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ORIGINAL RESEARCH ARTICLE

Distribution and invasiveness of a colonial ascidian, *Didemnum psammathodes*, along the southern Indian coastal water☆

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Summary Ascidians are well known worldwide for their rapid invasions and also for the presence of potential biomedical molecules. Members of the family Didemnidae are widely distributed in tropical waters and they are reported to be among the families possessing rich bioactive compounds. *Didemnum psammathodes* has a cosmopolitan distribution in tropical waters. The growing evidence of multifarious potential and ever increasing invasion of this species accentuated the need for additional research into its diversity and distribution for sustainable utilization and conservation. The present study was intended to focus on distribution and invasiveness of colonial ascidian, *D. psammathodes*, along the southern Indian peninsular waters. The present data are based on our own observations made during 2012—2014 period and also on the published and unpublished records of the last 20 years. Out of 45 stations surveyed, *D. psammathodes* was encountered at a maximum of 41 stations and was found to be more abundant in Hare Island ($n = 42$), North Break Water ($n = 38$) and Vizhinjam bay ($n = 32$). This species was

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absent at four different stations. Catch per unit effort was higher (19.6) in Hare Island followed by NBW (16.0) and Vizhinjam bay (6.8). The highest number of colonies (136) was observed in calcareous stones, followed by embedded rocks (54) and molluscan shells (33). Hydrographical parameters showed no significant differences between the stations ($p < 0.005$). It is concluded that *D. psammathodes* has the potential to invade most of the stations and its distribution was not influenced by hydrographical parameters rather than substrates.

1. Introduction

Ascidians (also known as Tunicates) are a dominant and ever present group among benthic organisms in tropical and temperate regions (Goodbody, 1993; Hernandez-Zanuy and Carballo, 2001; Sahade et al., 1998). This group of animals have been acknowledged worldwide for the presence of potent secondary metabolites and rapid invasion. The colonial ascidian, *Didemnum vexillum*, first recorded in the 1980s along the coasts of North America was the first best example of an invasion and spreading. This species established a large population in numerous sites and overgrew many sessile plants and animals (Valentine et al., 2007), including other tunicates, resulting in considerable ecological and economic damage (Adams et al., 2011; Carman et al., 2010). The impact of non-indigenous ascidians on local species and habitats is currently being studied in several countries around the world (Bullard and Carman, 2009; Lambert and Lambert, 2003; Shenkar and Loya, 2009; Stachowicz et al., 2002a). On the other hand, ascidians have been proven to be a rich source of pharmacological compounds (Davidson, 1993; Haefner, 2003; Jain et al., 2008; Rinehart, 2000). Because of their high nutritive value of ascidians, some of them are used as food for man and feed for culturable species (Nanri et al., 1992; Nguyen, 2007; Randall, 1967; Tamilselvi and Abdul Jaffar Ali, 2013; Tapic Jopia and Toledo, 2007). Other ascidians have been used as flagship species for environmental monitoring (Abdul Jaffar Ali, 2004; Abdul Jaffar Ali et al., 2011, in press; Tamilselvi, 2008).

The increasing evidence of ascidians multifarious potential and their rapid invasion highlight the need for additional research of sustainable utilization, management and conservation of this group of animals. To date, limited studies have been carried out to report the invasive status of ascidians in Indian waters. Abdul Jaffar Ali et al. (2009) reported 34 non-indigenous ascidians from southern coast of the Indian peninsula and Tamilselvi et al. (2011) reported 22 non-indigenous ascidians from Thoothukudi coast of India. No study has been conducted on intercoastal spread of invasive ascidians. Such data are of great importance in terms of estimating the rate of invasion and possible effects on the native fauna in the natural environment.

Members of the family Didemnidae (class Ascidiacea, suborder Aplousobranchia) are widely distributed in tropical waters and are reported to possess chemically diverse novel compounds with potent biological activity (Carte, 1996; Davidson, 1993; Dunlap et al., 2011; Schmidt et al., 2013). This group has attracted increasing attention around the world for their potential invasion of marine communities. Didemnids adapt to survive in a wide range of environmental variables (Bullard et al., 2007; Valentine et al., 2007). In recent past, interest in *Didemnum psammathodes* has heightened due to the presence of bioactive compounds with potent antibacterial and antifouling properties (Anand and Paterson, 2002; Ramasamy and Murugan, 2003; Sri Kumaran et al., 2011; Thakur, 2001).

In India, *D. psammathodes* was first documented along the Thoothukudi coast, by Renganathan (1981), and appeared in additional locations in Vizhinjam bay (Abdul Jaffar Ali and Sivakumar, 2007), Palk Bay (Karthikeyan et al., 2009) and the Gulf of Mannar (Meenakshi and Senthamarai, 2013). As with many species, the actual date of invasion is uncertain. The present study reveals the occurrence, distribution pattern, surface preference and intercoastal invasiveness of the colonial ascidian, *D. psammathodes*, along the southern Indian peninsula regions.

2. Material and methods

Studies were conducted during the 2012—2014 period covering all the seasons at 45 stations (Fig. 1) along the stretch of 110 km of southwest and 130 km of southeast coastlines of India. The survey was carried out on foot, via snorkelling and SCUBA diving in different habitats. Observations were made on different substrates available in the study areas. Description of each substrate is briefed below.

