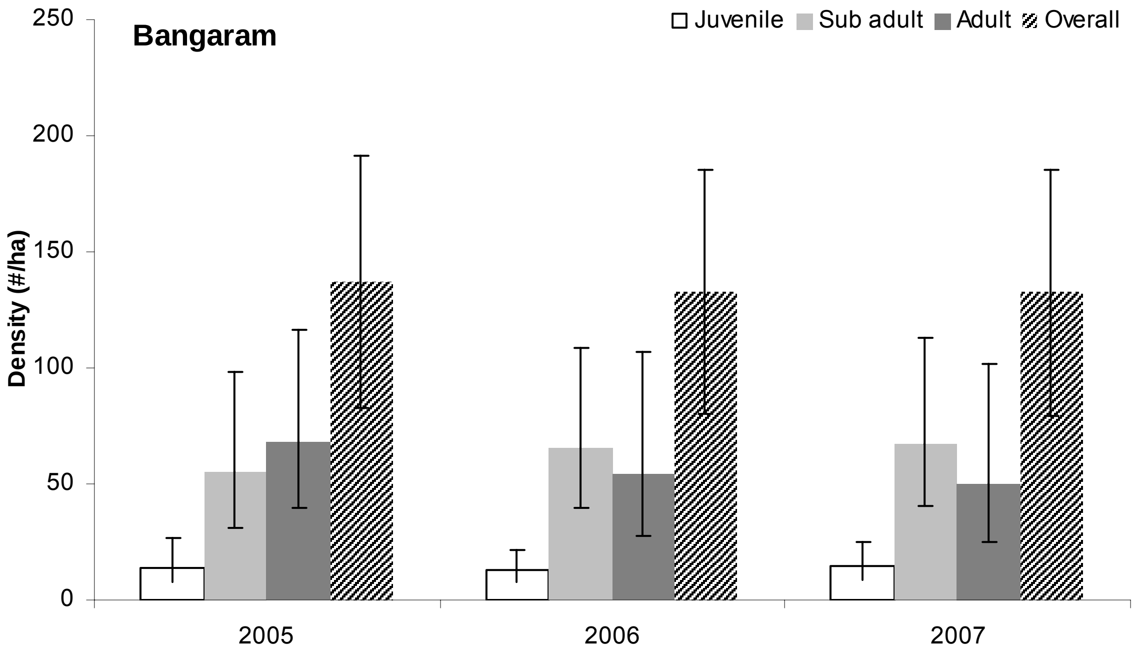
Figure 11.1.4. Comparison of juvenile, sub adult and adult densities in *T. maxima* population across the study years (2005-2007) in different islands of Lakshadweep Archipelago



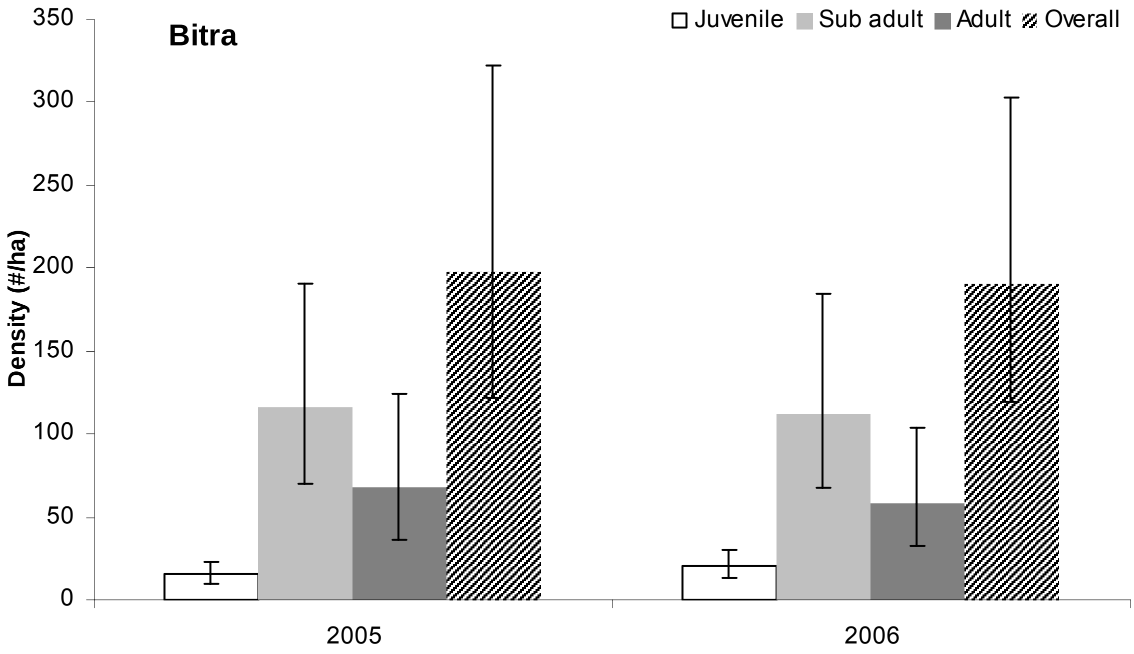
Error bars are 95% Confidence intervals



Error bars are 95% Confidence intervals



Error bars are 95% Confidence intervals



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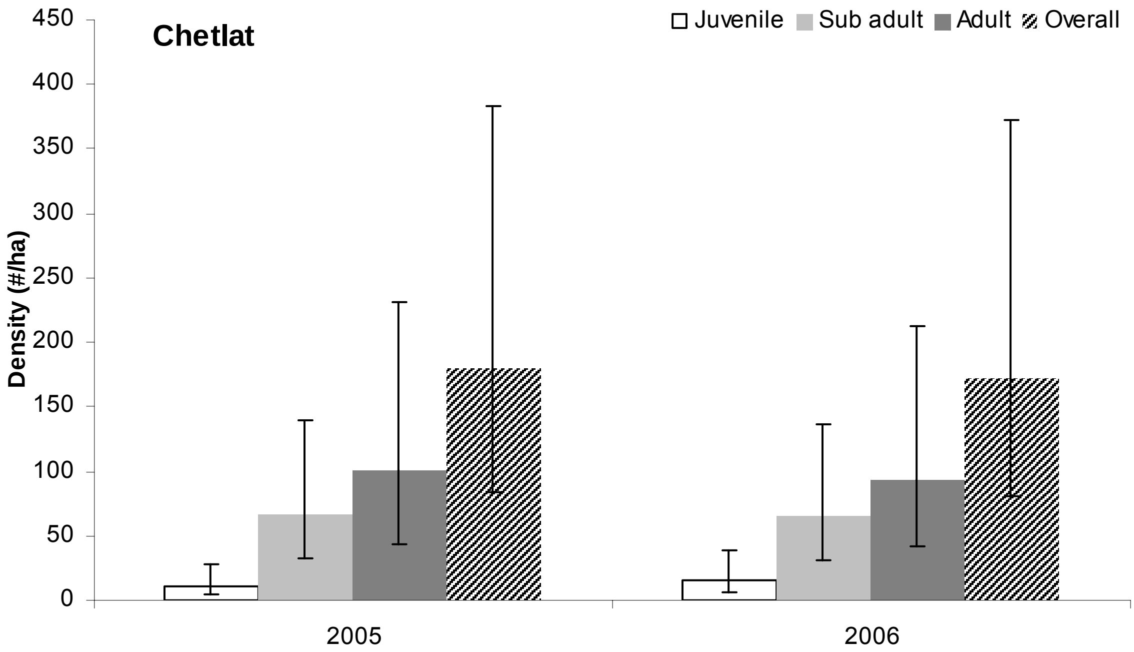

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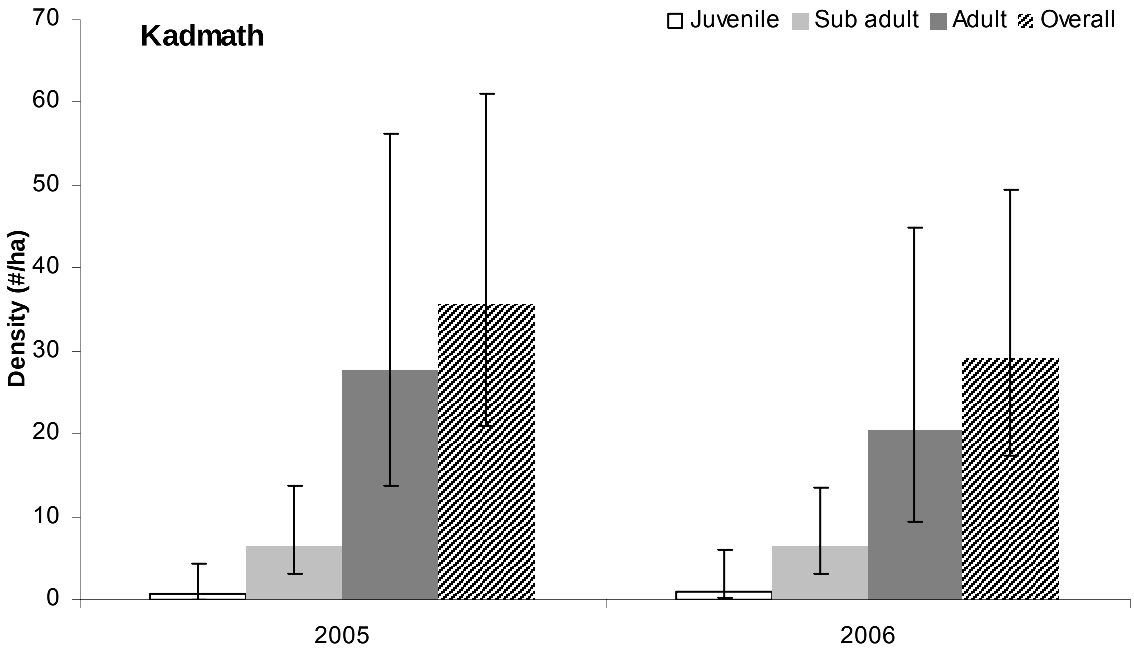

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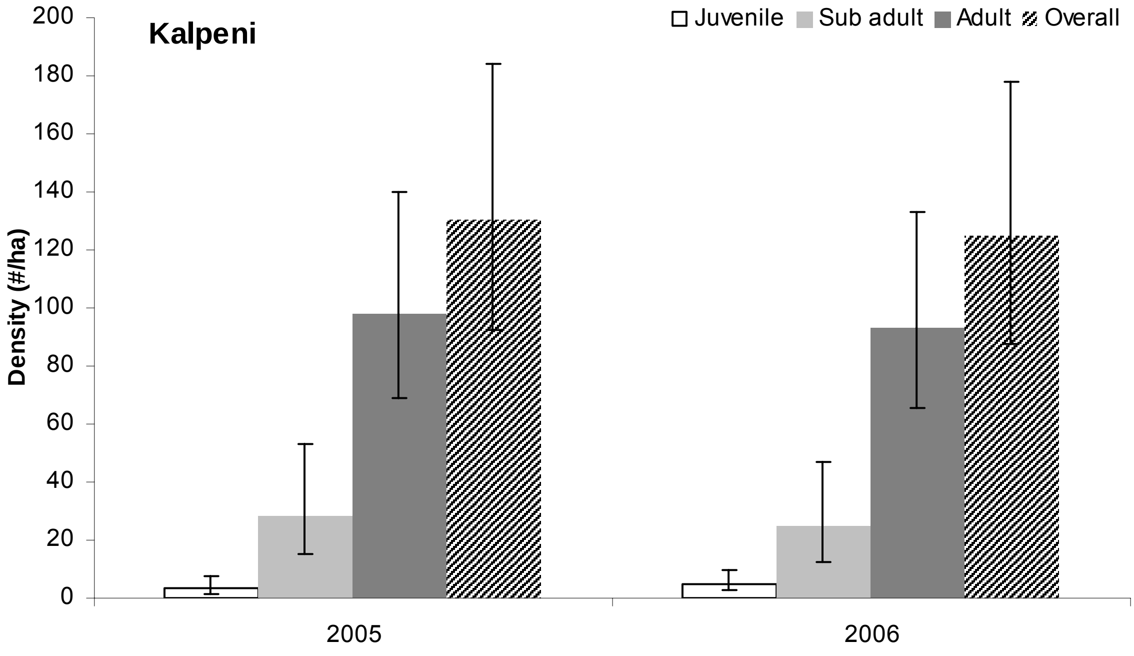

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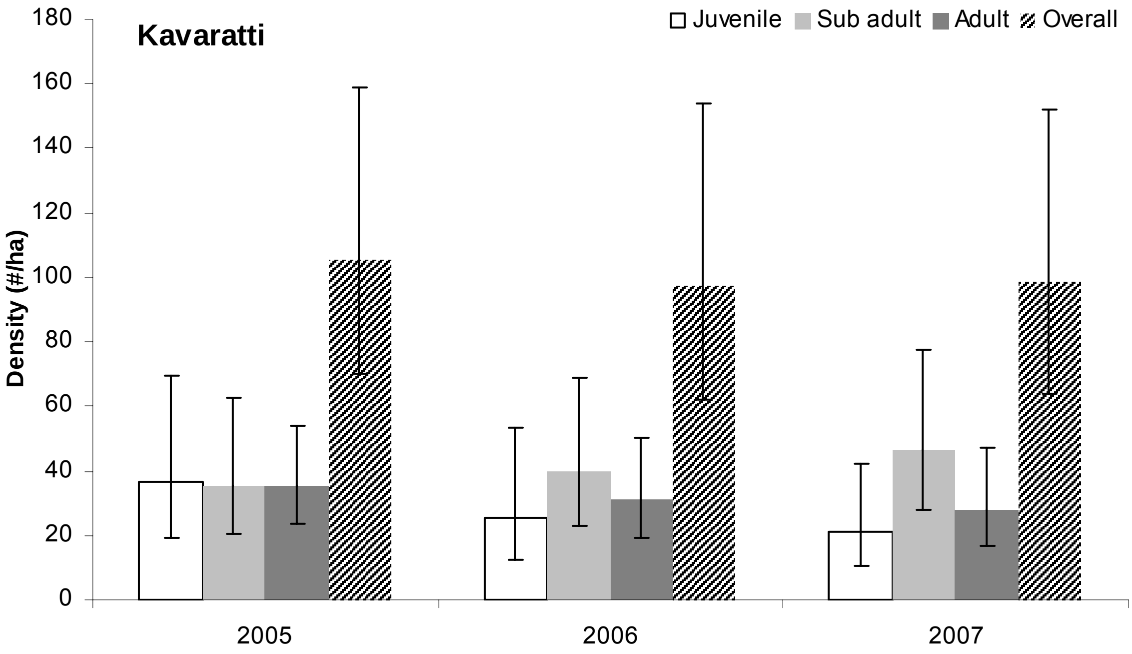

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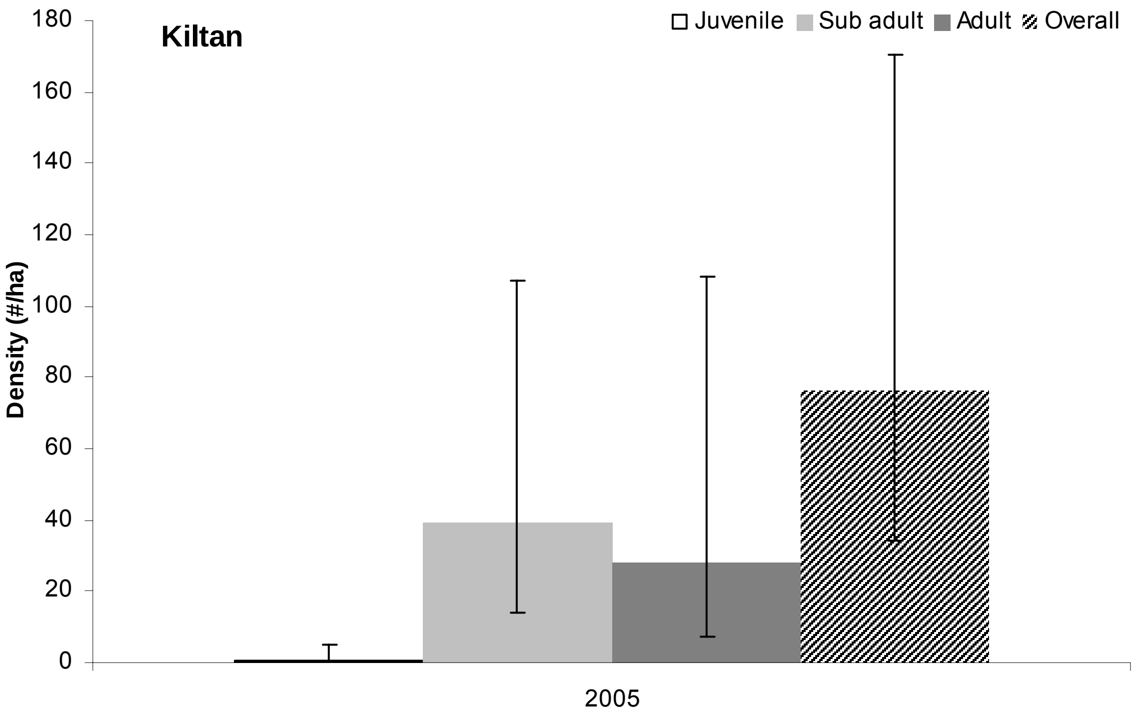

