Available online at: www.mbai.org.in doi: 10.6024/jmbai.2017.59.2.1910-12

Shipwrecks in Andaman and Nicobar Islands: An artificial habitat for corals

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Received: 10 June 2016 Accepted: 20 Dec 2017 Published: 30 Dec 2017

Original Article

Abstract

Globally scleractinian corals are facing the threats of devastation due to anthropogenic activities as well as natural calamities. The concept of artificial reef was developed to increase the parallel reef areas along with the natural reef to strengthen marine biodiversity. The artificial reef ecosystem can be developed with the help of shipwrecks, abandoned tyres, cars etc. while the reef ball concept is the modern one to adapt. Andaman and Nicobar Islands is one of the biologically diverse areas with healthy number of scleractinian corals. Four shipwrecks scattered along the waters of these islands are serving as substratum for 125 species of scleractinian corals. North Bay shipwreck alone reported 114 species under 41 genera with the diversity (H′) of 2.91. The studies on natural reef area showed 61% similarity in species content in comparison with the shipwrecks of North Bay region due to the proximity in location. The present study indicates that, shipwrecks serve as artificial substratum for the formation of coral reef with high diversity.

Keywords: *shipwreck, artificial reef, marine biodiversity, Andaman and Nicobar Islands.*

Introduction

The coral reefs are the most complex and diverse ecosystem of marine habitat. The structural attributes of corals along with symbiotic animals construct a reef which harbours plethora of associated faunal communities. The ecological, biological and pharmaceutical contributions of coral reefs are immeasurable. The estimated value of the total economic goods and services provided by coral reefs is around US$ 375 billion/year with an average value of around US$ 6,075/hectare of coral reef per year (Edwards and Gomez, 2007; Ammar, 2009). The coral reefs of the world's ocean are the oldest living creatures of the globe, which have been undergoing as well as disturbing through a variety of anthropogenic stresses and natural threat and severely deteriorate their condition towards destruction (Wilkinson, 2000). The activities may include un-managed recreational activities, anchoring of boat on reefs, siltation, sewage discharge, excessive nutrient input, thermal pollution, and overfishing etc. (Rinkevich, 1995; Luoma, 1996; Warzecha, 1997). The gradual loss and destruction of coral reefs can be replaced by focusing on the restoration programme of coral reef ecosystems. The concept of Artificial Reefs (ARs) was identified as a promising tool for reef restoration and rehabilitation which will develop the entire reef structure (Clark and Edwards, 1999;

Spieler *et al.,* 2001; Perkol-Finkel *et al.,* 2006). It is important to make a detailed framework about the scheme of artificial reef such as material used for the construction, their layering, shape, size, orientation, complications, sturdiness along with the ecological factors and their inter-relationship (Baine, 2001; Oren and Benayahu, 1997; Rilov and Benayahu, 2000; Connell and Jones, 1991).

The concept of artificial reef was taken due to enriched reef biodiversity in sunken ships, which usually form large artificial reefs (Warzecha, 1997). A new concept came to play the vital role for the construction of artificial reef was the Reef Ball (Warzecha, 1997). The said materials of artificial reef create structural complexity in artificial reef which enhance greater species diversity, density and distribution of associated faunal communities in comparison with natural reef also (Smith *et al.,* 1979; Bohnsack *et al.,* 1994; Eklund, 1996; Duedall and Champ, 1991; Svane and Petersen, 2001). The structural conformation of artificial reef creates a complex substratum for the settlement of coral species by the process of succession along with a number of other associates (Carleton and Sammarco, 1987; Guichard *et al.,* 2001; Perkol-Finkel *et al.,* 2006). The settlement patterns of benthic animals are completely dependent of chemical composition of the substratum, their toxicity and durability (Baine, 2001; Spieler *et al.,* 2001). In the present study four shipwrecks of Andaman and Nicobar Islands were taken up to assess the diversity and distribution of scleractinian corals.