Calcareous stones: At stations 1, 6, 8, 9, 17, 18, 32, 34, 35, 36, 37, 38, 39 and 44, the calcareous stones of varying sizes ranging from 1 to 5 m^3 are laid down to break the sea water. These stones are considered here as artificial substrates. Observations were made on the undersides of the stones.

Embedded rocks: At stations 1, 5, 6, 13, 16, 17, 18, 22, 29 and 35, small to large boulders are embedded partially in shallow water regions and intertidal flats. The samplings were made at the submerged parts of the boulders.

Mussel bed: Stations 1, 2 and 3 are known for molluscan fishery. Molluscan beds of varying size are available at a depth of 10—15 m. Generally brown mussel, green mussel and some other bivalves are seasonally fished at these stations. Observations were made on shells of these molluscans via SCUBA diving.

Hull of boat: At harbour stations (1, 4, 33 and 42), the observations were made on a hull of a fishing boat and barges via snorkelling and SCUBA diving.

Oyster cages: At stations 1 and 33, oyster cages are installed at a depth of 4—5 m by the Central Marine

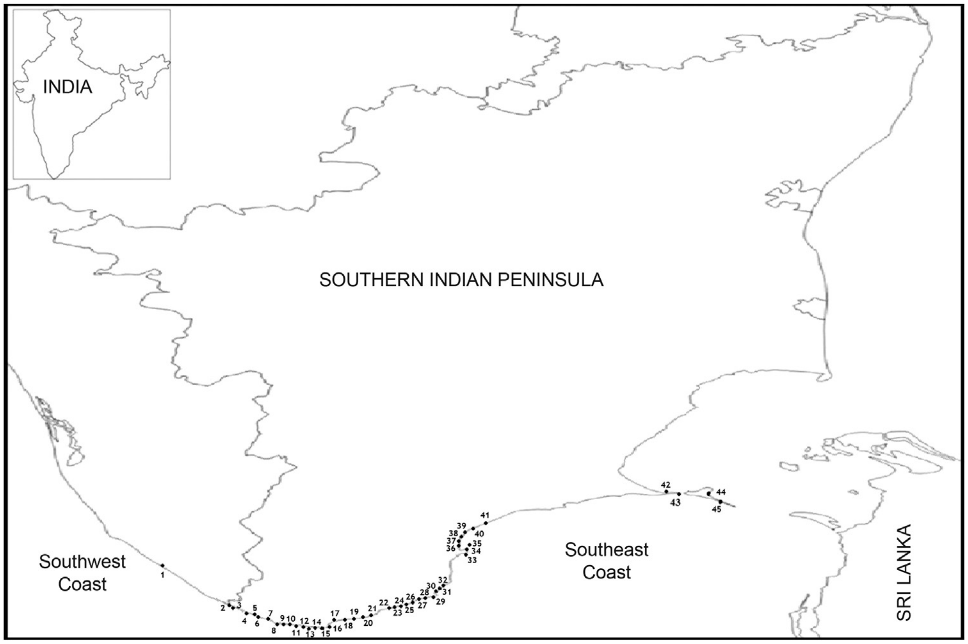

Figure 1 Map showing the study areas.

Fisheries Research Institute (CMFRI). The cages were observed for the presence of *D. psammathodes* during brushing.

Cement blocks: At stations 1, 4, 17, 33 and 42, harbour berths made of large sized cement blocks were sampled via snorkelling.

Molluscan shells: At stations 19, 30, 33 and 42, the samplings were made from broken and dead molluscan shells present in the shallow water region and intertidal flats.

Coral pieces: The stations 33 and 43 are known for coral reefs. Many dead coral pieces are found to occur in the shallow water and intertidal flats. They were also sampled.

Sea weeds: At station 40, large vegetation of sea weeds was observed for the occurrence of *D. psammathodes*.

All substrates (natural and artificial) at the surveyed sites were equally searched and when appropriate, small boulders and calcareous stones were overturned and examined. Since many ascidians have been trapped unintentionally during fishing at 15—20 m depth, fish landing centres were also visited to examine *D. psammathodes* from the fishing nets and trawl.

Hydrographic parameters such as temperature, salinity and pH were measured in situ using digital thermometer (Mextech), digital pH pen (Hanna-HI98107) and refractometer respectively. The dissolved oxygen in the water samples was measured using Water Quality Analyzer 301. Data of annual rainfall [mm] were obtained from meteorological departments of both states Tamilnadu and Kerala, India. Since search times differ at each site, the total number of *D. psammathodes* collected was standardized using catch per unit effort (CPUE). This measure was found by dividing the number of colonies observed by the number of person hours of search time (Mundo, 2009).

The data were analysed statistically by calculating mean and standard deviation for triplicates of the various parameters investigated. Analysis of variance (one-way ANOVA) was used to evaluate the significance of differences between groups of measured parameters at different stations with the significance level set at $p \leq 0.005$.

3. Results

Occurrence and distribution of *D. psammathodes* on various substrates at different stations along the southern Indian coastal waters are represented in Table 1. In the present survey, a total of 316 colonies of *D. psammathodes* were observed along the southern Indian coastal waters at 45 stations.

The number of colonies ranged from 1 to 32 in southwest coast. Maximum number of colonies was observed at Vizhinjam bay ($n = 32$) whereas no single colony was observed at Enayam. In southeast coast, *D. psammathodes* recruited majority of the stations (26) and the range varied between 2 and 42. The maximum number of colonies was observed at Hare Island ($n = 42$), followed by the North Break Water (NBW) ($n = 38$). *D. psammathodes* was absent in Therespuram, Rameswaram and Dhanushkodi (Table 2).