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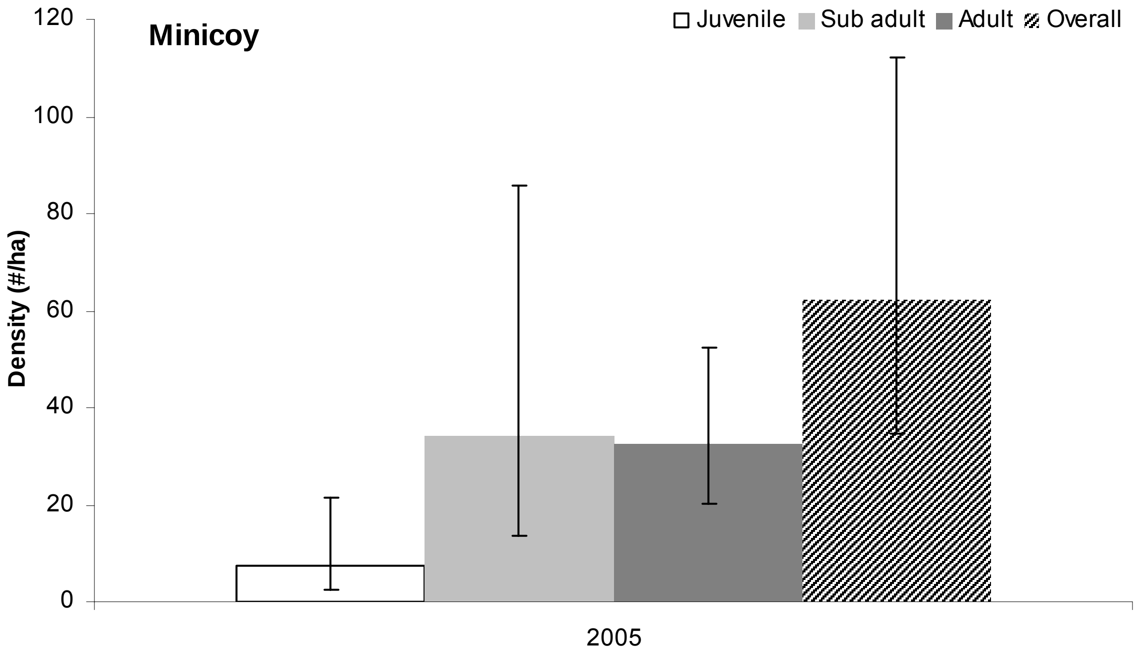
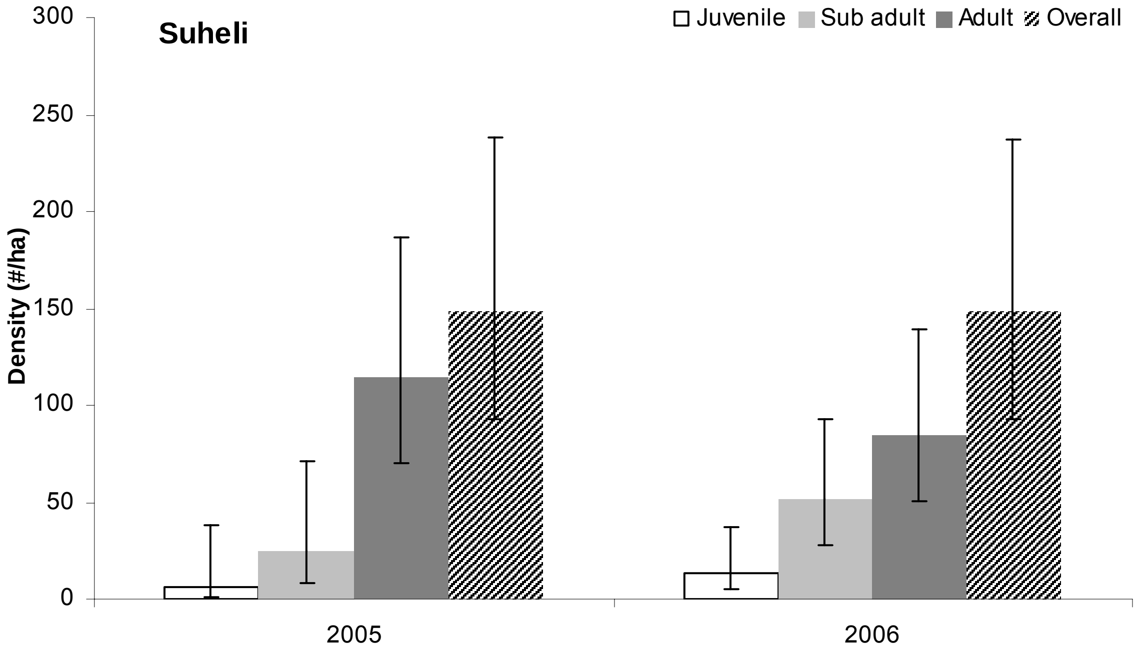
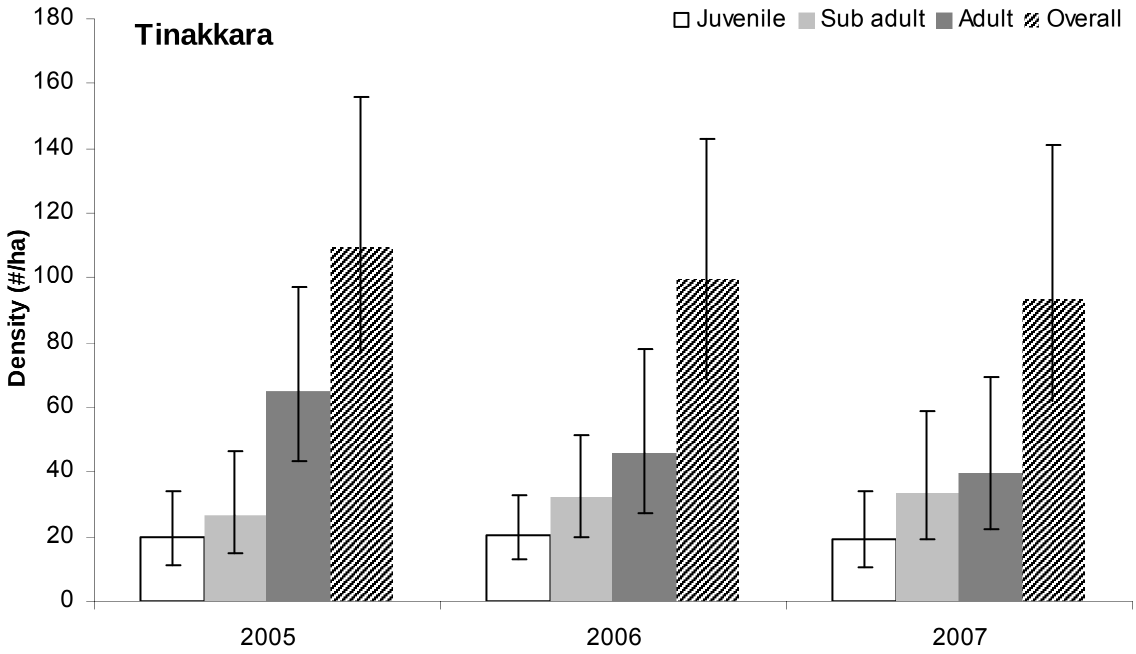


Error bars are 95% Confidence intervals



Error bars are 95% Confidence intervals



Error bars are 95% Confidence intervals

11.2. Recruitment

Gilbert *et al* (2006) reported that the recruitment is timed to coincide with lagoon water cooling events in French Polynesia. He also reported thermal stresses that trigger spawning in *T. maxima*. Fecundity of *T. maxima* is estimated to be 10 million eggs per adult of 180 mm size (Jameson, 1976). However, the size distribution of giant clam suggests that recruitment is erratic particularly for the larger species like *T. gigas*. This suggests that the mortality of early stages (pelagic as well as juveniles) is very high[14].

Data on recruitment collected from 134 transects across 11 lagoons covering 24 islands in 2006 and 55 transects across 3 lagoons covering 4 islands in 2007 were used to estimate the density of recruits by the conventional distance sampling analysis with default settings of the software DISTANCE 5.0[15]. Detection probability, pooled over all islands across 2006 and 2007 was 0.23 which is quite low compared to the other age classes (>0.60). Density was post-stratified on the basis of years and also islands. Recruitment density was 8.69/ha (n=54 sightings, 95%CL 5.91-12.79) in 2006 and 23.91/ha (n=55 sightings, 95%CL 15.03-38.02) in 2007. The overall density of recruits during 2005-07 was 11.97/ha (95%CL 8.05-17.79). Among the islands, density of recruits was relatively high in Kavaratti and Bitra, and there was no evidence of recruitment in the sampled transect of Kadmat and Amini.

Recruitment rate calculated as number of recruits per breeding individual, was 0.21 (SE = 0.11, n = 11 lagoons) between 2005 & 2007 (figure 11.2.1). A comparison of recruitment vis-à-vis adult densities across islands exhibited a feeble, non-significant relation (r = 0.054, p = 0.88, n = 10). Exclusion of Kavaratti and Bitra from the analysis,

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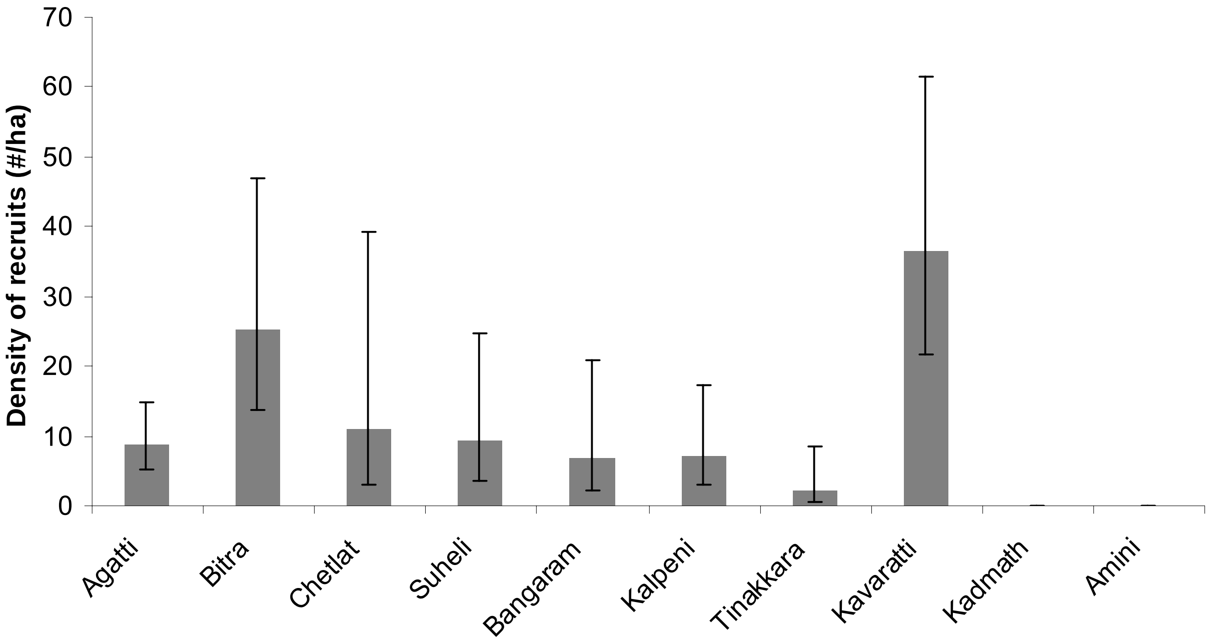
[14] Asano, 1937; Motoda, 1938b; Hester & James, 1974; McMichael, 1974
[15] http://www.ruwpa.st-and.ac.uk/distance/

however, showed a strong, positive and linear trend of recruitment against the breeding population (r^2 = 0.84, p = 0.001). This indicates that there are other ecological factors alongside a viable breeding population behind reproductive success which have marked manifestation in Kavaratti and Bitra (figure 11.2.2).

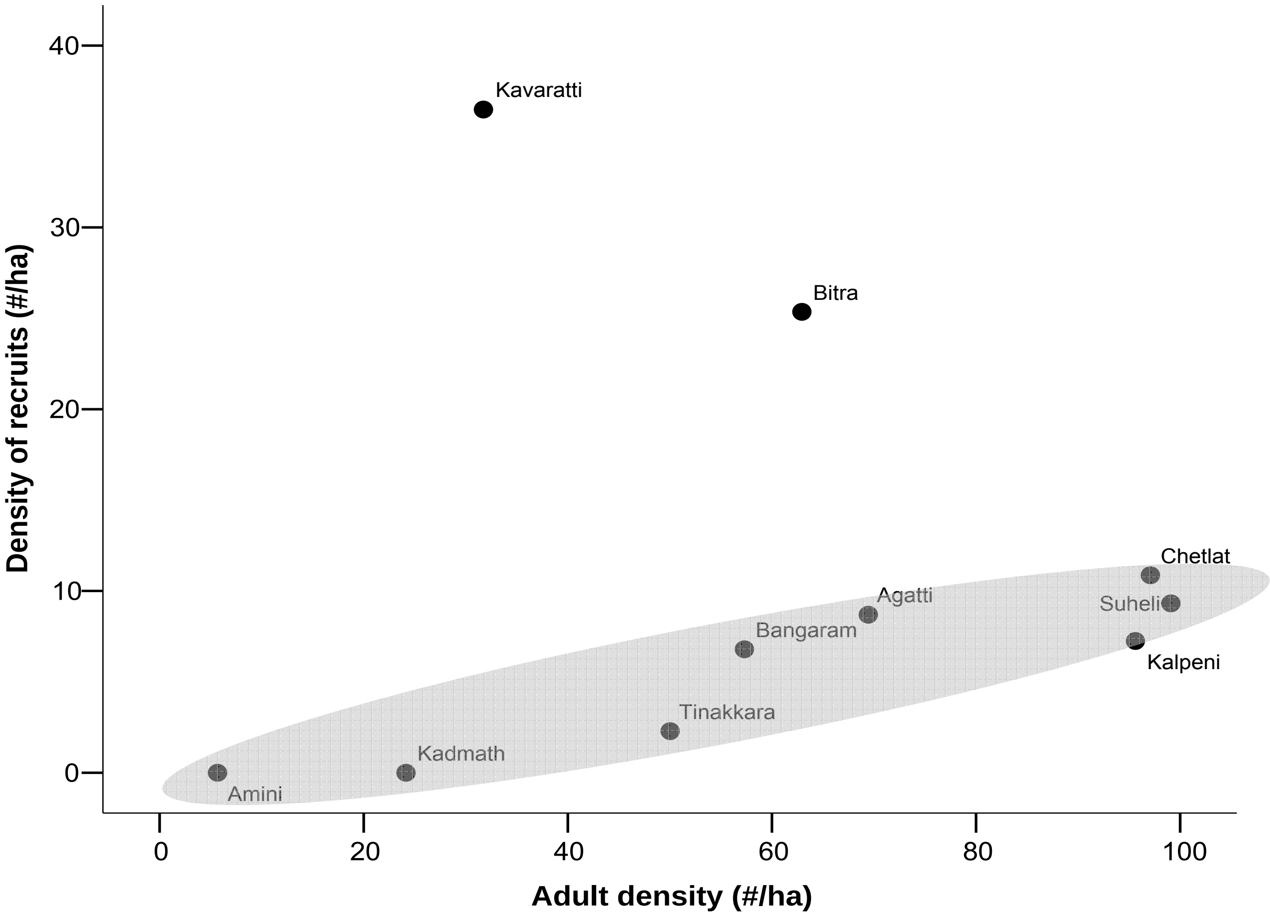
Figure 11.2.1 Recruitment in giant clam population across different islands of Lakshwadeep Archipelago in 2005-07



Error bars are 95%Confidence intervals

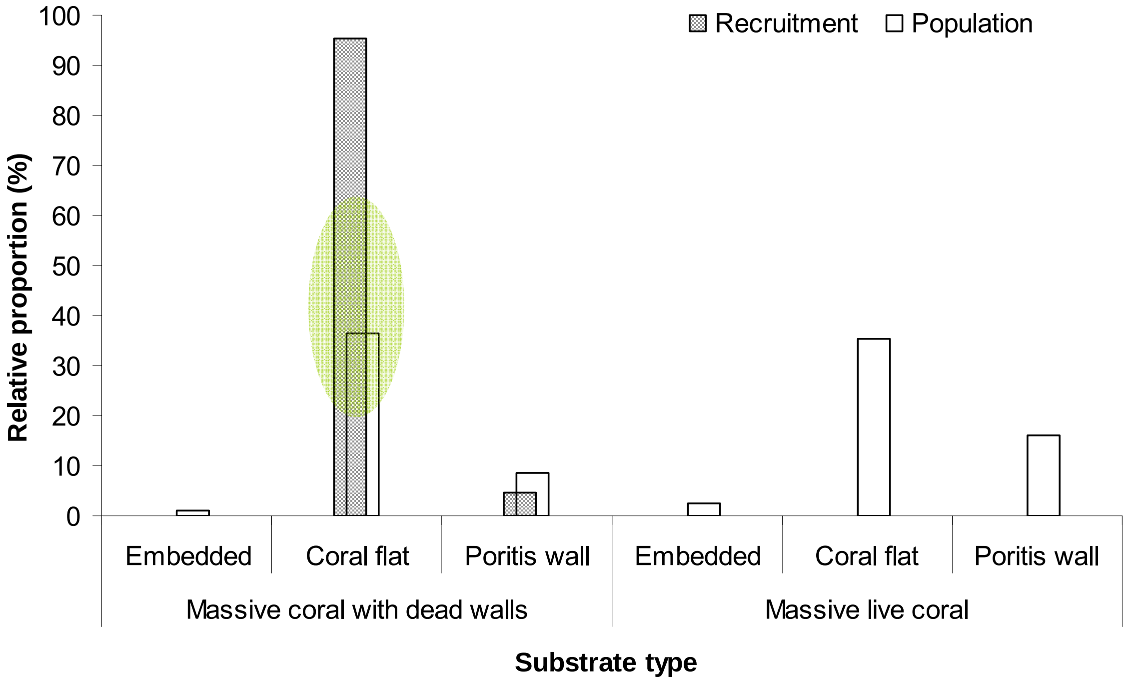
Monitoring of giant clam *T. maxima* population in Agatti, Kavaratti, Bangaram and Tinakkara for 3 consecutive years provided annual survivorship of recruits. Individuals of ≤60mm length, encountered in 2005, were assumed to be the recruits of the previous years. Encounter history in the binary presence (live) – absence (dead) form was produced from the fates of the recruits of 2005 and 2006 in the successive year(s). Survival rate of recruits in the first year obtained by bootstrapping was 62% (n = 53 recruits, 95%CL 49.1% - 71.7%). All of the first year's survivors (n = 23) survived to the second year also. First year survival rates of recruits were separately estimated for Agatti, Kavaratti and Bangaram & Tinakkara populations by bootstrapping. There was a trend of higher survival rates among recruits in Agatti than Kavaratti and Bangaram & Tinakkara (figure 11.2.3).