Material and methods

Extensive surveys were carried out at one natural reef area and the four shipwrecks of Andaman and Nicobar Islands (Fig. 1 and Table 1). First study was carried out at Car Nicobar Island ship wreck (Lat. 09°10’883”N and Long. 92°50’123”E) and its adjoining natural reef areas during November 2009 and July 2010 from the intertidal areas to the depth of 28 m (Plate 1). The wreck was around 50 m in length with highly corroded steel-hull. Second study was carried out at Sir William Peel Island ship wreck (Lat. 12°03’842”N and Long. 92°57’811”E) during January 2014 at the depth of 12 m while the adjoining natural reef areas were studied during September 2009 to January 2014 (Plate 2). The shipwreck was about 20 m in length with a wooden-hull. Third study was carried out at North Bay wreck (Lat. 11°43’006”N and Long. 92°45’465”E) at the depth of 10 m during March 2014 to June 2016 (Plate 3) while the natural reef areas of North Bay and adjoining areas were studied from November 2010 to June 2016. Here the wreck was around 60 m in length with steel-hull. Fourth study was carried out at Sinclair Bay wreck (Lat. 11°39’873”N and Long. 92°45’488”E) at the depth of 8 m during April 2015 (Plate 4). The wreck was 60 m in length with steel hull. Among the four wrecks, the wreck of Car Nicobar Island is the oldest one followed by Sinclair Bay wreck, North Bay wreck and Sir William Peel Island wreck are recent one as per the interaction was carried out with local fishermen and villagers. North Bay wreck and Sir Peel Island wreck are used as recreational dive sites.

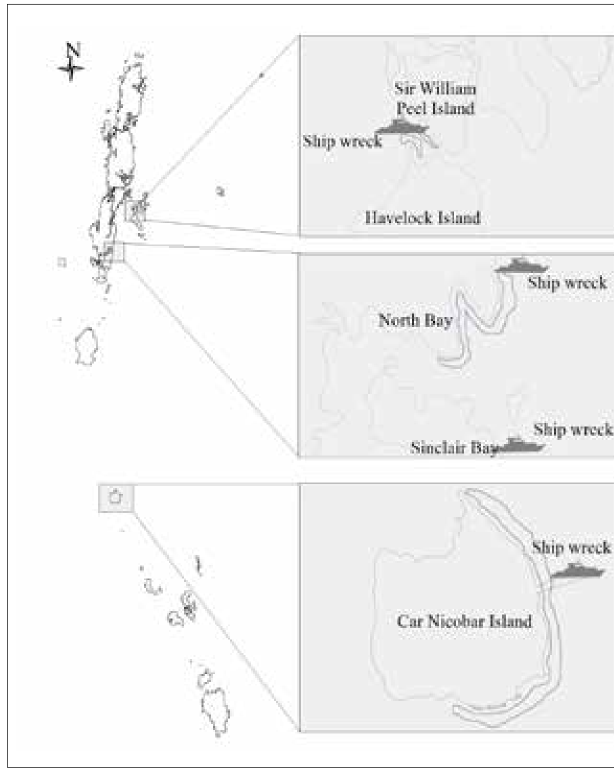

Fig. 1. Study areas (natural reef and shipwrecks) of Andaman and Nicobar Islands

Table 1. GPS coordinates of study areas

Sl. No.	Place	Latitude	Longitude
1.	Natural reef area of Sir William Peel Island and adjoining areas	12°03'105"N	92°58'345"E
2.	Ship wreck of Sir William Peel Island	12°03'842"N	92°57'811"E
3.	Ship wreck of North Bay	11°43'006"N	92°45'415"E
4.	Natural reef area of North Bay and adjoining area	11°42'070"N	92°45'042"E
5.	Ship wreck of Sinclair Bay	11°39'873"N	92°45'488"E
6.	Natural Reef area of Car Nicobar Island	09°10'182"N	92°50'122"E
7.	Ship wreck of Car Nicobar Island	09°10'883"N	92°50'123"E