Catch per unit effort (CPUE) for *D. psammathodes* ranged from 0.1 to 1.2 along the 18 stations of southwest coast and it was 6.8 at Vizhinjam bay. CPUE range was in between 0.1 and 4.4 along the 24 stations of southeast coast and it was higher (19.6) in Hare Island followed by NBW (16.0). CPUE was nil for four stations along the southwest and southeast coast of India.

Among the six available natural substrates in different stations encountered during the study, highest number of colonies (54) was recorded in embedded rocks followed by molluscan shells (33) and the low number of colonies was at sponges (11), whereas among the four artificial substrata, maximum number of colonies (136) was observed in calcareous stones followed by cement blocks (19), hull of boat (14) and oyster cages (9) (Fig. 2).

Table 1 Occurrence and distribution of *Didemnum psammathodes* along the southern Indian coastal waters.

No.	Stations	Coordinates	Substrates	Occurrence	CM
Southwest coast					
1	Vizhinjam bay	8°22′55″N, 76°59′26″E	CS	x	HP
			ER	x	HP
			MB	x	SD
			HB	x	SN
			OC	x	SD
			CB	x	SN
2	Enayam	8°12′55.2″N, 77°11′31.9″E	MB	a	TC
3	Mel Midalam	8°12′45″N, 77°12′51″E	MB	x	TC
4	Colachel	8°8′17″N, 77°18′12.7″E	CB	x	HP
			HB	x	HP
5	Kadiyapattanam	8°8′4″N, 77°18′31″E	ER	x	HP
6	Muttom	8°8′17″N, 77°18′12.7″E	ER	x	HP
			CS	x	HP
7	Pillai Thoppu	8°7′38″N, 77°20′9″E	–	x	TC
8	Azhikkal	9°07′59.1″N, 76°27′44.3″E	CS	x	HP
9	Pozhikarai	8°6′26″N, 77°24′4″E	CS	x	HP
10	KesavanPuthenThurai	8°6′21″N, 77°24′34″E	–	x	TC
11	PuthenThurai	8°6′11″N, 77°25′4″E	–	x	TC
12	Sanguthurai	8°5′56.1″N, 77°25′26.7″E	–	x	TC
13	Pallam	8°5′58″N, 77°25′55″E	ER	x	HP
14	Mel Manakudi	8°5′29″N, 77°28′48″E	–	x	TC
15	Keel Manakudi	8°5′21″N, 77°29′22″E	–	x	TC
16	Kanyakumari	8°4′42.1″N, 77°33′5.4″E	ER	x	HP
17	China Muttom	8°5′47″N, 77°33′50″E	CS	x	HP
			ER	x	HP
			CB	x	HP
18	Leepuram	8°6′46″N, 77°33′19″E	ER	x	HP
			CS	x	HP
19	Arokiya Puram	8°7′9″N, 77°33′37″E	MS	x	HP
Southeast coast					
20	Kootapuli	8°8′50″N, 77°36′0″E	–	x	TC
21	Koodankulam	8°10′28″N, 77°42′19″E	–	x	TC
22	Uvari	8°16′40″N, 77°53′27″E	ER	x	HP
23	Kooduthalai	8°17′59″N, 77°55′37″E	–	x	TC
24	Periyathalai	8°20′7″N, 77°58′21″E	–	x	TC
25	Manapad	8°22′28″N, 78°3′34″E	–	x	TC
26	Kulasekharapatnam	8°24′1″N, 78°3′24″E	–	x	TC
27	Alanthalai	8°28′0″N, 78°5′58″E	–	x	TC
28	Amali Nagar	8°29′21″N, 78°7′22″E	–	x	TC
29	Tiruchendur	8°29′49″N, 78°7′32″E	ER	x	HP
30	Veerapandiapattanam	8°32′08.6″N, 78°7′17.0″E	MS	x	TC
31	Kayalpatnam	8°34′15″N, 78°7′15″E	–	x	TC
32	Punnakkayal	8°38′3″N, 78°6′50″E	CS	x	HP
33	Thoothukudi (Harbour)	8°45′14″N, 78°12′39″E	CS	x	HP
			HB	x	SD
			OC	x	SD
			CB	x	SD
			MS	x	HP
			CP	x	HP
34	North Break Water	8°46′24.3″N, 78°12′5.6″E	CS	x	HP

Table 1 (*Continued*)

No.	Stations	Coordinates	Substrates	Occurrence	CM
35	Hare Island	8°46′36″N, 78°11′38″E	CS	x	HP
			ER	x	HP
36	Roch Park	8°48′59.3″N, 78°9′48.2″E	CS	x	HP
37	Inigo Nagar	8°47′22″N, 78°9′37″E	CS	x	HP
38	Collectors Bungalow	8°48′38″N, 78°9′53″E	CS	x	HP
39	Therespuram	8°48′59.3″N, 78°9′48.2″E	CS	a	HP
40	Vellapatti	9°7′7.6″N, 78°24′42.9″E	SW	x	HP
41	KeelaVaippar	8°59′54.8″N, 78°15′16.2″E	–	x	TC
42	Mandapam	9°17′29″N, 79°9′1.1″E	HB	x	HP
			CB	x	HP
43	Pamban	9°16′52.1″N, 79°11′53.5″E	MS	x	HP
			CP	x	HP
44	Rameswaram	9°17′2″N, 79°19′2″E	CS	a	HP
45	Dhanushkodi	9°12′42″N, 79°22′27″E	–	a	TC

Note: CM, collection method; CS, calcareous stones; ER, embedded Rocks; MB, mussel bed; HB, hull of boat; OC, oyster cages; CB, cement blocks; MS, molluscan shells; SW, sea weeds; CP, coral pieces; HP, hand picking; SD, SCUBA diving; SN, snorkelling; TC, trawl collection; x, present; a, absent.