Figure 11.2.2 Relation between breeding population and recruitment of giant clams in Lakshwadeep Archipelago



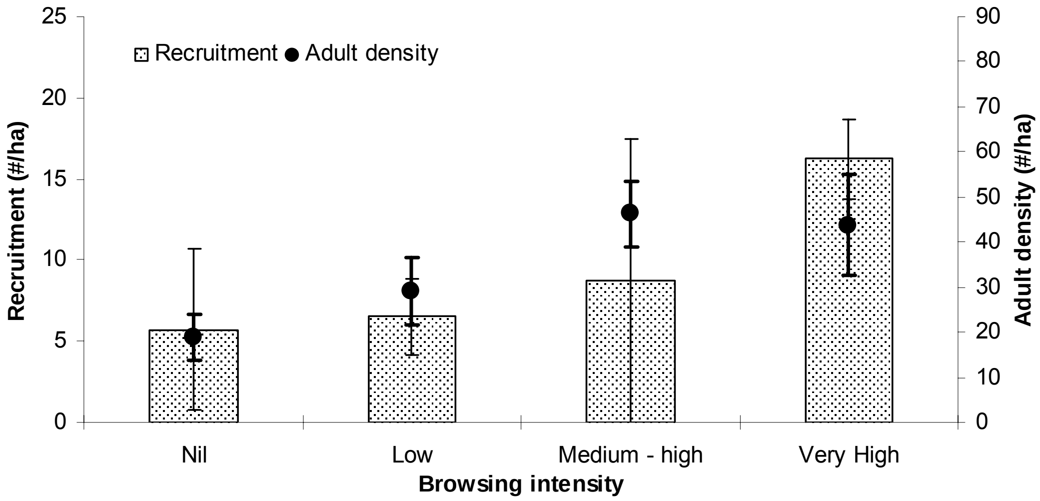
Relative frequency of recruits in each substrate type revealed that *Porites* with dead flat tops contributed to the majority of giant clam recruitment. There was hardly any recruitment on other substrate types (figure 11.2.3). Density of recruits when compared against the browsing intensity indexed as categorical variable across 15 transects in Kavaratti Island showed high recruitment in intensively browsed areas.

Figure 11.2.3 Recruitment in *T. maxima* population across different substrate types in Lakshwadeep Archipelago



Recruitment was highly correlated (r = 0.8, $p < 0.001$) with herbivory measured as indices of herbivorous fish abundance.

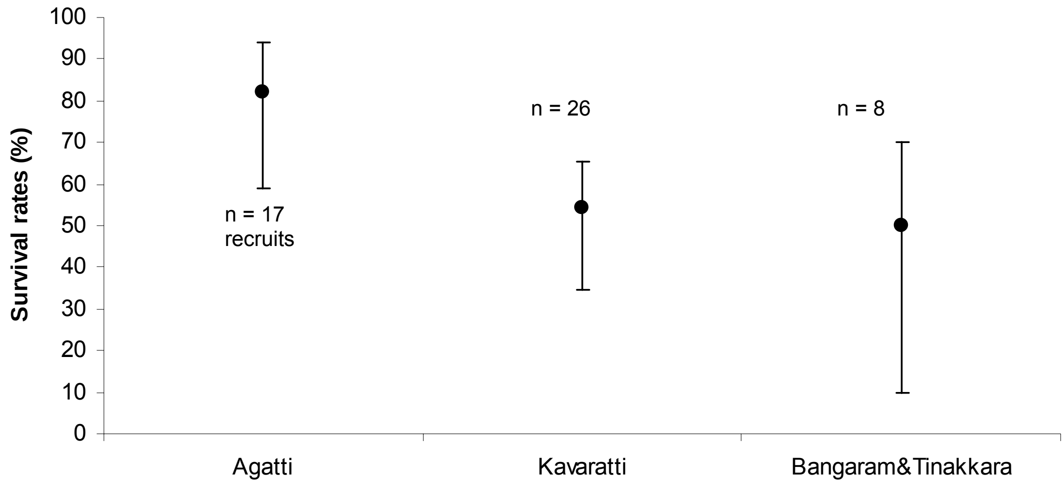
Figure 11.2.4 Recruitment and adult densities of giant clam *T. maxima* across a gradient of browsing activity by herbivorous fishes in Kavaratti Island



Error bars are 95% Confidence intervals

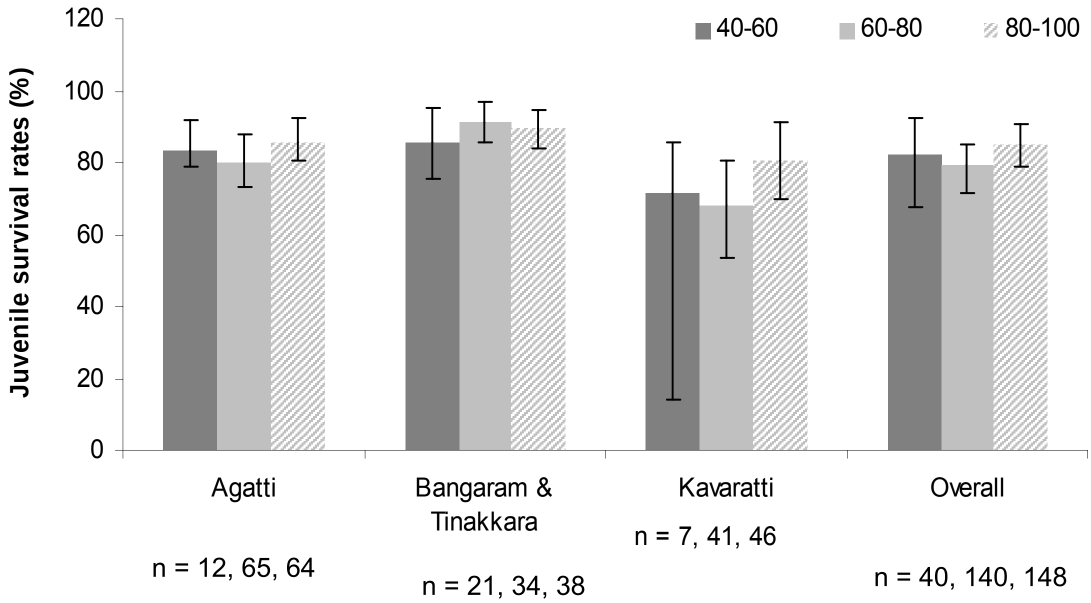
Thus *T. maxima* are low recruits with highest recruitment was noted in Bitra and Agatti being very low. This is surprising aspect of recruitment profile as the *T. maxima* density was highest in Agatti. The question is then how the Agatti lagoon has very high density with so low recruitment? The only explanation can be that the survival rate of recruit must be higher in Agatti as compared to other islands. To test this hypothesis, the survival rates of juveniles belonging to different size classes in Agatti, Bangaram & Tinakkara and Kavaratti lagoons during 2005-2007 were similarly estimated by bootstrapping to reveal the vulnerability of different size classes. Results did not show any substantial difference in survival rates among different size classes but there was a trend of low survival in Kavaratti population than the other two lagoons (figure 11.2.6).

Figure 11.2.5 Survival rates of recruits of *T. maxima* in the first year across Agatti, Kavaratti, Bangaram & Tinakkara islands during 2005-07.



Error bars are bootstrapped 95% confidence intervals

Figure 11.2.6 Survival rates of recruits of *T. maxima* in the first year across Agatti, Kavaratti, Bangaram & Tinakkara islands during 2005-07.



Error bars are bootstrapped 95% confidence intervals

Conclusion

1. *T. maxima* are a low recruit species. Highest recruitment was noticed in Kavaratti with 38 clams/ha. Tinakkara showed lowest recruitment density with 4 clams/ha.
2. Except Kavaratti and Bitra, all islands have shown strong relation of recruitment and adult density. The reasons for Kavaratti and Bitra not following the general trend seen on all other islands need further studies.

11.6. Mortality

Mortality at free floating larval stage

Beckver (1981) reported 99 % mortality from egg to juvenile stage of *T. gigas*. *T. deresa* showed less than 3% survival from veliger to juvenile.

The density dependent mortality of the pelagic larvae of *T. maxima* may operate to reduce the selective advantage of fixing a particular fecundity level, making clutch size divergent among the individuals within the same reproductive populations. Relatively poor synchrony in reproductive activity may also reflect the high variability in early survival because it acts iteroparity[16].

Mortality at Shell Stage

LaBarbera (1975) reported low larval and juvenile survival of tridacnid clams. Yamaguchi (1977) reported that larger species of giant clams shows erratic recruitment.

Faasili *et al* (1998) reported high mortality of reintroduced *T. squamosa* and *T. deresa*. They noticed 34% and 47% mortality respectively at the end of seven months and complete mortality at the end of the year.

Calumpong (2000) reported various modes of mortality in giant clams while restocking experiments in Philippines. He reported up to 35 % mortality due to typhoon and monsoon followed by 28 % mortality by predation and 5 % by poaching.

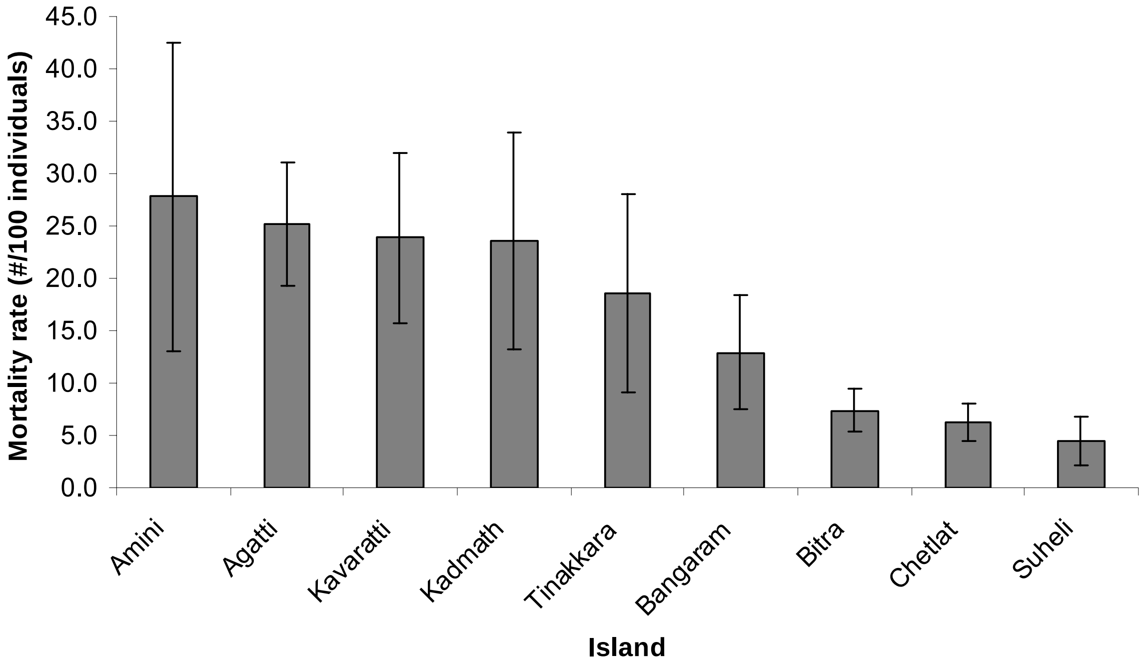
Hammer (1978) reported 12.5 % juvenile mortality due to intra-specific competition in *T. crocea* which in tern is density dependent. He also inferred that bimodal size frequency distribution was related to selective mortality in 1 to 3 year old clams.

Andrefouet *et al* (2006) reported natural events as a singly most dominant cause of mortality in *T. maxima* at Tuamotu Atolls. This is primarily attributed to the poor renewal rate of lagoon waters during abnormally low swell and wind conditions. *T. maxima* in these lagoons are so abundant that they form primary builder of lagoon structure.

Mortality rate was calculated from the dead clams between successive surveys with respect to the initial clam count for each transect. Mortality rate of giant clam *T. maxima* between 2005 & 2006 was 0.16 (SE = 0.023, n = 105). Anchorage failure contributed 15% to the overall mortality. Transect-wise mortality rates were pooled to calculate the average mortality rate for each island (figure 11.6.1). A one–way ANOVA test revealed that mortality rate was not varying significantly among islands ($F = 1.81$, $p = 0.08$).

[16] Murphy, G.I. 1968.

Figure 11.6.1. Mortality in giant clam *T. maxima* population across different islands of the Lakshwadeep Archipelago in 2005-06

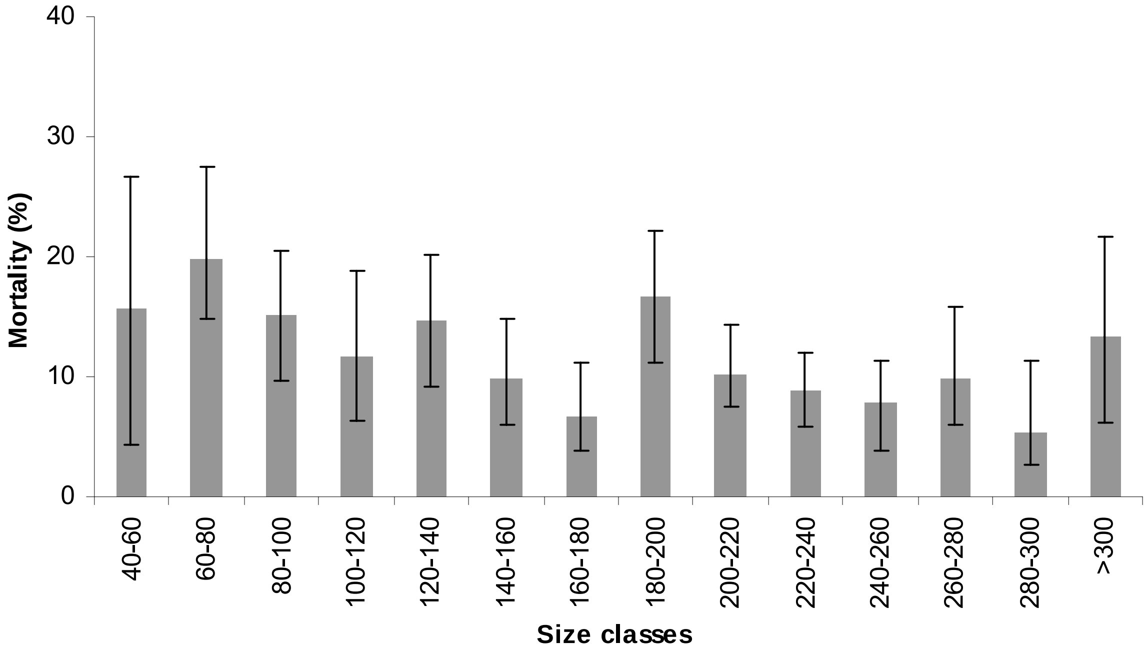


Error bars are Standard Errors

Assuming length to be a surrogate of age, size specific mortality (%) was calculated from the fate of the clams belonging to different size classes between successive surveys and estimates were obtained by bootstrapping the binary presence (live) – absence (dead) encounter history (figure 11.6.2). Mortality resulting from anchorage failure was also calculated for different size classes (figure 11.6.3).

Mortality rates were pooled from transects classified into density classes ranging from 0/ha to >300/ha, to find any pattern in mortality under a gradient of population densities (figure 11.6.4a). Island-wise mortality rates were not significantly related to the corresponding densities (fig 11.6.4b).