Intensive studies were carried out at natural reef areas of North Bay region (Lat. 11°42’070”N and Long. 92°45’415”E) since 2009 to compare the status of scleractinian corals with the adjoining shipwreck of North Bay which is about 2 km away in distance. *In situ* species inventory were carried out by employing SCUBA diving to assess the scleractinian coral diversity on the wrecks. Coordinates of the surveyed places were obtained by handheld Global Positioning System, Model GARMIN 12 Channel GPS unit and GARMIN OREGON 550. Studies on the live corals and species database were carried out by LIT

Plate 1. Shipwreck of Car Nicobar Islands

Plate 3. Shipwreck of North Bay

Plate 2. Shipwreck of Sir William Peel Island

Plate 4. Shipwreck of Sinclair Bay

method (20x20 m in triplicate) and quadrate methods (5x5 m in triplicate) (Loya, 1972; English *et al.,* 1997). The underwater species recording was done for detailed identification using Sony - Cyber shot, Model-T900, marine pack, 12.1 megapixels and Canon PowerShot G15 respectively. Identification of the recorded species was made referring Cairns (1991, 1994, 1997, 1999, 2001), Veron and Pichon (1976, 1979, 1982), Veron *et al.* (1977), Veron and Wallace (1984), Veron (2000) and Wallace (1999). The Shannon-Weaver Index (H') (Shannon and Weaver, 1963) was applied to ascertain the species diversity through PAST version 1.83 (Hammer *et al.,* 2001). The Sørensen index, also known as Sørensen's similarity coefficient (Sørensen, 1948) was used to calculate the species similarity between wrecks.

Results

A total of 272 species of scleractinian corals under 66 genera and 15 families were recorded from study areas of Andaman and Nicobar Islands. The natural reef area of North Bay represented maximum 190 species of corals under 56 genera and 14 families (Table 2). A total of 125 species under 43 genera and 14 families of scleractinian corals were recorded from all the four wrecks in Andaman and Nicobar Islands. Among them, North Bay wreck represented a maximum number of 114 species under 41 genera and 13 families while minimum of 20 species were recorded under 11 genera and 4 families from Sir William Peel Island wreck (Table 2). A total of 247 species belonging to 65 genera and 14 families were recorded from the natural reef areas during the studies while only 21 species of scleractinian corals under 12 genera and 7 families were recorded exclusively from four shipwrecks (Table 2). The detailed studies were carried out on the wrecks of all the four areas. Three wrecks were made up of steel hull while the wreck of Sir William Peel Island was made up of wooden hull. It was also recorded that only two species of corals i.e. *Favites pentagona* and *Favites abdita* are common to all the shipwreck reef ecosystems.

Table 2. Scleractinian coral diversity on natural reef area (A D F) and four shipwrecks (B C E G) of Andaman and Nicobar Islands