Table 2 Catch per unit effort (CPUE) per site.

S. no.	Stations	*N*	Time [min]	No. of person hours	Area [m^2]	CPUE
Southwest coast						
1	Vizhinjam bay	32	150	4.69	115	**6.8**
2	Enayam	0	30	0.00	60	0.0
3	Mel Midalam	6	30	5.00	60	1.2
4	Colachel	7	60	8.57	50	0.8
5	Kadiyapattanam	3	60	20.00	20	0.2
6	Muttom	7	80	11.43	70	0.6
7	Pillai Thoppu	2	30	15.00	–	0.1
8	Azhikkal	2	30	15.00	60	0.1
9	Pozhikarai	2	30	15.00	60	0.1
10	KesavanPuthenThurai	1	20	20.00	–	0.1
11	PuthenThurai	1	35	35.00	–	0.0
12	Sanguthurai	1	25	25.00	–	0.0
13	Pallam	2	50	25.00	65	0.1
14	Mel Manakudi	2	40	20.00	–	0.1
15	Keel Manakudi	2	25	12.50	–	0.2
16	Kanyakumari	5	60	12.00	60	0.4
17	China Muttom	12	120	10.00	75	1.2
18	Leepuram	5	30	6.00	80	0.8
19	Arokiya Puram	2	20	10.00	65	0.2
Southeast coast						
20	Kootapuli	4	40	10.00	–	0.4
21	Koodankulam	4	25	6.25	–	0.6
22	Uvari	6	60	10.00	80	0.6
23	Kooduthalai	2	30	15.00	–	0.1
24	Periyathalai	3	30	10.00	–	0.3
25	Manapad	3	60	20.00	–	0.2
26	Kulasekharapatnam	7	60	8.57	–	0.8
27	Alanthalai	7	30	4.29	–	1.6
28	Amali Nagar	5	30	6.00	–	0.8
29	Tiruchendur	12	90	7.50	80	1.6
30	Veerapandiapattanam	6	40	6.67	60	0.9
31	Kayalpatnam	3	30	10.00	–	0.3

Table 2 (*Continued*)

S. no.	Stations	*N*	Time [min]	No. of person hours	Area [m^2]	CPUE
32	Punnakkayal	5	40	8.00	85	0.6
33	Thoothukudi (Harbour)	20	90	4.50	225	4.4
34	North Break Water	38	90	2.37	120	**16.0**
35	Hare Island	42	90	2.14	160	**19.6**
36	Roch Park	10	60	6.00	70	1.7
37	Inigo Nagar	9	60	6.67	70	1.4
38	Collectors Bungalow	10	60	6.00	70	1.7
39	Therespuram	0	30	0.00	60	0.0
40	Vellapatti	4	40	10.00	80	0.4
41	KeelaVaippar	4	30	7.50	–	0.5
42	Mandapam	12	90	7.50	180	1.6
43	Pamban	6	40	6.67	120	0.9
44	Rameswaram	0	30	0.00	120	0.0
45	Dhanushkodi	0	30	0.00	–	0.0

Bold values signify the study areas Hare Island, North Break Water and Vizhinjam Bay recruited significantly higher number of colonies of Didemnum psammathodes species.

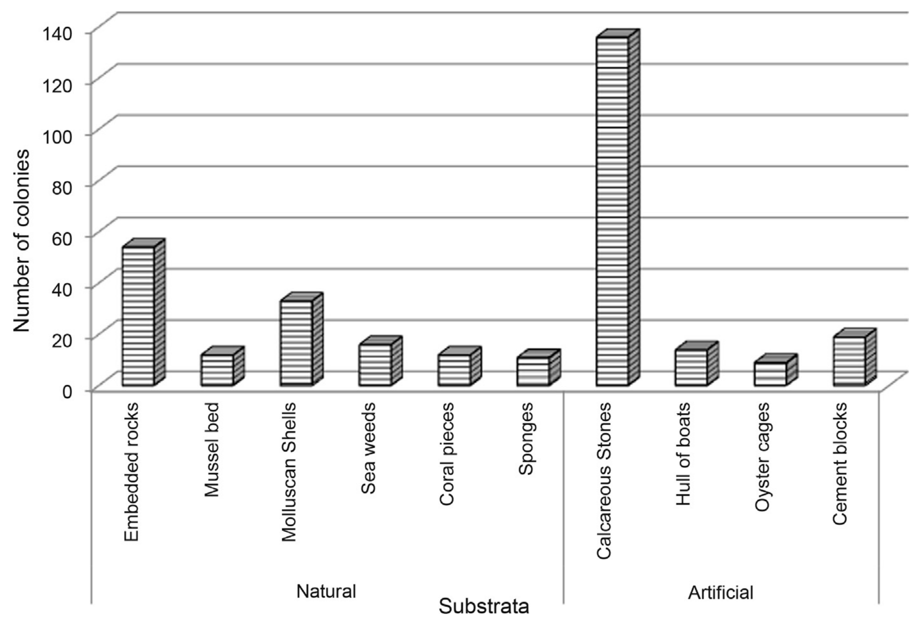

Figure 2 Number of colonies of *Didemnum psammathodes* observed on the various substrata.