Figure 11.6.2. Size specific mortality in giant clam *T. maxima* population of Lakshwadeep Archipelago in 2005-07



Error bars are bootstrapped 95% Confidence Intervals

Figure 11.6.3. Mortality from anchorage failure in giant clam population of Lakshwadeep Archipelago in 2005-06

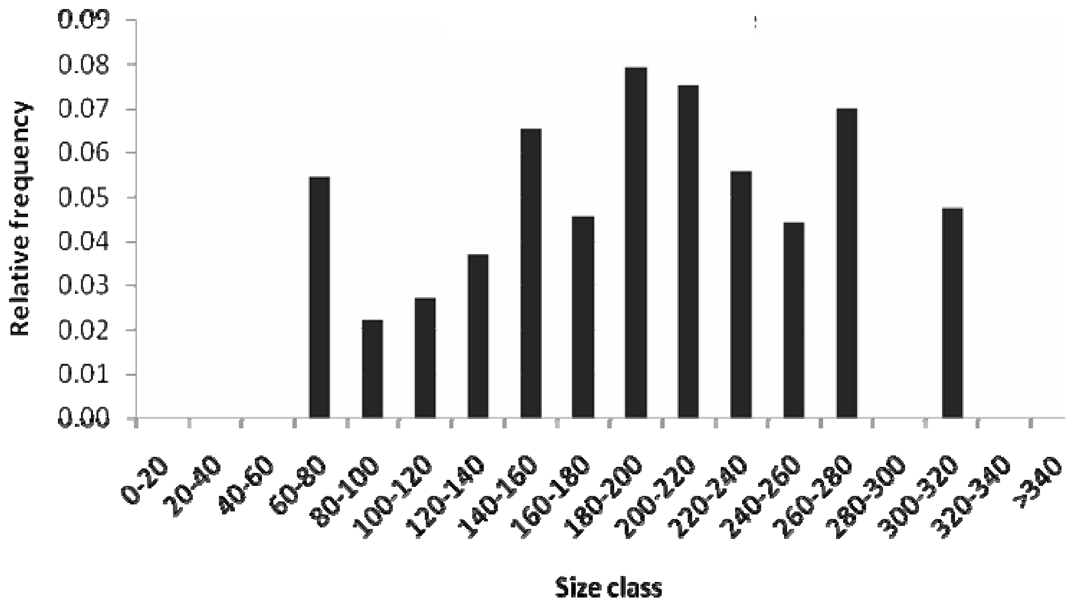
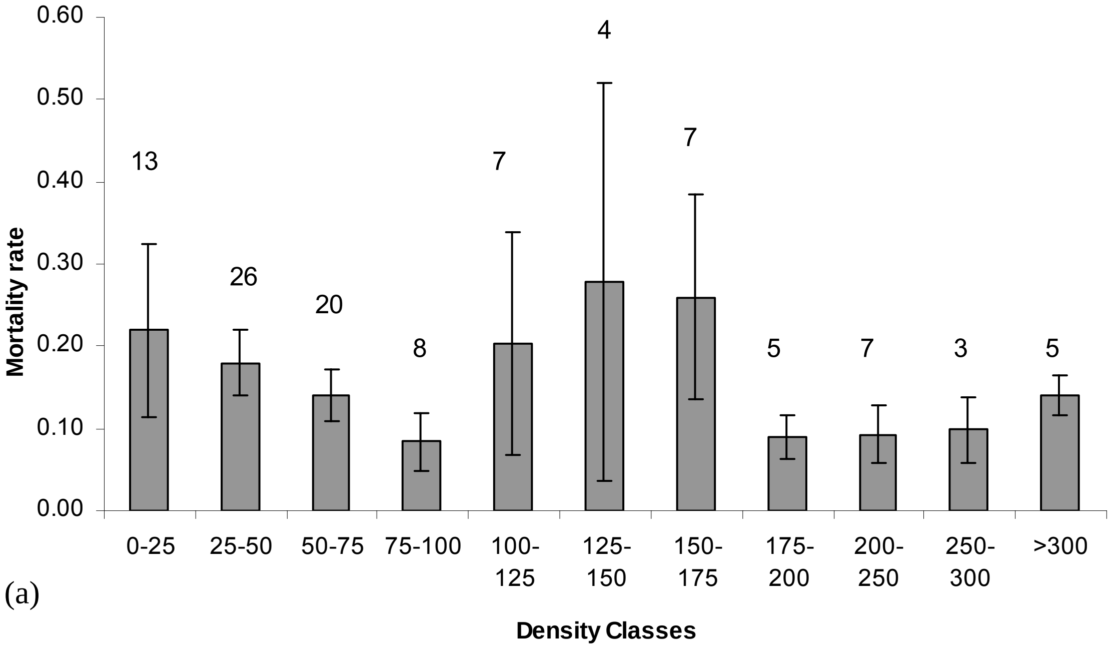
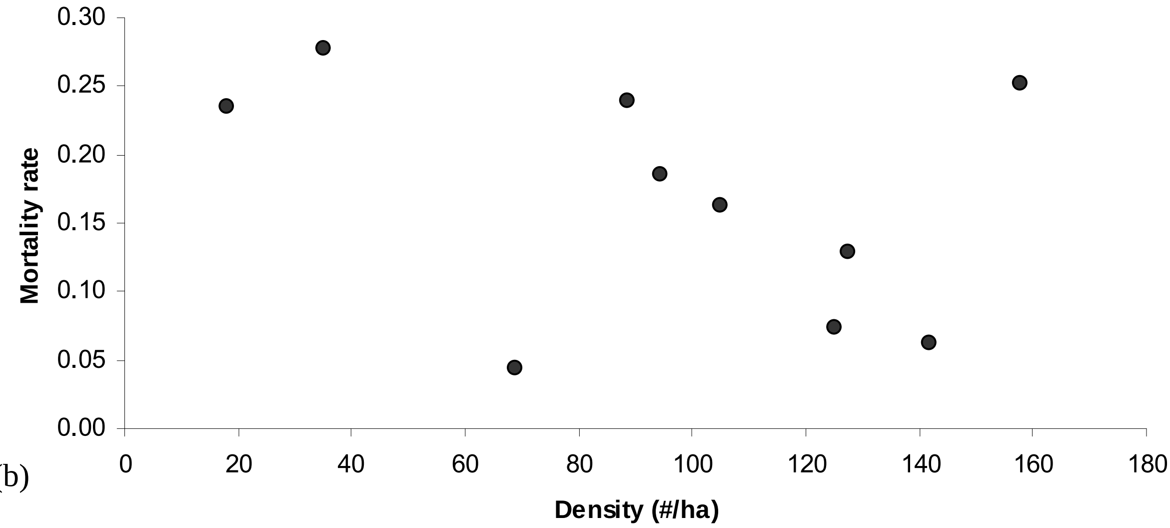


Figure 11.6.4. Variation of mortality with population density of giant clam *T. maxima* in Lakshwadeep Archipelago during 2005-2007



(a)

Error bars are Standard Errors



(b)

Mortality rates calculated across a gradient of water depths revealed relatively less mortality between 0.1 m and 0.5m but high degree of mortality between 0.6m and 0.7 m from the sea floor (figure 11.6.5).

Relative proportions of mortality in different substrate types closely followed the population distribution except the disproportionately low mortality in the flat tops of massive coral with dead walls, and disproportionately high mortality among clams embedded in the massive live corals (figure 11.6.6). A G-test however, did not reveal any significant variation in the frequency distributions of mortality among different substrate types ($G = 2.79$, $p = 0.73$).

Figure 11.6.5. Variation of mortality rates of *T. maxima* across the gradient of water depths in Lakshwadeep Archipelago

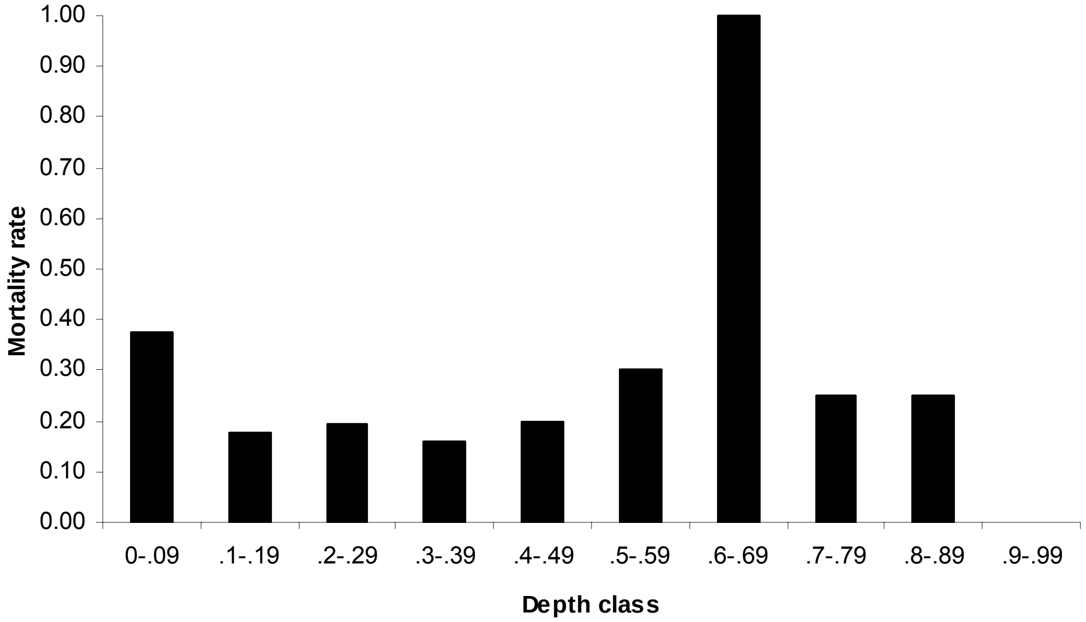


Figure 11.6.6. Mortality in giant clam *T. maxima* population across different substrate types in Lakshwadeep Archipelago

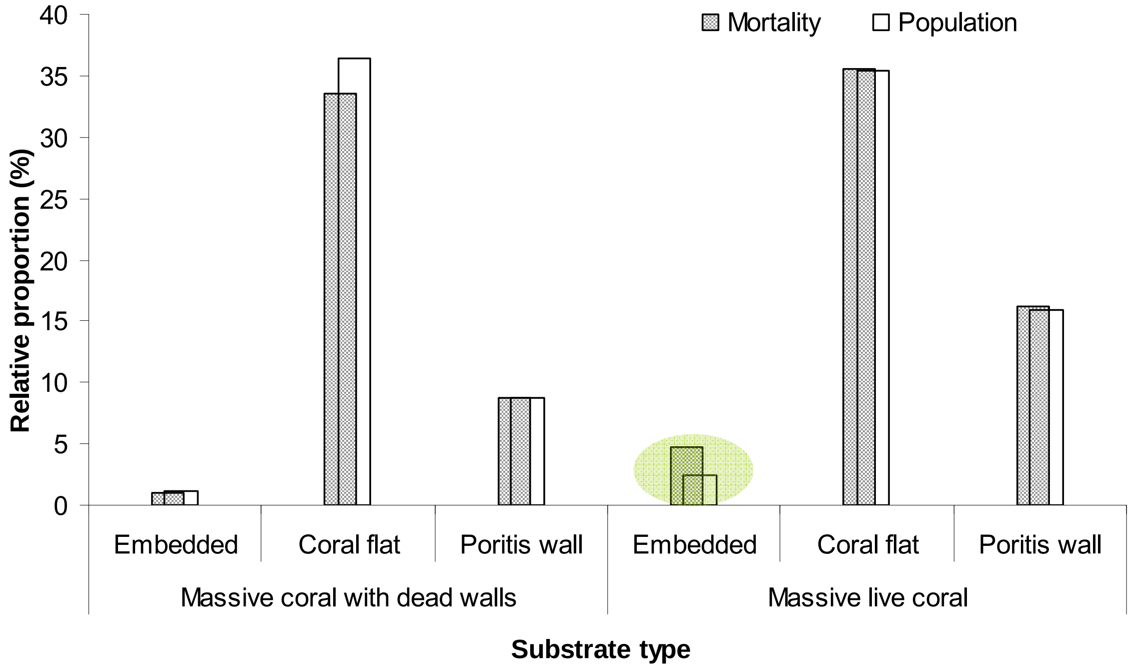
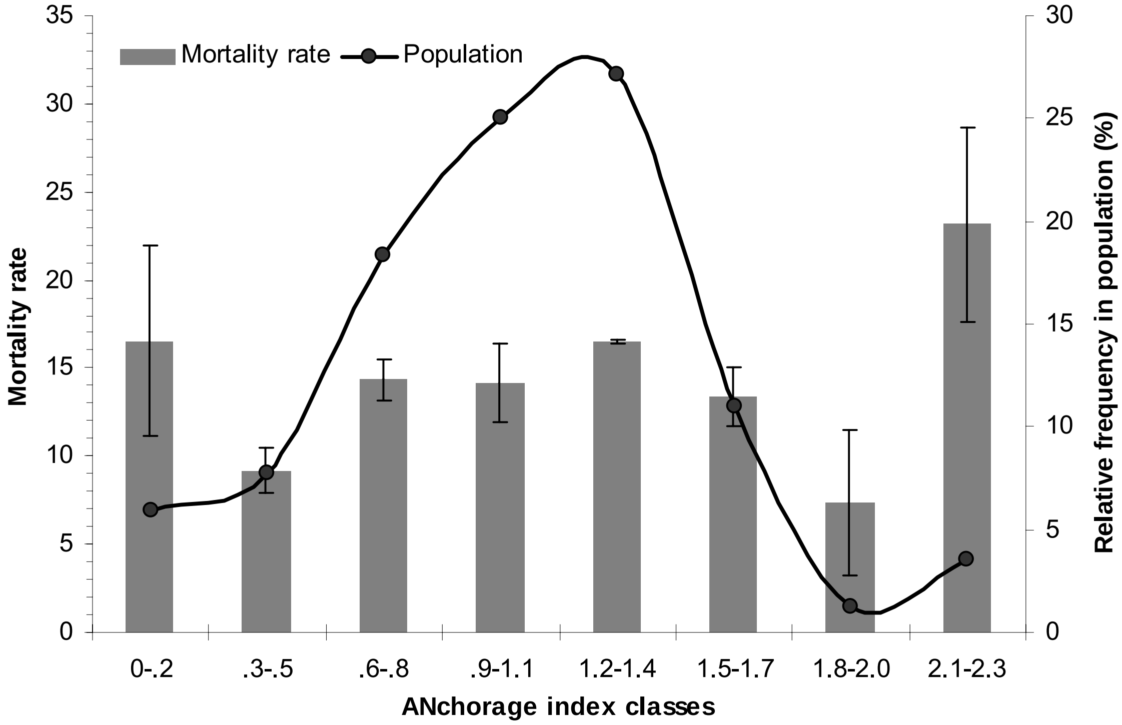


Figure 11.6.7. Mortality against anchorage index



Natural causes of Mortality

a) Mortality due to bleaching

Giant clams are prone to temperature variations. This is primarily due to symbiotic association of zooxanthellae with giant clams. As the temperature rises beyond a threshold limit, zooxanthellae will loose its chloroplast and eventually die. In absence of zooxanthellae, giant clams also die. During El Niño, there were reports of giant clam bleaching as well. Thus rise in sea temperature can have devastating impact on giant clam populations. Besides temperature, few more factors can cause bleaching. One is increase in turbidity which can cut light reaching giant clams. Secondly, dislodged giant clams which then fall on sea floor are prone to bleaching as the mantle can not open fully. Thus the area which is not receiving sun light tends to bleach.

b) Mortality through disease

Shelley *et al*, 1988 studied trematode infection in *Tridacna crocea* from Great Barrier Reef. They noticed up to 12 % clams were infected with trematode. The impact of these parasites on reproductive capacity of *T. crocea* was remarkable. We have not reported any disease among *T. maxima* and *T. squamosa* in Lakshadweep. However, *Porites lutea* is heavily infected by various diseases such as Pink-line Syndrome, Black-band Disease and White-band Disease.

c) By Predation

Heslinga (1984) in his studies observed complete mortality of *T. derasa*, *T. squamosa*, *T. gigas* and *H. hippopus* when he introduced maricultured clams of 10-20 mm in the wild. The mortality was primarily due to predation. He observed that sea bream, *Monotaxis grandoculis* (Family: Lethrinidae) was the main predator for these clams. At 130 mm *T. derasa* showed 89% survival after one year of the release in the wild while as 170 mm clams showed 100 % survival.

Heslinga (1984) reported *Chicoreus ramosus*, Octopus *sp*. as major predators of *T. squamosa*. Perron *et al* (1985) reported predation of giant clams by *Cymatium muricinum*. He reported over 25% mortality due to this species thus becoming a main predator of giant clams. Perio & Belda (1988) reported predation by *Cantharus fumosus*. *Vexillum plicarium* was noted as predator by Richardson (1991). Abdon & Alcazar (1989) reported *Chicoreus brunneus* and *Cymatium aquatile* as predators of giant clams while as Heslinga *et al* (1990) reported *Tathrella iredalei* as predatory mollusc on giant clams. Govan (1992) reported *Chicoreus brunneus, C. microphyllum, C. margariticola, Morula granulate, Mericodrupa fiscella, Thais aculeate, Turbonilla sp., Cymatium aquatile, Cymatium muricinum, Cymatium nicobaricum* and *Cymatium pileare* as main predators of giant clams.