Sl. No.	Taxa	A	B	C	D	E	F	G
	Family ACROPORIDAE Verrill, 1902							
	Genus *Acropora* Oken, 1815							
1.	*Acropora tenuis* (Dana, 1846)	•						
2.	*Acropora torresiana* Veron, 2000	•						
3.	*Acropora grandis* (Brook, 1892)	•						
4.	*Acropora chesterfieldensis* Veron and Wallace, 1984	•						
5.	*Acropora selago* (Studer, 1878)	•						
6.	*Acropora muricata* (Linnaeus, 1758)	•	•	•				
7.	*Acropora speciosa* (Quelch, 1886)	•						
8.	*Acropora vaughani* Wells, 1954	•						
9.	*Acropora austera* (Dana,1846)	•						
10.	*Acropora abrotanoides* (Lamarck, 1816)	•						
11.	*Acropora millepora* (Ehrenberg, 1834)	•						
12.	*Acropora hyacinthus* (Dana, 1846)	•	•	•				
13.	*Acropora divaricata* (Dana, 1846)	•	•	•	•	•		
14.	*Acropora retusa* (Dana, 1846)	•						
15.	*Acropora latistella* (Brook, 1891)	•	•					
16.	*Acropora insignis* Nemenzo, 1907	•	•	•				
17.	*Acropora rudis* (Rehberg, 1892)	•						
18.	*Acropora gemmifera* (Brook, 1892)	•	•	•				
19.	*Acropora granulosa(Milne* Edwards and Haime, 1860)	•	•	•	•			
20.	*Acropora meridiana* Nemenzo, 1971	•						
21.	*Acropora subulata* (Dana, 1846)	•	•					
22.	*Acropora cervicornis* (Lamarck, 1816)	•						
23.	*Acropora loripes* (Brook, 1892)	•	•	•	•			
24.	*Acropora* abrolhosensis Veron, 1985	•	•					
25.	*Acropora digitifera* (Dana, 1846)	•	•	•				
26.	*Acropora schmitti* Wells, 1950	•	•					
27.	*Acropora solitaryensis* Veron and Wallace, 1984	•						
28.	*Acropora subglabra* (Brook,1891)	•						
29.	*Acropora samoensis* (Brook, 1891)	•	•	•				
30.	*Acropora palmerae* Wells, 1954	•	•					
31.	*Acropora spicifera* (Dana, 1846)	•	•					
32.	*Acropora aspera* (Dana, 1846)	•						
33.	*Acropora variolosa* (Klunzinger, 1879)	•						
34.	*Acropora natalensis* Riegl, 1995	•						
35.	*Acropora squarrosa* (Ehrenberg,1834)	•						
36.	*Acropora plantaginea* (Lamark, 1816)	•						
37.	*Acropora monticulosa* (Bruggemann, 1879)	•	•					
38.	*Acropora horrida* (Dana, 1846)	•						
39.	*Acropora cerealis* (Dana, 1846)	•	•					
40.	*Acropora efflorescens* (Dana,1846)	•						
41.	*Acropora willisae* Veron and Wallace, 1984	•						
42.	*Acropora valida* (Dana, 1846)	•						
43.	*Acropora robusta* (Dana, 1846)	•						
	Genus *Isopora* Studer, 1878							
44.	*Isopora palifera* (Lamarck, 1816)	•						
45.	*Isopora brueggemanni* (Brook, 1891)	•	•	•				
	Genus *Astreopora* de Blainville, 1830							
46.	*Astreopora myriophthalma* (Lamarck,1816)	•	•	•	•	•		
47.	*Astreopora randalli* Lamberts, 1980	•						
48.	*Astreopora suggesta* Wells, 1954	•						
	Genus *Montipora* de Blainville, 1830							
49.	*Montipora turtlensis* Veron and Wallace,1984	•	•					
50.	*Montipora informis* Bernard, 1897	•	•	•				
51.	*Montipora monasteriata* (Forskal, 1775)	•						
52.	*Montipora undata* Bernard, 1897	•						
53.	*Montipora grisea* Bernard, 1897	•						
54.	*Montipora turgescens* Bernard, 1897	•	•					
55.	*Montipora peltiformis* Bernard, 1897	•	•					
56.	*Montipora meandrina* (Ehrenberg, 1834)	•						
57.	*Montipora aequituberculata* Barnard, 1897	•						
58.	*Montipora vietnamensis* Veron, 2000	•						
59.	*Montipora cebuensis* (Nemenzo,1976)	•						
	Family OCULINIDAE Gray,1847							
	Genus *Galaxea* Oken, 1815							
60.	*Galaxea fascicularis* (Linnaeus, 1767)	•	•	•	•	•	•	
61.	*Galaxea astreata* (Lamarck, 1816)	•	•	•				
	Family POCILLOPORIDAE Gray, 1842							
	Genus *Pocillopora* Lamarck, 1816							
62.	*Pocillopora meandrina* Dana, 1846	•	•	•				
63.	*Pocillopora verrucosa* (Ellis and Solander, 1786)	•	•	•	•	•		
64.	*Pocillopora danae* Verrill, 1864	•	•					
65.	*Pocillopora damicornis* (Linnaeus,1758)	•	•	•				
66.	*Pocillopora elegans* Dana, 1846	•						