Hydrographical parameters and number of colonies of *D. psammathodes* of southeast and southwest coasts of India are represented in Table 3. Temperature, salinity, dissolved oxygen and pH of the stations along the southwest coast ranged from 26.2 to 27.4°C, 30.1 to 31 ppt, 4.2 to 4.5 ml L^{-1} and 7.2 to 7.6 respectively whereas, in the southeast coast the values ranged from 30.4 to 31°C, 34.1 to 35.2 ppt, 4.1 to 4.3 ml L^{-1} and 7.7 to 7.9. Statistical analysis (one-way ANOVA) of these four parameters showed no significant differences between the different sites ($p < 0.005$).

4. Discussion

In the present survey, occurrence and distribution of *D. psammathodes* were investigated along the Arabian Sea, Indian Ocean and the Bay of Bengal. The maximum number of colonies was recorded at the southeast coast of India. It could be correlated with the availability of structures, both natural (embedded rocks, seaweed, mussel bed, coral pieces, etc.) and man-made as well (stones, cement blocks, hulls of boat, oyster cages, etc.) (Fig. 2) which might have influenced the settlement of the ascidian.

The study on station-wise abundance of *D. psammathodes* revealed maximum record at Vizhinjam bay and Hare Island along the southwest and southeast coasts respectively. This could be attributed to the fact that these two stations are provided with numerous small-embedded rocks and loosely bound stones. Moreover, these stations experience very calm and low wave action, which facilitates *D. psammathodes* to encrust the substrata nearby. Colonies of *D. psammathodes* are found either single or in clumps (2—5 colonies), and sometimes as a very large mat. They are more commonly available in the immediate-sublittoral zone at approximately 1 m depth. In their natural habitat, majority of the colonies are located underneath stones and crevices of embedded

Table 3 Hydrographical parameters of various stations along the southeast and southwest coast of India.

Stations	Temperature [°C]	Salinity [ppt]	DO [ml L^{-1}]	pH	*N*
Vizhinjam bay	27.0	30.7	4.4	7.6	32
Enayam	27.3	30.5	4.2	7.6	0
Mel Midalam	27.3	30.5	4.2	7.6	6
Colachel	27.4	30.1	4.3	7.6	7
Kadiyapattanam	27.0	31.0	4.5	7.6	3
Muttom	26.2	30.8	4.4	7.3	7
Pillai Thoppu	27.0	30.5	4.3	7.3	2
Azhikkal	27.0	30.5	4.3	7.3	2
Pozhikarai	27.0	30.5	4.3	7.3	2
KesavanPuthenThurai	27.0	30.5	4.3	7.3	1
PuthenThurai	27.0	30.5	4.3	7.3	1
Sanguthurai	27.0	30.5	4.3	7.4	1
Pallam	27.0	30.5	4.3	7.4	2
Mel Manakudi	26.8	30.5	4.3	7.2	2
Keel Manakudi	26.8	30.5	4.3	7.2	2
Kanyakumari	26.8	30.5	4.3	7.2	5
China Muttom	26.8	30.5	4.3	7.2	12
Leepuram	26.7	30.7	4.3	7.2	5
Arokiya Puram	26.7	30.7	4.3	7.2	2
Kootapuli	30.4	34.6	4.2	7.8	4
Koodankulam	31.0	35.2	4.3	7.9	4
Uvari	30.5	34.2	4.2	7.8	6
Kooduthalai	30.5	34.2	4.2	7.8	2
Periyathalai	30.5	34.2	4.2	7.8	3
Manapad	30.5	34.2	4.2	7.8	3
Kulasekharapatnam	30.5	34.2	4.2	7.8	7
Alanthalai	30.5	34.2	4.2	7.8	7
Amali Nagar	30.5	34.2	4.2	7.8	5
Tiruchendur	30.8	34.5	4.2	7.8	12
Veerapandiapattanam	30.8	34.5	4.2	7.8	6
Kayalpatnam	30.8	34.5	4.2	7.8	3
Punnakkayal	30.8	34.5	4.2	7.9	5
Thoothukudi (Harbour)	30.5	34.2	4.3	7.9	20
North Break Water	30.5	34.2	4.3	7.7	38
Hare Island	30.5	34.2	4.3	7.8	42
Roch Park	30.5	34.2	4.3	7.8	10
Inigo Nagar	30.5	34.2	4.3	7.8	9
Collectors Bungalow	30.5	34.2	4.3	7.8	10
Therespuram	30.5	34.2	4.3	7.8	0
Vellapatti	30.5	34.2	4.3	7.8	4
KeelaVaippar	30.5	34.2	4.3	7.8	4
Mandapam	30.2	34.1	4.1	7.8	12
Pamban	30.2	34.1	4.1	7.8	6
Rameswaram	30.2	34.1	4.1	7.7	0
Dhanushkodi	30.2	34.1	4.1	7.7	0
Mean	**29.0**	**32.7**	**4.3**	**7.6**	**7.0**

rocks. Shaded areas such as rock crevices and undersides tend to be favourable habitats for ascidians (Young and Chia, 1984). Ascidian larvae response to phototactic negative effect contributes to recruitment into these habitats (Svane and Dolmer, 1995; Svane and Young, 1989; Young and Chia, 1984).