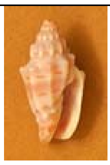
The giant clams are known to be predated by shells from families Ranellidae (= Cymatidae)[17] and Pyramidellid[18,19].

Besides molluscs, few species of crustacean and fishes also feed on giant clams. Alcazar (1986) reported predation by reef fish *Balistapus undulates*. Heslinga *et al* (1984 & 1990) reported predation by *Monotaxis grandoculis*, *Pseudobalistes flavi marginatus*, *Aetobatis narinari* and *Tetrodon stellatus*. Richardson (1991) found *Canthagaster solandri*, *Thalassoma hardwicke*, *Thalassoma lunare*, *Cheilinus fasciatus*, *Choerodon ancharago* and *Choerodon schoenleinii* feeding on giant clams.

Table no. 11.6.1 Predatory molluscs of giant clams as reported by various authors

Sr. No	Species of Predatory mollusca	Image

[17] Sims & Howard, 1988
[18] Bell & Pernetta, 1988
[19] Cumming, 1988

1	*Chicoreus microphyllus* An uncommon species from Lakshadweep (Specimen from Smithsonian Institute (USNM 670899)	
2	*Chicoreus ramosus* A common species in Lakshadweep.	
3	*Chicorius brunneus* A common species in Lakshadweep.	
4	*Morula granulata* An uncommon species in Lakshadweep.	
5	*Cymatium muricinum* An uncommon species in Lakshadweep. (Specimen from Smithsonian Institute USNM 703881)	
6	*Cymatium pileare* A common species in Lakshadweep.	
7	*Cymatium pileare aquatile* An uncommon species in Lakshadweep.	
8	*Vexillum plicaria* A common species in Lakshadweep.	

During the first two years study we have noticed *Cymatium pileare, Cymatium muricinum* and *Vexillum plicaria* as predators of *T. maxima* in Lakshadweep. We have also collected few species of Pyramidellids as predators of *T. maxima*. However, we are not yet able to identify them.

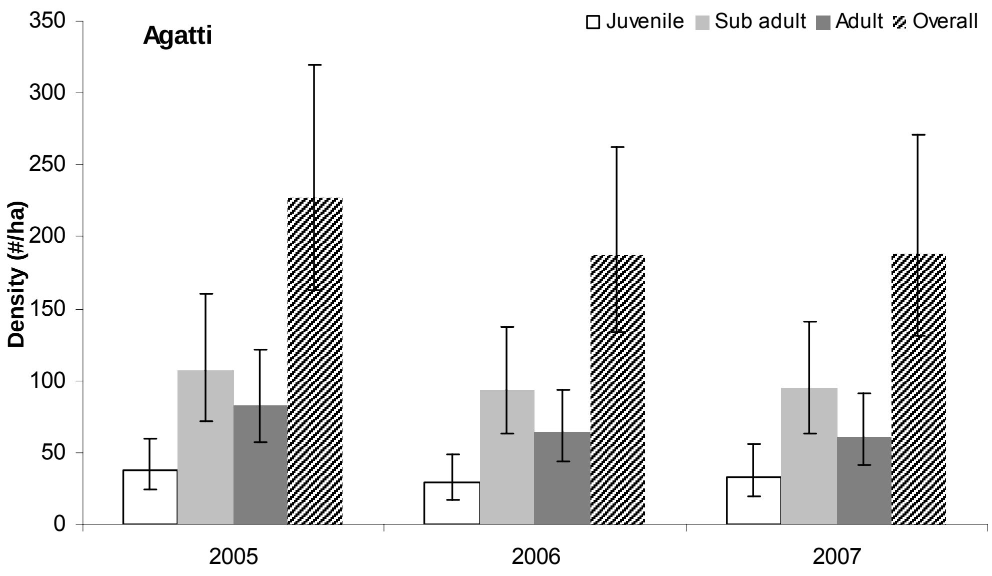
In Lakshadweep however, the level of predation and predation related mortality could not be assessed due to survey limitations and wide areas of coverage.

11.7. Population projection of giant clam *T. maxima* in Agatti, Bangaram, Tinakkara and Kavaratti islands of Lakshadweep archipelago

Giant clam *T. maxima* population was monitored along 20 transects in Agatti, 8 transects in Bangaram, 10 transects in Tinakkara and 15 transects in Kavaratti lagoons for 3 successive years between 2005 and 2007. Average annual growth rate of clams was calculated from repetitive measurements and clams were classified into 3 growth stages: juveniles (<100mm), sub adults (≥ 100 mm, < 200mm) and adults (≥ 200 mm). Density estimates of the overall population, individual age classes as well as recruits were obtained through distance sampling analysis by the software Distance 5.0[20] (for details, refer to the previous chapters). Density estimates of 2006 were used to calculate the initial/seed populations of each age class in the lagoon with the assumption that potential habitat for giant clam *T. maxima* is 30% of the lagoon area or 525 ha in Agatti, 149 ha in Kavaratti and 1388 ha for Bangaram and Tinakkara combined. The transition matrix/ projection matrix of the population was constructed from the survival and recruitment rates estimated from the 2005-06 and 2006-07 time steps. Proportion of each age class that is surviving to the succeeding age class was calculated from the repetitive growth measurements. The life history of giant clam *T. maxima* was diagrammatized (figure 11.7.2) and an arrow leading from stage X to stage Y was represented in the projection matrix by an entry in column X and row Y of the projection matrix. The population projection matrix was analyzed by the MS-Excel add-in software "POPTOOLS"[21] (table 11.7.1 & 11.7.2). The seed population was subjected to deterministic projection across a time span of 10 years using the projection matrix (figure 11.7.3).

Giant clam *T. maxima* population projection of Agatti Island

Figure 11.7.1. Density estimates of various age classes and overall population of giant clam *T. maxima* in Agatti Island across the study years, 2005-07



Error bars are 95 % Confidence Intervals

[20] http://www.ruwpa.st-and.ac.uk/distance/
[21] Poptools: http://www.cse.csiro.au/CDG/poptools/index.htm

Figure 11.7.2. Life history diagram of giant clam *T. maxima* in Lakshadweep archipelago

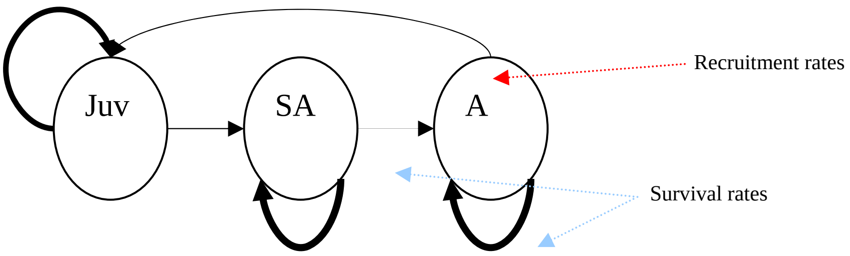


Table 11.7.1. Population projection matrix of giant clam in Agatti Island during 2005-07

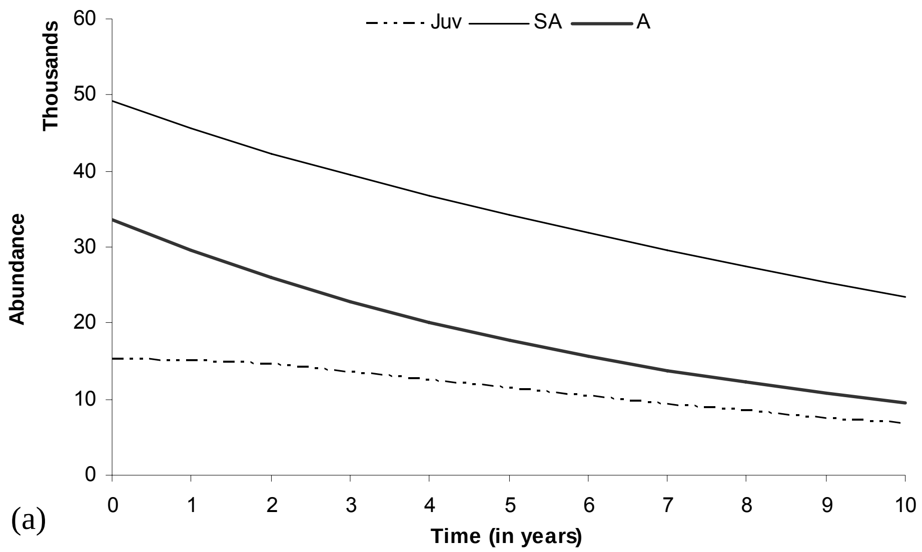
	Juv	SA	A
Juv	0.696	0	0.135
SA	0.135	0.885	0
A	0	0.009	0.865

Highlighted cells show recruitment rates, rest of the cells show survival rates

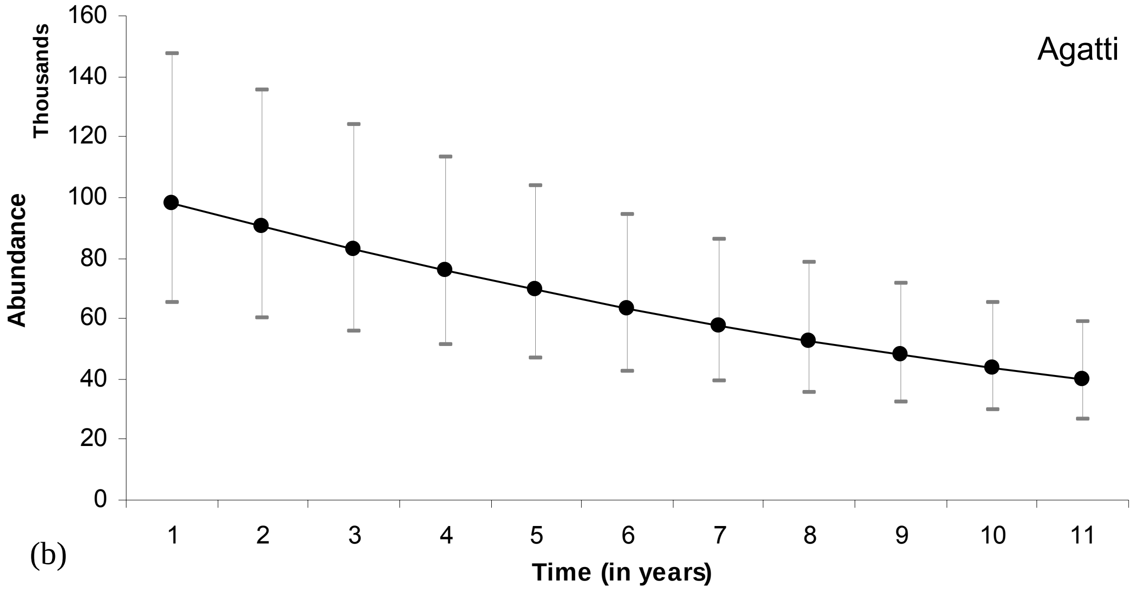
Table 11.7.2. Results of the projection matrix analysis

Eigenvalues		Eigenvectors (R&L)
Real	Imaginary	Age/stage struct
0.90476084	0	10.7%
0.83977429	0	72.8%
0.70146487	0	16.5%
Rate of increase, r	-0.10008	
Expected number of replacements, Ro	0.034754	
Generation time, T	33.5662	

Figure 11.7.3. Deterministic population projection of giant clam *T. maxima* in Agatti island across a time span of 10 years for (a) different age classes and (b) entire population



(a)



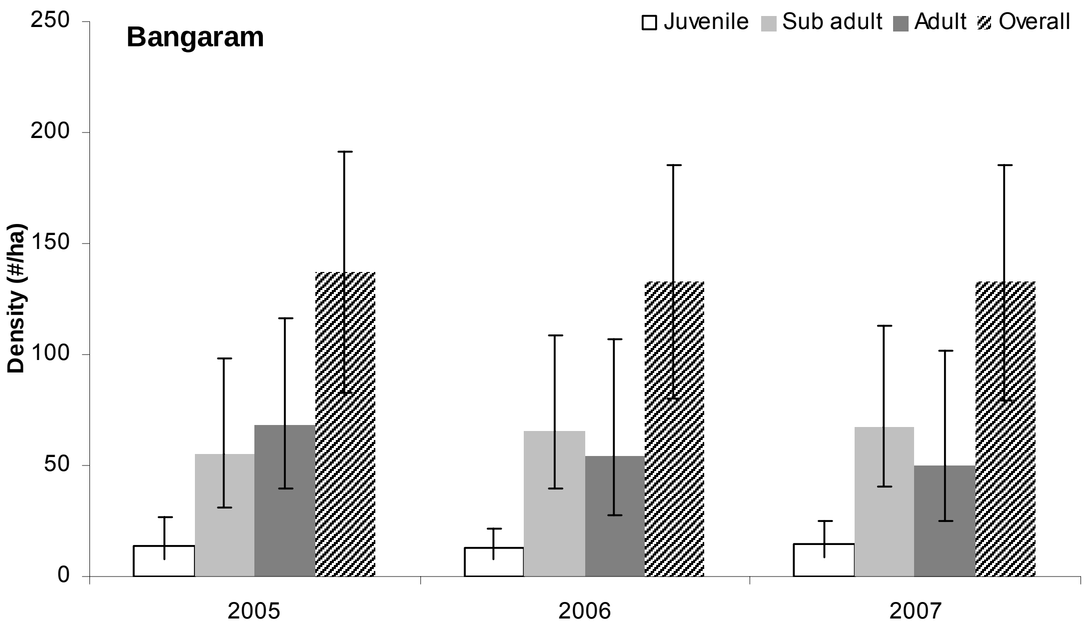
(b)

Error bars are 95 % Confidence Intervals

Similar exercises were done for Bangaram, Tinakkara and Kavaratti islands.

Giant clam *T. maxima* population projection of Bangaram Island

Figure 11.7.4. Density estimates of various age classes and overall population of giant clam *T. maxima* in Bangaram Island across the study years, 2005-07



Error bars are 95 % Confidence Intervals

Table 11.7.3. Population projection matrix of giant clam in Bangaram Island during 2005-07

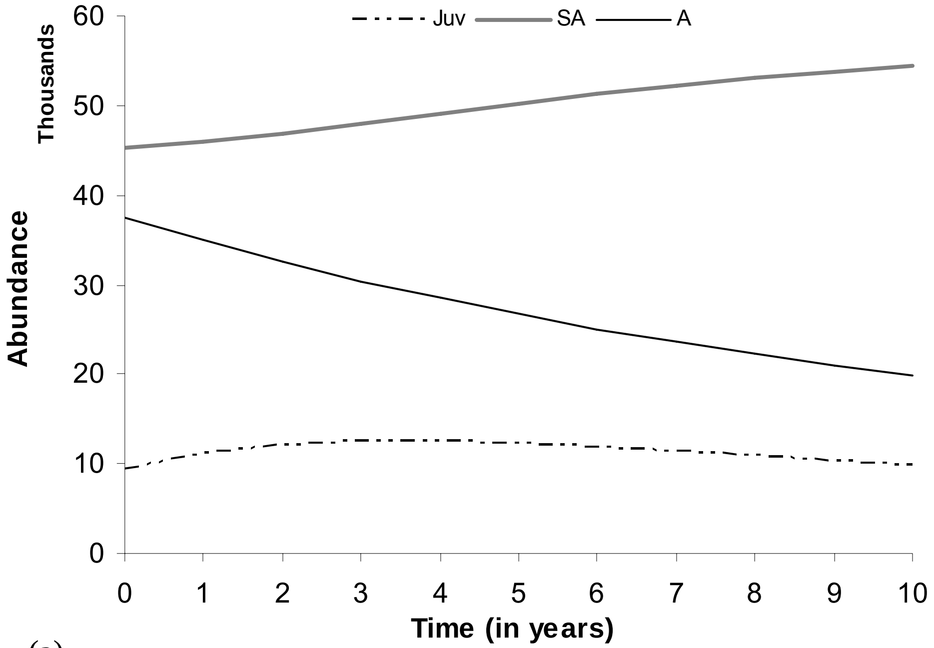
	Juv	SA	A
Juv	0.6931	0.0000	0.1258
SA	0.1789	0.9770	0.0000
A	0.0000	0.0100	0.9200