Out of 45 stations, 16 stations, including Dhanushkodi, Enayam, Therespuram and Rameswaram, are sandy in nature and devoid of any substrata. In these stations, the sampling of *D. psammathodes* was done by examining the fishing nets used for catching fishes from deep sea up to the depth of 15—20 m. The present observation confirmed the reports of Young (1989) and Tamilselvi et al. (2012) who reported that habitat stability is an important criterion for survivorship of an organism and sand movement adversely affects the settlement of its larvae.

Because of the uncertainty concerning the origin of this species, its status as non-indigenous species remains unclear.

Various levels of evidence suggest that this species is categorized into cryptogenic species (Abdul Jaffar Ali et al., 2009; Carlton, 1996). Since worldwide shipping facilitates the exotic species to invade the ports of various countries such as Japan, Malaysia, Indonesia, New Zealand, New South Wales (Central E coast), Queensland (Central E coast, Great Barrier Reef, NE coast), Victoria (Bass Strait), the western Indian Ocean, the Red Sea and India (Cariton and Geller, 1993; Hewitt et al., 2004; Monniot and Monniot, 1991, 1994), the invasiveness of this species into the Indian water could also be substantiated. In the previous report, this species was categorized as cryptogenic but based on the present observation, this species can be categorized as established cryptogenic based on various criteria proposed by Carlton (1996).

The occurrence of *D. psammathodes* was more common in harbour area, followed by fish landing centre nearby. This might be due to the connectivity of the ports, movement of ships and also the release of ballast water at the ports. Furthermore, the large number of boats with fouled hulls, especially fishing vessels that move from one harbour to another undoubtedly provide new breeding stock to recolonize the denuded surfaces and also enhance gene flow of *D. psammathodes* populations between the harbours. The increasing invasiveness of this species proved beyond doubt that the heavy traffic of fishing vessels and ship movements interlinking all the major ports and fishing harbours of southern India could probably pave the way for invasion of this non-native ascidian. Kott (2002), Abdul Jaffar Ali (2004) and Tamilselvi et al. (2011) reported that provisions of maritime and other installations associated with commercial harbour could have facilitated the settlement of ascidians species.

In the present study, hydrographical parameters in the southeast and southwest coasts of India showed slight variations but did not show any significant correlation with the number of colonies of *D. psammathodes*. On the contrary, the role of temperature in influencing Didemnum recruitment was suggested by Stachowicz et al. (2002b). Carlton (2000) recorded that the given temperature and species composition significantly impacted temperate subtidal communities and cumulative impact of these factors may facilitate the future invasion. As adult ascidians are sedentary in nature, its abundance and distribution of species are highly influenced by the larval behaviour rather than physical disturbance, predation and competition (Svane and Young, 1989). Along with these factors, the substrate features also determine the composition of ascidians (Tamilselvi and Abdul Jaffar Ali, 2013).

Worldwide distribution of *D. psammathodes* is often explained by its high dispersive capability and also by certain aspects of their life cycle including motility of larval, budding, colony fragmentation, etc. The short-lived larvae released from a colony facilitate the dispersal of the species over short distances. The larvae also settle close to the parental colony (Tamilselvi et al., 2011; Yund and Stires, 2002). The present survey also revealed the rapid invasion and spread of *D. psammathodes* along the southern Indian coastal waters. The distribution and abundance of *D. psammathodes* are determined by availability of diverse substrates, heavy traffic and intercoastal movement of ships and fishing vessels and also life-history traits.

Since the search time differs at each site, the total number of *D. psammathodes* collected was standardized using catch per unit effort (CPUE). Higher CPUE at Hare Island and NBW could possibly occur because this species formed the colonies at undersides of loosely bound and embedded rocks close to surface of the water and collection did not take as long compared to searching underneath boulders and rock crevices in Muttom, Kadiyapattanam and Kanyakumari regions of Tamilnadu, India.

To conclude, *D. psammathodes* has strong potential to invade most of the stations along southern Indian coastal waters at a significantly greater rate and its distribution is not influenced by hydrographical parameters but by substrates. Owing to ever changing coastal diversity and topography of the collection spots, a special attention should be given to the biofoulers such as ascidians. This study will definitely be very helpful for researchers, coastal planners, port authorities, coastal thermal plants and atomic power plants in proper management. Since there is no concrete solution to prevent and/or eradicate bioinvasion, *D. psammathodes* can be better utilized in a positive way by preparing supplementary feed for culturable organisms and to isolate the novel lead molecules as reported by earlier studies.

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References

Abdul Jaffar Ali, H., 2004. Comparative study on ecology of *Phallusia nigra* Savigny 1816 from Tuticorin (southeast coast) and Vizhinjam (southwest coast). (Ph.D. thesis). Manonmaniam Sundaranar Univ., Tirunelveli.

Abdul Jaffar Ali, H.A., Sivakumar, V., 2007. Occurrence and distribution of ascidians in Vizhinjam bay (southwest coast of India). J. Exp. Mar. Biol. Ecol. 342 (1), 189—190.

Abdul Jaffar Ali, H.A., Sivakumar, V., Tamilselvi, M., 2009. Distribution of alien and cryptogenic ascidians along the southern coasts of Indian peninsula. World J. Fish Mar. Sci. 1 (4), 305—312.

Abdul Jaffar Ali, H., Tamilselvi, M., Sivakumar, V. Non-indigenous ascidians in V.O. Chidambaram port, Thoothukudi, India. Indian J. Geo-Mar. Sci. in press.