Highlighted cells show recruitment rates, rest of the cells show survival rates

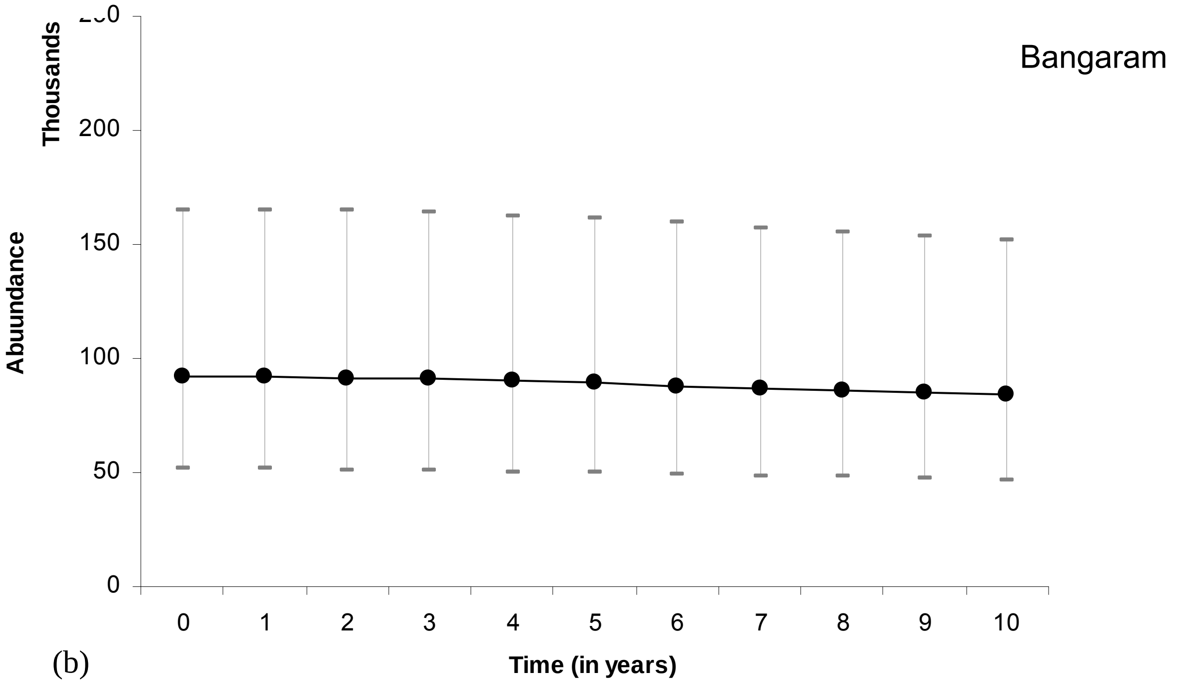
Table 11.7.4. Results of the projection matrix analysis

Eigenvalues		Eigenvectors (R&L)
Real	Imaginary	Age/stage struct
0.988185	0	5.2%
0.905219	0	82.7%
0.696696	0	12.1%
Rate of increase, r	-0.01188	
Expected number of replacements, Ro	0.398544	
Generation time, T	77.40362	

Figure 11.7.5. Deterministic population projection of giant clam *T. maxima* in Bangaram Island across a time span of 10 years for (a) different age classes and (b) entire population



(a)

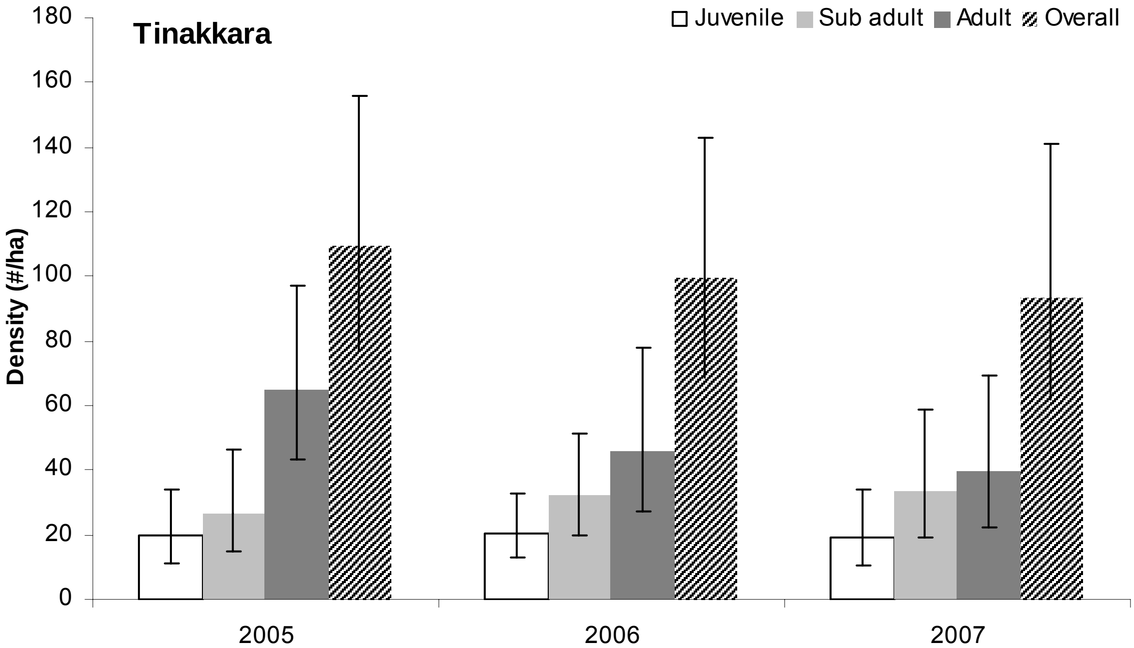


(b)

Error bars are 95 % Confidence Intervals

Giant clam *T. maxima* population projection of Tinakkara Island

Figure 11.7.6 Density estimates of various age classes and overall population of giant clam *T. maxima* in Tinakkara Island across the study years, 2005-07



Error bars are 95 % Confidence Intervals

Table 11.7.5 Population projection matrix of giant clam *T. maxima* in Tinakkara Island during 2005-07

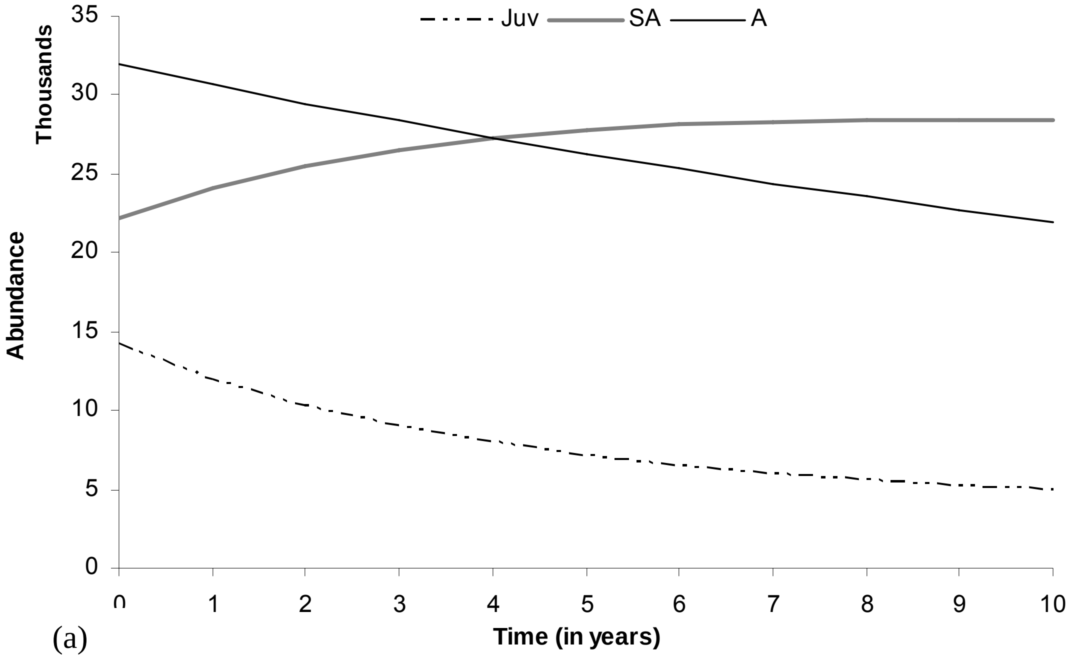
	Juv	SA	A
Juv	0.7296	0	0.0497
SA	0.1884	0.964	0
A	0	0.01	0.953

Highlighted cells show recruitment rates, rest of the cells show survival rates

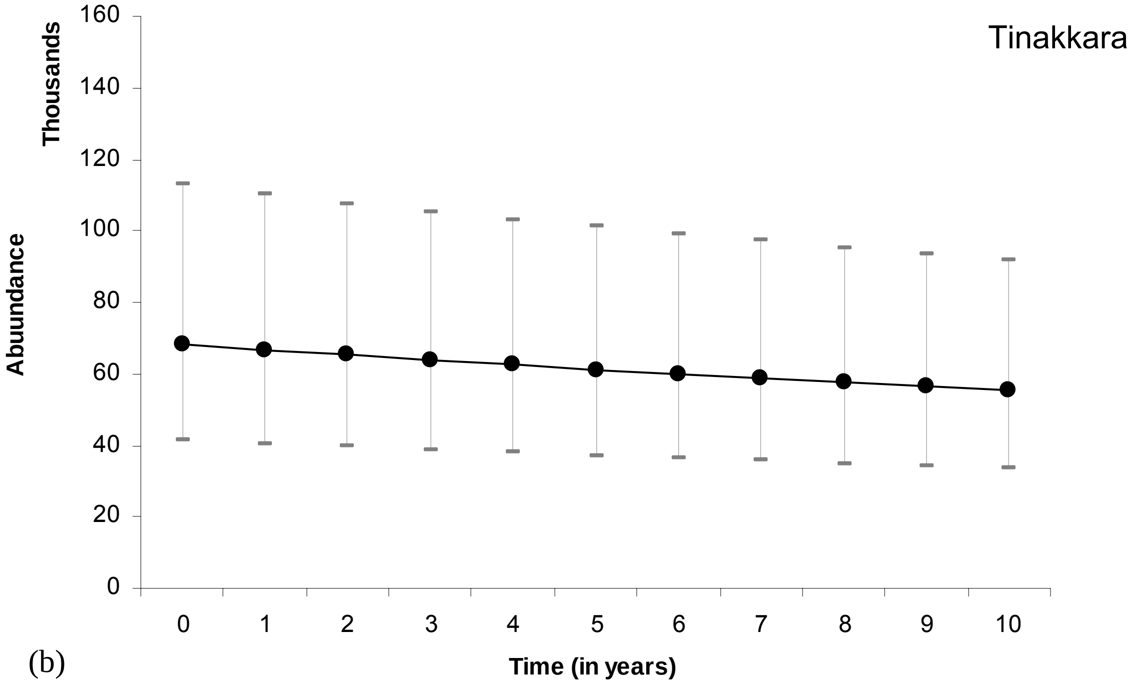
Table 11.7.6 Results of the projection matrix analysis

Eigenvalues		Eigenvectors (R&L)
Real	Imaginary	Age/stage struct
0.978655	0	5.3%
0.936528	0	68.1%
0.731417	0	26.6%
Rate of increase, r	-0.02158	
Expected number of replacements, Ro	0.204659	
Generation time, T	73.5252	

Figure 11.7.7 Deterministic population projection of giant clam *T. maxima* in Tinakkara Island across a time span of 10 years for (a) different age classes and (b) entire population



(a)



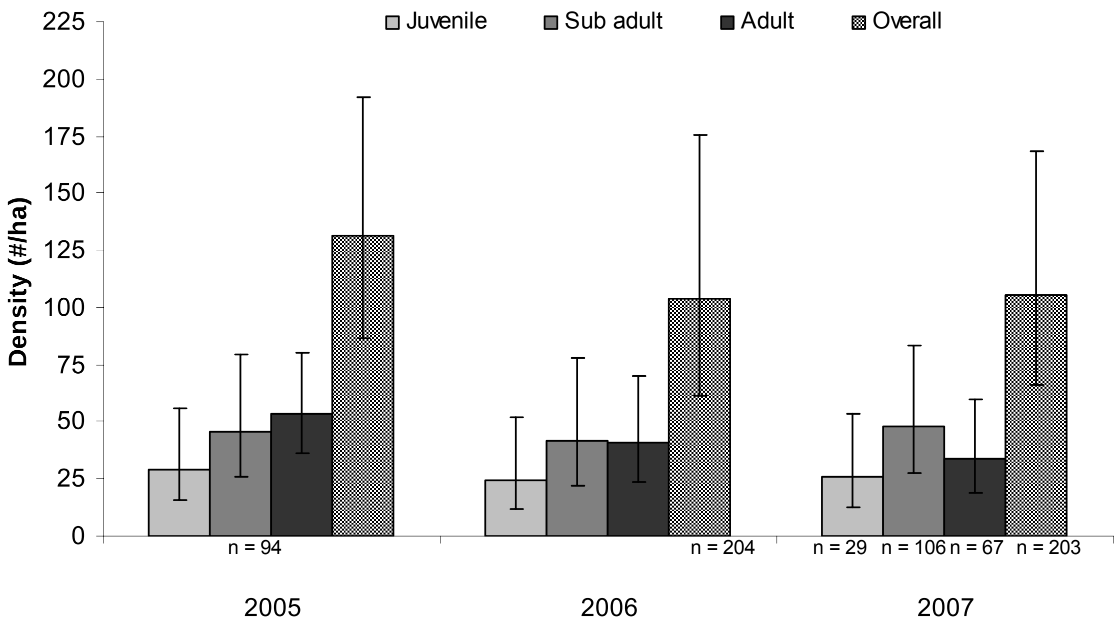
(b)

Error bars are 95 % Confidence Intervals

Giant clam *T. maxima* population projection of Kavaratti Island

T. maxima population of Kavaratti Island was monitored along 14, 100 X 20 m transects between 2005 and 2007. Average annual growth rate of clams were calculated from repetitive measurements and clams were classified into 3 growth stages: juveniles (<100mm), sub adults (≥ 100 mm, < 200mm) and adults (≥ 200 mm). Density estimates of individual age classes as well as overall population were obtained through the conventional distance sampling analysis (Distance 5.0)[22] from observations within 10 m perpendicular distance from the transects. Age classes were selected as different layers; detection probability was estimated globally and density estimation was stratified on the basis of islands (figure 11.7.8). Recruitment density was also estimated as a separate layer. Detection probability of new recruits was quite low at 0.26 as against 0.54 in juveniles, 0.77 in sub adults and 0.69 in adults.

Figure 11.7.8. Density estimates of various age classes and overall population of *T. maxima* in Kavaratti Island across the study years



Error bars are 95 % Confidence Intervals

The transition matrix/ projection matrix of the population was constructed from the average survival and recruitment rates estimated from the vital rates of 2005-06 and 2006-07 time steps . For simplicity, the life history of *T. maxima* was diagrammatized (figure 11.7.9) and an arrow leading from stage X to stage Y was represented in the projection matrix by an entry in column X and row Y of the projection matrix. The population projection matrix was analysed by the MS-Excel add-in software "POPTOOLS" [23] (table 11.7.7 & 11.7.8).

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[22] http://www.ruwpa.st-and.ac.uk/distance/
[23] Poptools: http://www.cse.csiro.au/CDG/poptools/index.htm

Figure 11.7.9. Life history diagram of *T. maxima* in Kavaratti Islands

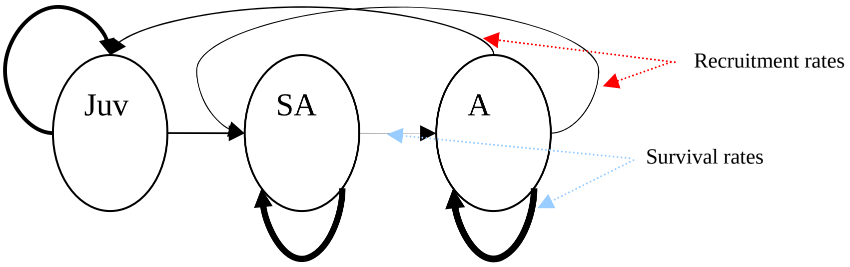


Table 11.7.7 Population projection matrix of *T. maxima* in Kavaratti Island

	Juv	SA	A
Juv	0.48	0	0.5
SA	0.22	0.79	0.37
A	0	0.02	0.79

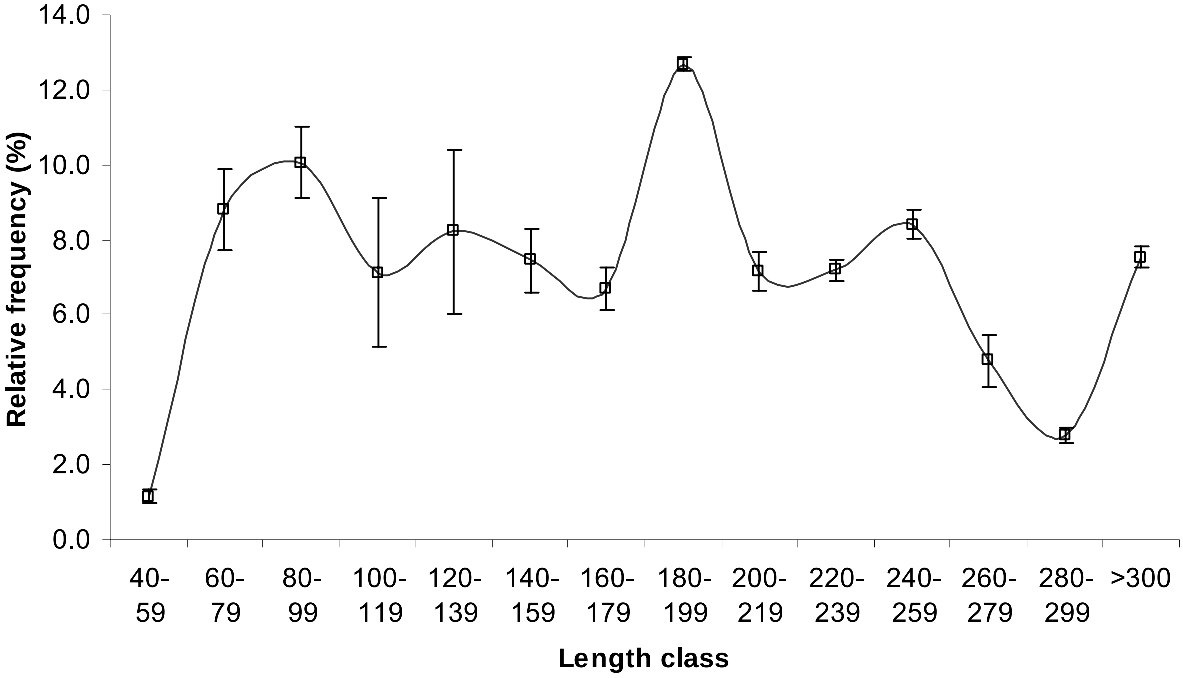
Highlighted cells show recruitment rates, rest of the cells show survival rates

Table 12.7.8. Results of the projection matrix analysis

Eigenvalues		Eigenvectors (R&L)
Real	Imaginary	Age/stage struct
0.902293	0	15.2%
0.646399	0	72.0%
0.511308	0	12.8%
Rate of increase, r	-0.10282	
Expected number of replacements, Ro	0.11528	
Generation time, T	21.01217	

The initial/seed population in different stages of the *T. maxima* in Kavaratti Island was obtained from the density estimate of 131.3/ha over an effective area of 149 ha in 2005, and the corresponding relative frequencies of different age classes in the population (figure 11.7.10). This seed population was projected across a time span of 10 years using the projection matrix (figure 11.7.11).