Abdul Jaffar Ali, H., Tamilselvi, M., Sivakumar, V., Zaman, G.M.H., Muthu Mohamed, H.S., 2011. Marine ascidian biodiversity — a promising resource for bioactive compounds. Suppl. Adv. Biotech. 10 (10), 26—32.

Adams, C.M., Shumway, S.E., Whitlach, R.B., Getchis, T., 2011. Biofouling in marine molluscan shellfish aquaculture: a survey assessing the business and economic implications of mitigation. J. World Aquac. Soc. 42 (2), 242—252.

Anand, T., Paterson, J.K., 2002. Antimicrobial activity in the tissue extracts of five species of cowries *Cypraea* spp. (Mollusca: Gastropoda) and an ascidian *Didemnum psammathodes* (Tunicata: Didemnidae). Indian J. Mar. Sci. 31 (3), 239—242.

Bullard, S.G., Carman, M.R., 2009. Current Trends in Invasive Ascidian Research. Invasive Species: Detection, Impact and Control. Nova Sci. Publ., New York, 217 pp.

Bullard, S.G., Lambert, G., Carman, M.R., Byrnes, J., Whitlatch, R. B., Ruiz, G., Miller, R.J., Harris, L., Valentine, P.C., Collie, J.S., Pederson, J., McNaught, D.C., Cohen, A.N., Asch, R.G., Dijkstra, J., Heinonen, K., 2007. The colonial ascidian *Didemnum* sp. A:

current distribution, basic biology and potential threat to marine communities of the northeast and west coasts of North America. J. Exp. Mar. Biol. Ecol. 342 (1), 99—108.
Cariton, J.T., Geller, J.B., 1993. Ecological roulette: the global transport of nonindigenous marine organisms. Science 261 (5117), 78—82.
Carlton, J.T., 1996. Pattern, process, and prediction in marine invasion ecology. Biol. Conserv. 78 (1—2), 97—106.
Carlton, J.T., 2000. Global change and biological invasions in the oceans. In: Hobbs, R.J., Mooney, H.A. (Eds.), Invasive Species in a Changing World. Island Press, Covelo, CA, 31—53.
Carman, M.R., Morris, J.A., Karney, R.C., Grunden, D.W., 2010. An initial assessment of indigenous and invasive tunicates in shellfish aquaculture of the North American east coast. J. Appl. Ichthyol. 26 (S2), 8—11.
Carte, B.K., 1996. Biomedical potential of marine natural products. Bioscience 46 (4), 271—286.
Davidson, B.S., 1993. Ascidians: producers of amino acid derived metabolites. Chem. Rev. 93 (5), 1771—1791.
Dunlap, W.C., Long, P.F., Jaspars, M., 2011. Biomedicinals from the microbial metagenomes of marine invertebrates. In: de Brujin, F. J. (Ed.), Handbook of Molecular Microbial Ecology, vol. II: Metagenomics in Different Habitats. Wiley Blackwell, Hoboken, New Jersey, pp. 517—544.
Goodbody, I., 1993. The ascidian fauna of a Jamaican lagoon: thirty years of change. Rev. Biol. Trop. 41 (10), 35—38.
Haefner, B., 2003. Drugs from the deep: marine natural products as drug candidates. Drug Discov. Today 8 (12), 536—544.
Hernandez-Zanuy, A.C., Carballo, A.C., 2001. Distribution and abundance of ascidian assemblages in Caribbean reef zones of the Golfo de Batabano (Cuba). Coral Reefs 20 (2), 159—162.
Hewitt, C.L., Willing, J., Bauckham, A., Cassidy, A.M., Cox, C.M.S., Jones, L., Wotton, D.M., 2004. New Zealand marine biosecurity: delivering outcomes in a fluid environment. New Zeal. J. Mar. Freshw. Res. 38 (3), 429—438.
Jain, R., Sonawane, S., Mandrekar, N., 2008. Marine organisms: potential source for drug discovery. Curr. Sci. India 94 (3), 292 pp.
Karthikeyan, M.M., Ananthan, G., Balasubramanian, T., 2009. Antimicrobial activity of crude extracts of some ascidians (Urochordata: Ascidiacea), from Palk Strait (Southeast Coast of India). World J. Fish Mar. Sci. 1 (4), 262—267.
Kott, P., 2002. A complex didemnid ascidian from Whangamat, New Zealand. J. Mar. Biol. Assoc. UK 82 (4), 62—628.
Lambert, C.C., Lambert, G., 2003. Persistence and differential distribution of nonindigenous ascidians in harbours of the Southern California Bight. Mar. Ecol. Prog. Ser. 259, 145—161.
Meenakshi, V.K., Senthamarai, S., 2013. Diversity of ascidians from the Gulf of Mannar. In: Venkataraman, K., Sivaperuman, C., Raghunathan, C. (Eds.), Ecology and Conservation of Tropical Marine Faunal Communities. Springer, Berlin, Heidelberg, 213—229.
Monniot, C., Monniot, F., 1991. Discovery of a new lineage among the deep sea ascidians: a carnivorous Ascidiidae. C. R. Acad. Sci. Ser. III 312 (8), 383—388.
Monniot, C., Monniot, F., 1994. Additions to the inventory of eastern tropical Atlantic ascidians: arrival of cosmopolitan species. Bull. Mar. Sci. 54 (1), 71—93.
Mundo, G.M., 2009. Phylogenetic and phylogeographic study of the New Zealand endemic sea tunicate *Cnemidocarpa nisiotis*. (Master thesis). School Biol. Sci., Univ. Canterbury, Christchurch, New Zealand, 136 pp.
Nanri, K., Ogawa, J., Nishikawa, T., 1992. Tunic of a pyurid ascidian *Microcosmus hartmeyeri* Oka is eaten locally in Japan. Nanki Seibutu 34 (2), 135 pp.
Nguyen, T.T.T., 2007. Aquaculture of sea-pineapple, *Halocynthia roretzi* in Japan. Aquac. Asia XII (2), 21—23.
Ramasamy, M., Murugan, A., 2003. Chemical defense in ascidians *Eudistoma viride* and *Didemnum psammathodes* in Tuticorin, southeast coast of India: bacterial epibiosis and fouling deterrent activity. Indian J. Mar. Sci. 32 (4), 337—339.
Randall, J.E., 1967. Food habits of reef fishes of the West Indies. Stud. Trop. Oceanogr. 5, 665—847.
Renganathan, T.K., 1981. On the occurrence of colonial ascidian, *Didemnum psammathodes* (Sluiter, 1985) from India. Curr. Sci. India 50 (20), 922 pp.
Rinehart, K.L., 2000. Antitumour compounds from tunicates. Med. Res. Rev. 20 (1), 1—27.
Sahade, R., Tatian, M., Kowalke, J., Kuhne, S., Esna, G.B., 1998. Benthic faunal associations on soft substrates at Potter Cove, King George Island, Antarctica. Polar Biol. 19 (2), 85—91.
Schmidt, E.W., Donia, M.S., McIntosh, J.A., Fricke, W.F., Ravel, J., 2013. Origin and variation of tunicate secondary metabolites. J. Nat. Prod. 75 (2), 295—304.
Shenkar, N., Loya, Y., 2009. Non-indigenous ascidians (Chordata: Tunicata) along the Mediterranean coast of Israel. Mar. Biodivers. Rec. 2 (e166), 1—7.
Sri Kumaran, N., Bragadeeswaran, S., Meenakshi, V.K., 2011. Evaluation of antibacterial activity of crude extracts of ascidian *Didemnum psammathodes* Sluiter, 1895 against isolated human and fish pathogens. Asian Pac. J. Trop. Biomed. 1 (1), S90—S99.
Stachowicz, J.J., Fried, H., Osman, R.W., Whitlatch, R.B., 2002a. Biodiversity, invasion resistance, and marine ecosystem function: reconciling pattern and process. Ecology 83 (9), 2575—2590.
Stachowicz, J.J., Terwin, J.R., Whitlatch, R.B., Osman, R.W., 2002b. Linking climate change and biological invasions: ocean warming facilitates nonindigenous species invasions. Proc. Natl. Acad. Sci. U.S.A. 99 (24), 15497—15500.
Svane, I., Dolmer, P., 1995. Perception of light at settlement: a comparative study of two invertebrate larvae, a *Scyphozoan planula* and a simple ascidian tadpole. J. Exp. Mar. Biol. Ecol. 187 (1), 51—61.
Svane, I., Young, C.M., 1989. The ecology and behaviour of ascidian larvae. Oceanogr. Mar. Biol. Annu. Rev. 27, 45—90.
Tamilselvi, M., 2008. Ecological studies on ascidians of Tuticorin coast. (Ph.D. thesis). Manonmaniam Sundaranar Univ., Tirunelveli, India.
Tamilselvi, M., Abdul Jaffar Ali, H., 2013. Exploration of untapped resource of ascidians along the Thoothukudi coast of India. Mult. Res. J. VVV. Coll. 1 (1), 139—145.
Tamilselvi, M., Sivakumar, V., Abdul Jaffar Ali, H., Thilaga, R.D., 2011. Distribution of alien tunicates (Ascidians) in Tuticorin coast, India. World J. Zool. 6 (2), 164—172.
Tamilselvi, M., Sivakumar, V., Abdul Jaffar Ali, H., Thilaga, R.D., 2012. Diversity and seasonal variations of class Ascidiacea in Thoothukudi coast, India. Int. J. Environ. Sci. 3 (3), 1097—1105.
Tapic Jopia, C., Toledo, N.B., 2007. Pesqueria de *Pyura chilensis* (Molina 1782) (Tunicata, Ascidiacea, Pyuridae). Investigacion situacion pesquerias bentonicas 2006. Instit. Fomento Pesquero (IFOP). Valparaíso 66 pp., (in Spanish).
Thakur, N.L., 2001. Studies on some bioactivity aspects of selected marine organisms. (Ph.D. thesis). Goa Univ., Goa.
Valentine, P.C., Carman, M.R., Blackwood, D.S., Hefferon, E.J., 2007. Ecological observations on the colonial ascidian *Didemnum* sp. in a New England tide pool. J. Exp. Mar. Biol. Ecol. 342 (1), 109—122.
Young, C.M., 1989. Distribution and dynamics of an intertidal ascidian pseudopopulation. Bull. Mar. Sci. 45 (2), 288—303.
Young, C.M., Chia, F.S., 1984. Microhabitat-associated variability in survival and growth of subtidal solitary ascidians during the first 21 days after settlement. Mar. Biol. 81 (1), 61—68.
Yund, P.O., Stires, A., 2002. Spatial variation in population dynamics in a colonial ascidian (*Botryllus schlosseri*). Mar. Biol. 141 (5), 955—963.