Figure 11.7.10 Relative proportions of different size classes in the *T. maxima* population of Kavaratti Island across the study years



Variations in relative proportions of different size classes in the *T. maxima* population of Kavaratti Islands across the study years

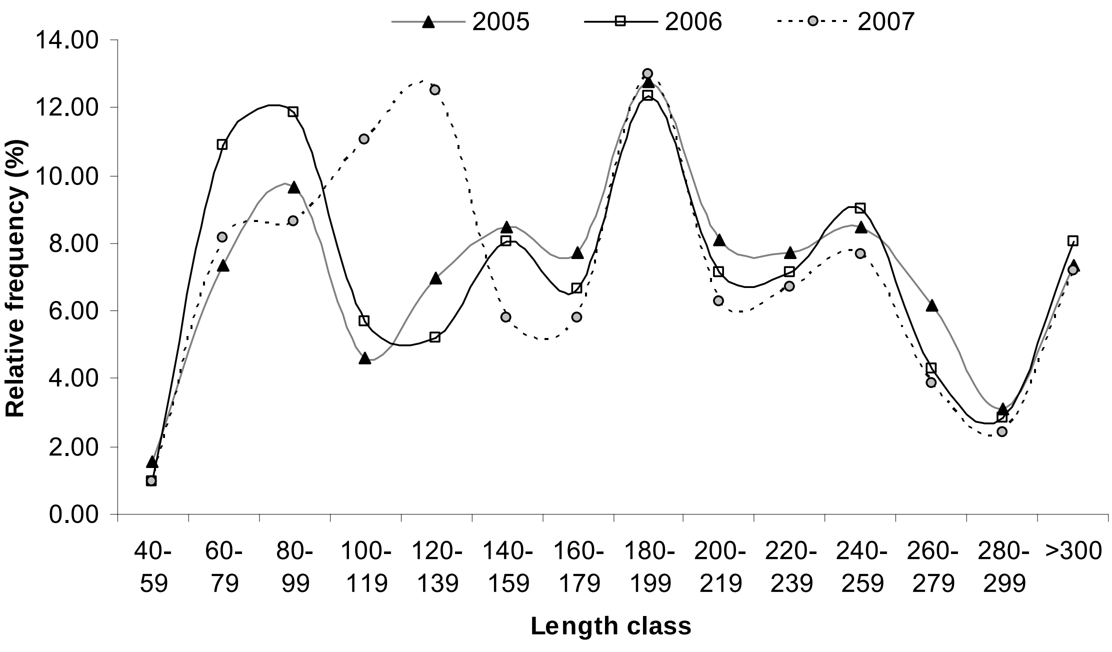
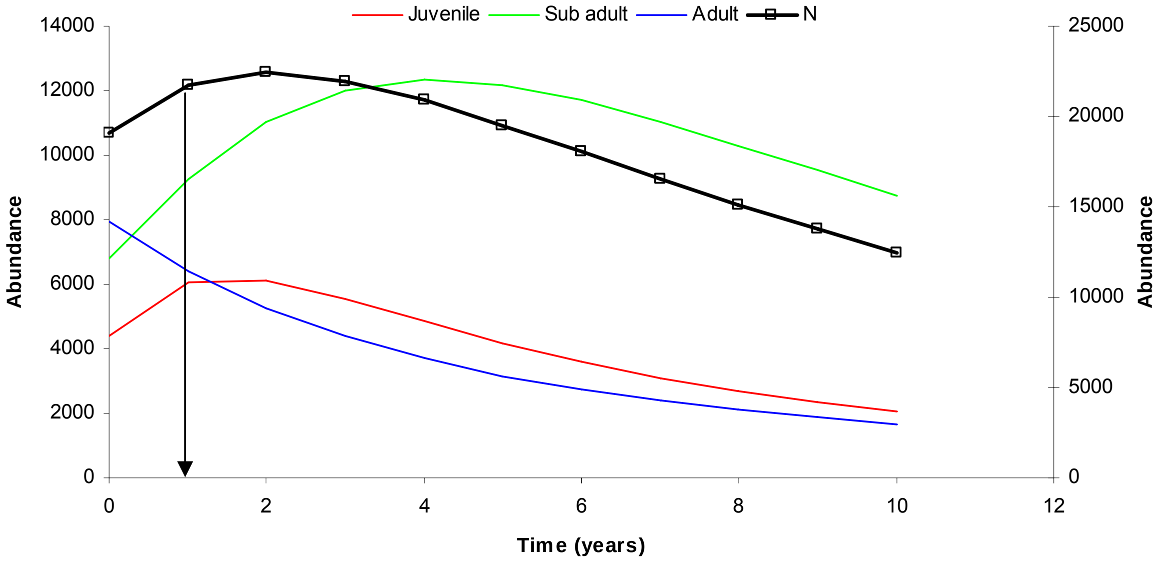


Figure 11.7.11 Population projection of *T. maxima* in Kavaratti Island across a time span of 10 years



Projections of individual stages have been plotted along primary Y-axis and that of the overall population has been plotted along the secondary Y- axis.

T. maxima population projection for Kavaratti and Agatti Islands showed negative growth rates and might decline by < 35% and < 40%over the coming 10 years. Tinakkara population is also on decline but with much slower rate. Bangaram however, had shown stabilization of population and seems much stable.

N.B. Since the vital rates of the two successive time steps (2005-06 and 2006-07) showed considerable variation, unreal, pooled vital rates were used for population projection. This would provide an undistorted picture of the population picture from 2007 onwards.

12. Conservation Issues of Giant Clams

12.1 Trade in giant clams

Giant clams formed an important part in various civilizations as a protein rich food source[24]. For thousands of years giant clams played important role in the diets and cultures of Pacific peoples. Faulkner (1974) documented existence of giant clams in the folklore and mythology of Pacific Island communities. Some of these communities practised traditional forms of giant clam ranching on village reefs (Banner, 1952; Heslinga and Perron, 1984a).

However, as the population increased, the harvesting pressure on giant clams increased many folds thereby over exploiting natural stocks. Today, in many countries, the populations of giant clams diminished to non recoverable levels and are now considered endangered species. Tridacnids have been harvested extensively, mostly illegal to cater Asian markets for highly prized adductor muscle (Bryan & McConnel, 1976; Pearson, 1977; Summerhaya, 1979; Cropp, 1982: Dawson, 1984). Bryan & McConnel (1976) studied population densities of giant clams at Helen Reef, Southwest Palau and reported significant reduction in densities due to harvesting by foreign vessels. Beckvar (1981) reported extension of *T. gigas* from reefs of Ponape, Palau due to over harvesting. Pearson (1977) reported that over 1,56,000 giant clams were harvested from Swan Reef, Australia since 1969. Planes *et al* 1993 reported impact of tourism on standing stocks of giant clams. Munro (1989) reported that 85.7 tonnes of adductor muscle of giant clam had been purchased in Milne Bay Province for export in the period between January 1983 and May 1988. The period between 1967 & 1981 saw a sharp increase in the illegal entry into the province of foreign fishermen, with sightings and arrests of numerous long-range Taiwanese fishing vessels (Bartlett, 1975; Potter, 1975; Standing, 1975). This is just an indication of the level of harvesting of these species in the past. Not surprisingly over harvesting is the single most reason for its decline between 70's and early 80's. Local extinctions are not uncommon due to over harvesting. *T. gigas* has become locally extinct on four islands of Micronesia[25]. Subsequently, cyanide poisoning and dynamite fishing of the reefs for ornamental fish has drastically reduced reef habitat. The over exploitation of matured giant clams and deteriorating reef habitat has cumulative effect on the declining population of most of the giant clam species.

Yung *et al* (1992) did extensive market surveys in Japan, Taiwan, Hong Kong, Australia and USA in terms of uses of giant clams. *T. crocea* is the most preferred species in Japan which amounts up to 500 metric tons annually for sashimi and sushi. Taiwan has a market of over 240 metric tons of fresh and frozen giant clam adductor muscle. Giant clams are popular food on all Pacific island nations.

The harvesting in Japan is mainly for food, aquarium and shell. The domestic catch consists of *T. crocea*, *T. squamosa* and *Hippopus hippopus*. Supply of giant clams to Taiwan market comes from Fiji, Indonesia and Papua New Guinea. It consists of *T. gigas*, *T. derasa*, *T. squamosa*, *T. crocea* and *Hippopus hippopus*.

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[24] Rosewater, 1965
[25] Heslings *et al*, 1984

In 1977, the value of dried adductor muscles of giant clam ranged from 200 to 350 US $ per pound in Hong Kong markets. This high value to the muscle has led to pursuit of intensive illegal fishing mostly by Taiwanese fishing vessels (Gwyther & Munro, 1981).

In Australia and USA, giant clams are popular in aquarium, though the trade is not quantified. However, trade from Australia is restricted only from captive bred stock. Togan community in Australia (originated from Pacific Islands) do consume giant clams from wild. However, the quantity of the same is not known.

Planes *et al* (1993) documented extensively the impacts of tourism related fishing on *T. maxima* populations in Bora Bora lagoon of French Polynesia. He observed a significant decrease in the average shell size of the living populations of *T. maxima*. The average size of *T. maxima* consumed by tourists fell from 130 mm to 108 mm.

T. maxima are considered with possible concern in various range states such as Federated States of Micronesia, Fiji, Marshall Islands, New Caledonia, Vanuata, Vietnam in South Pacific[26]. These are the same areas where once giant clams dominated the reefs. Over harvesting for consumption and souvenirs is the main cause of its dramatic decline. Though giant clams are protected in these countries either under export ban or regulated wild collections, the status of giant clams still remains a great concern. More over there are no studies on wild populations of various species of giant clams in these countries which further complicate the management issues.

Mozambique exported wild sourced *T. maxima* in large quantities ranging between 21-64 tonnes per year from 1995 to 2001. This means appx. 27000 giant clams per year. Most of the catch was sold in European markets. However, since 2001 no trade from Mozambique is reported.

Harvesting *T. maxima* in New Caledonia is primarily for meat. The annual harvest of *T. maxima* is pegged at around 2-3 tonnes per year. The entire harvest comes from wild populations of *T. maxima* (Baillion *et al*, 2002). Tuamotu lagoon supplies around 50,000 clams annually to Tahiti market (Andrefouet *et al*, 2005b).

Zann and Ailing (1988) reported consumption of *T. maxima* meat in Vanuatu and it is considered as prized subsistence food. Heslinga and Watson (1985) reported large scale decline in Tridacnid clams in Indo-West Pacific coral reefs primarily due to over harvesting for subsistence and commercial purpose.

The trade of various species of giant clams from Solomon Island and Indonesia is significant. However, no authentic data is available and at present under review by CITES.

Maldives, which is very close to Lakshadweep with same geographical and anthropogenic settings, also witnessed massive collection of *T. squamosa* (Over 90,000 adult clams in 1991) primarily for the supply to Taiwanese market. However, realizing the magnitude of trade, Government of Maldives through ministry of Trade and Industries stopped issuing licences for the export of giant clams.

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[26] Raymakers *et al*, 2003

Indian population of *T. maxima* are considered least concerned with no reported trade[27]. However, there are no supported documents to this claim. Sporadically giant clams are used as food in Lakshadweep, Andaman and Nicobar islands. There is a possibility of a trade, though of small volume mainly from Andaman and Nicobar Islands. However, there is no data to support it and the information is mostly through traders which needs further validation.

Realizing the need for the conservation of giant clams and its potential as a protein rich diet, many countries started massive programmes on its captive rearing. Simultaneously, many countries provided protection of various degrees to giant clams.

Giant clam use in Lakshadweep

In Lakshadweep giant clams are not removed for any trade purpose. In some islands, however, such as Kiltan, Chetlat, Bitra and Amini, *T. maxima* and *T. squamosa* is removed for consumption. In Amini, we lost over 50 % adult *T. maxima* in one season in one transect to poaching for food. Such actions have disastrous impact on *T. maxima* population especially for the islands like Amini which has low density of *T. maxima* (20.84/hect). The impact gets compounded since most of the harvesting is of adult or sub-adult clams. Such selective removals have adverse impact on recruitment, which is adult density dependent.

12.2 Removal of *Porites lutea*

Porites lutea dominates shallow lagoons in Lakshadweep except Minicoy where this species is not common. *Porites sp*. also commonly called as massive corals are a navigational hazard for fishing vessels. This is more so specially during evening or late night fishing activity where the brown colour of this massive coral becomes invisible. These massive corals formations thus limit the movement of fishing boats within lagoon waters. Thus in many places, these corals are removed for fast movement of fishing boats. This in turn have disastrous impact on *T. maxima* which needs these massive corals as substrate. This is clearly evident from the studies in Minicoy Island.

Minicoy case study
Minicoy is the southern most islands in Lakshadweep Archipelago. Though part of Lakshadweep Archipelago, this island is different in cultural and social setting. This small island (3.7 sq.km) has ten villages which are distinct. Each village is clearly demarcated by boundary wall. While doing close examination of the wall, we found that it is primarily built by using massive corals boulders of *Porites lutea* from lagoon. Thus over several years, the massive corals are systematically removed for both constructions of village boundary walls as well as for maintenance of channel for fishing vessels.

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[27] AC 22 Doc 10.2 Annex 8f. CITES

Village boundary wall like this is entirely made from *Porites lutea* and *Porites solida*

Benthic studies clearly reveal that the Minicoy lagoon is devoid of massive corals. This niche was then easily overtaken by fast growing *Heliopora coerulea*. As compared to massive corals, this species is softer and highly septate structure. Thus *T. maxima* can not anchor on this species. Even if they anchor, as they grow, they fall apart easily. It is clearly evident from population studies of *T. maxima*. The density of *T. maxima* in Minicoy is third lowest, 62.29 clams/hect, next only to Amini which has 20.84 clams/hect and Kadmat 35.78 clams/hect.

Heliopora coerulea dominates Minicoy lagoon

Highly septate structure of *Heliopora coerulea* is not suitable for the growth of *T. maxima*

12.3 Disease to massive corals or *Porites lutea*

Porites lutea being most important substrate for *T. maxima*, any impacts on this species have influence on *T. maxima* populations. *Porites* are known to get affected with several coral diseases and bioeroders. Some of them are summarized below. However, we have not assessed the magnitude of these diseases and its impact in Lakshadweep.

The Black-band Disease is most common and wide spread disease affecting different types of corals and particularly massive reef building corals. It is caused by cyanobacterium *Phormidium corallyticum* (Rutzler & Santavy, 1983). The disease has been reported from Carribean (Garrett & Ducklow, 1975; Rutzler *et al*, 1983), Indo-Pacific (Antonius, 1985a) and the Red Sea (Antonius, 1988). Bruckner and Bruckner (1997) studied it from Jamaica. Gladfelter (1982) reported extensive mortality of *Acropora palmata* from Virgin Islands due to White-band Disease (WBD). Richardson (1998) reported white plague II disease from Florida reefs. Sweatman *et al* (2002) reported White syndrome from reefs of Papua New Guinea.

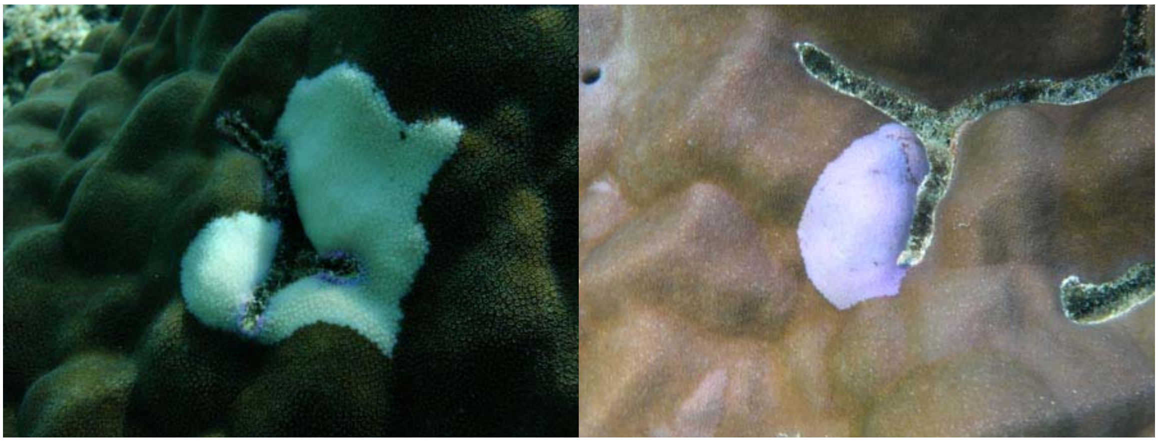
Ravindran and Raghukumar (2002) reported Pink-line Syndrome in *Porites lutea* in Lakshadweep. Ravindran *et al* (1998) reported disease and stress induced mortality of corals from Andaman Island. They also reported necrotic lesions, flashy algal over growth, Black-band Disease and White-band Disease from Lakshadweep. Necrotic lesions were common in *Porites lutea*.

The disease affects the live coral polyps by killing it and as the band progresses, filamentous algae grown over dead corals followed by growth of turf and crustose algae.

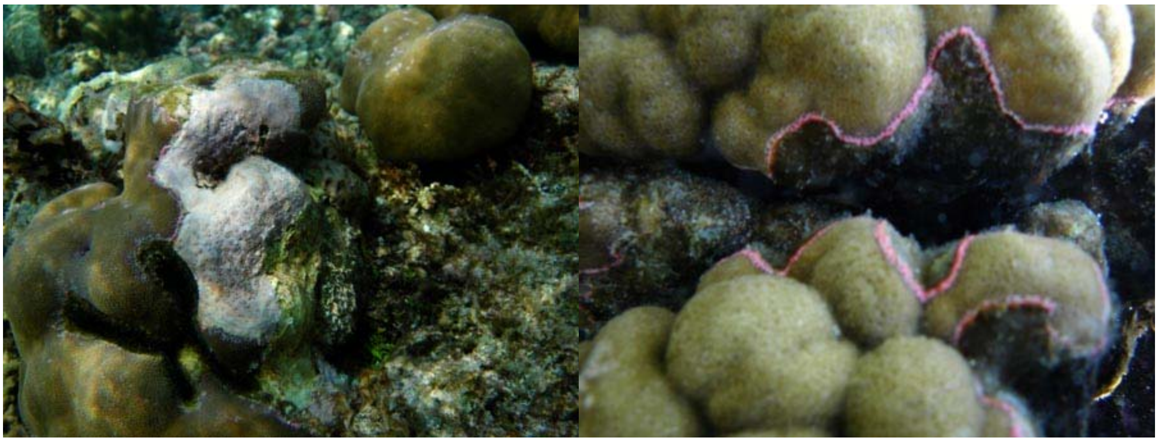
Though we have noticed several diseases in *Porites lutea*, it is still not a major concern as it is very patchy and insignificant. However, as reef resilience decreases with events such as El Niño, the dormant diseases can become epidemic thus killing the most important substrate of *T. maxima*. A detailed investigation on types of diseases and its magnitude needs to be assessed in Lakshadweep. Goreau *et al* (2000) found that

Porites were least impacted by 1998 El Niño and especially after the mortality of *Acropora*, became dominant corals in Indo-Pacific reefs. However, Ravindran *et al* (1998) in India reported that these corals are dying at the rate of few centimetres per year due to Pink-line disease.

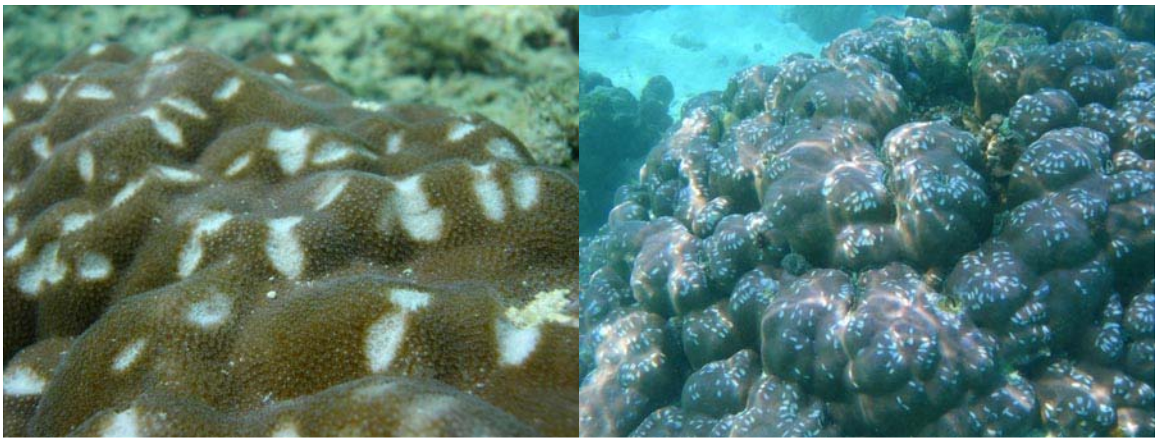
If global warming is rising the baseline on which the regional ENSO fluctuations occur, then global warming needs to be considered an important factor for bleaching (Williams & Bunkley-Williams, 1990; Goreau *et al*, 2000).



White patch disease of *Porites lutea* and *Porites solida*



Pink-line Syndrome of *Porites lutea*



Unknown disease of *P. lutea* and *P. solida*

12.4 Bioeroders

Massive corals are prone to bioerosion by various organisms. Hutchinge (1986) stressed that bioerosion is a major structuring force operating in coral reefs. The initial boring community is dominated by polychaetes which subsequently replaced by sponges, sipuncules and bivalves. Hutchinge and Peyrot-Clausade (1988) studied boring communities of *Porites* in Australia. Giant clams are also one of the bioeroders for *Porites*. Hassan *et al* (1997) studied boring activity in *Porites lutea*. However, in the present study the impact of bioeroders on *Porites* community was not studied in Lakshadweep. The impact of bioeroders can have some influence on available substrate for new recruits of *T. maxima* and *T. squamosa*.

Christmas-tree Worm (*Spirobranchus giganteus*) is one of the most common bioeroder on *Porites lutea*

Many species of polychaetes bores inside *P. lutea*

Dredging and subsequent sedimentation

Lakshadweep is predominantly atoll formations. These atolls have natural channels (main channel in the north side and a central channel) which are in recent times deepened for navigation. These channels need annual maintenance for sand and sediment deposit. Disposal of dredged sand from these channels on the reef and other parts of lagoon is a critical issue which is responsible for the increase in the sedimentation.

12.5 Low adult density

The data clearly indicate that the recruitment of *T. maxima* is directly dependent on adult density. Except for Kavaratti and Bitra which showed skewed results, all other islands, clearly indicate that 60-100 adults per hect (figure 12.2.2) are required to have successful recruitment. Since *T. maxima* is low density species in Lakshadweep, the population trends will continue to decline unless reintroduction efforts are made. Table 11.1.4 provides the densities of adults across various islands. A combination of many factors such as low adult density and low recruitment combined with high mortality and anthropogenic stresses will continue to be cause of concern for *T. maxima* in Lakshadweep.

12.6 El Niño and coral bleaching

The 1997–1998 El Niño Southern Oscillation (ENSO) event which elevated Sea Surface Temperatures (SSTs) of tropical oceans by more than 3°C, was one of the most extreme ENSO events in recent history. Such increases in SSTs above the seasonal average can trigger widespread bleaching in coral reefs. This the first time we realized the magnitude of the damage such events can cause. Even after 10 years, several reefs have not yet recovered from the colossal damage. Warming of seas with increasing frequency can spell doom for coral associated species. Arthur (2000) reported extensive bleaching of reefs in Lakshadweep to the tune of 82% and bleaching related mortality of about 26% within lagoons of Kavaratti and Kadmat. He also reported complete bleaching of massive corals forms up to 19.89 % and partial bleaching up to 36.94 %. The impact of it on *T. maxima* however was not studies. Thus comparative data is not available. Subsequent monitoring data by Lakshadweep Coral Reef Monitoring Network (LCRMN) shows partial recovery up to 50-60 % in several islands. This clearly indicates that the high sea reef formations are more resilient that the reefs close to land where anthropogenic pressures affect the recovery.

January 2007 also seen high warm water regimes, however, the bleaching was sporadic and not what has been seen during 1998 El Niño. From some parts of

Lakshadweep bleaching have been reported by divers. However within confined water, no bleaching was seen in any of the islands.

Recovery of Coral cover in Agatti and Kavaratti post El Niño

The Lagoon recovery of Agatti and Kavaratti was pegged at 58 % and 60 % respectively by Project Giant Clam. The outer reef recovery is much slow and pegged at 30% and 43% at Kavaratti and Agatti by LCRMN. This is a clear indication that with even a conservative estimate, it may take up to 10-15 years of time for the recovery after a massive bleaching event like the one happened in 1998. In the light of such events happening with increasing frequency (even if of not the scale on 1998), the reefs at Lakshadweep are in serious threats. Increasing reef resilience through people's participation is thus paramount to counter the threats of rising sea temp. Though we can do little to control such events we can atleast try to reduce anthropogenic pressures on reefs and thus helping reef to be more resilient.

14. Role in ecosystem

Lagoon enrichment through nitrogen: Giant clams play a crucial role in lagoon ecology by releasing zooxanthellae packed faeces, thus releasing large amount of organic mater in to the lagoon water.

Carbonate budget of the reefs: Many biotic and abiotic factors affect the carbonate budget of the reefs. Several authors reported bioerosion in reefs by various organisms (Banes *et al*, 1974; Clapp and Kenk, 1973; Hammer and Jones, 1976, Glynn, 1973; Randall, 1974; Evans, 1968; Ahr and Stanton, 1963; Neumann, 1966; Rutzler and Rieger, 1973; Futterer, 1974; Rutzler, 1975). Sponges, annelids, sipencules, bivalves perform important role of bioerosion.

Burrowing clams such as *T. maxima* and *T. crocea* erodes massive corals with deep and wide holes. Thus their role as bioeroders is very important. Hammer and Jones (1976) reported that *T. crocea* produces 200 gm sediment/m^2/year which is comparable to the bioerosion by sponges.

In the present project however, we have not studied these aspects.

15. Key Findings

Giant clam *T. maxima* is a key indicator species in coral reefs due to its selective ecological requirements. Monitoring of its populations can be used as a tool to monitor changes in the lagoon ecology.

- *T. maxima* primarily occur in shallow waters in Lakshadweep and mostly distributed inside lagoons.
- Moderate intensity brown pigment is super dominant in *T. maxima* population of Lakshadweep Archipelago probably because of camouflaging suitability in the ambient habitat. Other primary and accessory colours showed variations across islands and to some extent with age and water depth.
- *T. maxima* occur in low densities in Lakshadweep. Agatti has the highest density being 227.84 clams/ha declining to 188.40 clams/ha. Amini has lowest density of 20.84 clams/ha declining to 13.66 clams/ha.
- The overrall density of recruits during 2005-07 was 11.97/ha (95%CL 8.05-17.79). Survival rate of recruits in the first year obtained by bootstrapping was 62%. Recruitment was highly correlated ($r = 0.8$, $p < 0.001$) with herbivory measured as indices of herbivorous fish abundance.
- *T. maxima* in Lakshadweep archipelago grows at a slow annual rate of 8 – 11 mm in the juvenile stage with growth becoming slower and stochastic with age.
- *Porites lutea* is the main substrate on which the juvenile settle and anchor itself. Thus any removal of these massive corals will have catastrophic impact on *T. maxima* population as evident from Minicoy Island population of *T. maxima*.
- *T. maxima* prefer live coral substrate with dead coral tops as an ideal anchor site.
- It revealed an exclusive use of *Porites lutea* (>80% relative use). *Porites* flats are most favoured site selection criterion for the recruitment of juveniles.
- Habitat use Vs Availability: 64% of the samples fell into the low density class (90-100/ha), 22% in the medium density (100-200/ha) and only 14% in the high density class (>300/ha), indicating that bulk of the habitat available for the species is sub-optimal, and optimal habitats are scarce.
- Giant clam *T. maxima* prefers the dead flat tops (with live coral on all sides) and to lesser extent, the walls of the coral *Porites lutea* within a narrow range of water depth (0.2 - 0.8m) in the lagoon. Such specific habitat requirements leave very little potential space (~ 3 % crude estimation) for the species in the lagoon.
- Mortality in juveniles is highly influencing the populations. Mortality rate of giant clam *T. maxima* between 2005 & 2006 was 0.16 (SE = 0.023, n = 105). Anchorage failure contributed 15% to the overall mortality.
- *T. maxima* are a low recruit species. Recruitment rate was as low as 0.21 (SE = 0.11, n = 11 lagoons recruits per breeding individual. Recruitment is seen mostly near lagoon entrance there by suggesting requirement of strong currents.
- *Tridacna maxima* showed a mortality rate of 0.16 (SE = 0.023, n = 105) and a slow recruitment rate of 11.97/ha (95%CL 8.05-17.79) offspring per breeding individuals resulting in a negative intrinsic growth rate.
- *T. maxima* recruitment is adult density dependent and need between 60 to 100 adult clams per hect for successful recruitment.
- The size class distribution, a surrogate of the age distribution of the species is a bell shaped curve with medium sized individuals dominating the population.
- Population structure was skewed from normal distribution towards greater size classes probably due to the rapid growth of juveniles (<160mm) and extremely

slow growth of adults (>200mm) leading to higher proportions of mid-sizes. Age/size distribution varied considerably across islands with Bangaram, Tinakkkara, Minicoy and Amini (but not Agatti, Bitra, Chetlat, Kadmat, Kalpeni, Kavaratti, Kiltan and Suheli) showing age/size structure similar to the typical population.

- Convict Surgeonfish (*Acanthurus triostegus*) is the single most dominant browser inside lagoon waters. Thus role of this species in maintaining microhabitat for new recruits is most crucial part of *T. maxima* life cycle.
- Deeper embedment is crucial for the survival of adults especially in light of high wave surge in monsoon.
- *T. maxima* juveniles showed an annual growth of 10-12mm per year. The growth rate reduces significantly post sub-adult stage.
- *T. maxima* are niche selective species. This species is specialized to a narrow range of reef canopy with ~ 90% of the population utilizing a range of 0.2-0.6 m from the sea floor
- *T. maxima* are highly vulnerable for rise in sea temperature in the events like El Niño. This is primarily due to presence of zooxanthellae inside the body of *T. maxima*.
- *T. maxima* are regularly consumed in Amini, Chetlat, Kiltan and Bitra islands. There is no evidence to suggest its consumption on other islands.
- Giant clams play a crucial role in lagoon ecology by releasing zooxanthellae packed faeces, thus releasing large amount of organic mater in to the lagoon water.
- Being boring clams, *T. maxima* plays important role as bioeroders in lagoon ecology.
- With low recruitment, high mortality, low adult density and niche selectivity, the *T. maxima* population in Lakshadweep can be considered critical.
- The population models for Kavaratti and Agatti, suggest predicted decline of 35% over next 10 years. Bangaram and Tinnakara populations however, are comparatively stable.
- The large sized individuals in the *T. maxima* population is an interesting finding of the present study. It is not an individual instance and large size clams are not an uncommon sight especially at Cheriyam, Bangaram, Bitra and Suheli.
- *Cymatium pileare, Cymatium muricinum* and *Vexillum plicaria* as predators of *T. maxima* in Lakshadweep.

16. Recommendations

1. Long term monitoring of *T. maxima* is essential to make population projections. The permanent transects laid during the project can be used to continue monitoring of *T. maxima* populations.
2. As the *T. maxima* grow exclusively on massive corals *Porites lutea* its destruction and removal must be avoided. These massive corals are usually removed for easy navigation within lagoon.
3. Population studies on Convict Surgeon fish *Acanthurus triostegus* will be useful for management of *T. maxima*. It is a main table fish for locals in Lakshadweep thus further studies are required to assess the impact of harvesting of this fish species on *T. maxima* recruitment.
4. Lagoon sedimentation needs to be monitored. As *T. maxima* prefer lower reef strata. An excess sedimentation in the lagoon can have significant impact its populations.
5. Sea temperature monitoring is essential as *T. maxima* are prone to sea temperature rise.
6. Education campaigns are required especially at Amini, Chetlat, Kiltan and Bitra where *T. maxima* are consumed regularly.
7. The large size clams found in the Lakshadweep needs genetic studies to ascertain the species level identification.
8. Mariculture of *T. maxima* must be explored for reintroduction in some islands where populations are dismal. The islands which need special attention are Kadmat, Minicoy and Amini.
9. Dredging activities for channel maintenance and sand disposal in all islands must be carefully planned and executed. Disposal of dredged sand inside lagoon must be avoided as it can lead to substrate clogging.
10. Opening of new channels through breaking of reef crest must not be done as it can alter the lagoon ecology significantly as seen in Minicoy Island. This can not only affect *T. maxima* but also coral community as well.
11. The existing protection to giant clams (*T. maxima*, *T. squamosa,* and *Hippopus hippopus*) under Schedule I of the Wildlife (Protection) Act, 1972 must continue.
12. Similar studies are required for *T. squamosa* whose population is much less than *T. maxima* in Lakshadweep.

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