67.	*Pocillopora eydouxi* Milne Edwards and Haime, 1860	•				
68.	*Pocillopora kelleheri* Veron, 2000	•	•			
	Genus *Stylophora* Schweigger, 1819					
69.	*Stylophora pistillata* Esper, 1797	•	•			
	Genus *Seriatopora* Lamarck, 1816					
70.	*Seriatopora hystrix* Dana, 1846	•				
	Family SIDERASTREIDAE Vaughan and Wells, 1943					
	Genus *Psammocora* Dana, 1846					
71.	*Psammocora profundacella* Gardiner, 1898	•	•			
72.	*Psammocora digitata* Milne Edwards and Haime, 1851	•				
73.	*Psammocora nierstraszi* Horst, 1921	•				
74.	*Psammocora contigua* (Esper, 1797)	•				
75.	*Psammocora obtusangula* (Lamarck, 1816)	•	•			
76.	*Psammocora haimeana* Milne Edwards and Haime, 1851	•	•	•		
77.	*Psammocora explanulata* Horst, 1922	•	•			
	Genus *Coscinaraea* Milne Edwards and Haime, 1848					
78.	*Coscinaraea monile* (Forskal, 1775)	•	•	•		
79.	*Coscinaraea wellsi* Veron and Pichon, 1980	•				
80.	*Coscinaraea columna* (Dana, 1846)	•				
	Family AGARICIIDAE Gray, 1847					
	Genus *Pavona* Lamarck,1801					
81.	*Pavona duerdeni* Vaughan, 1907	•	•	•	•	
82.	*Pavona bipartita* Nemenzo, 1980	•	•	•	•	
83.	*Pavona cactus* (Forskal, 1775)	•				
84.	*Pavona venosa* (Ehrenberg, 1834)	•	•			
85.	*Pavona frondifera* (Lamarck, 1816)	•				
86.	*Pavona varians* Verrill, 1864	•	•	•	•	•
87.	*Pavona explanulata* (Lamarck, 1816)	•	•	•	•	
88.	*Pavona gigantea* Verrill, 1864	•				
89.	*Pavona minuta* Wells, 1954	•	•	•		
	Genus *Leptoseris* Milne Edwards and Haime,1849					
90.	*Leptoseris mycetoseroides* Wells, 1954	•	•	•	•	
91.	*Leptoseris striata* Fenner and Veron, 2000	•	•	•	•	•
92.	*Leptoseris scabra* Vaughan, 1907	•	•	•	•	
93.	*Leptoseris cucullata* (Ellis and Solander, 1786)	•	•			
94.	*Leptoseris yabei* (Pillai and Scheer, 1976)	•				
95.	*Leptoseris explanata* Yabe and Sugiyama, 1941	•	•	•	•	
96.	*Leptoseris solida* (Quelch, 1886)	•	•	•		
97.	*Leptoseris hawaiiensis* Vaughan, 1907	•	•			
98.	*Leptoseris incrustans* (Quelch, 1886)	•	•	•	•	
99.	*Leptoseris foliosa* Dinensen, 1980	•	•	•		
	Genus *Gardineroseris* Scheer and Pillai, 1974					
100.	*Gardineroseris planulata* (Dana, 1846)	•	•	•		
	Genus *Pachyseris* Milne Edwards and Haime, 1849					
101.	*Pachyseris speciosa* (Dana, 1846)	•	•	•		
102.	*Pachyseris gemmae* Nemenzo,1955	•	•			
103.	*Pachyseris rugosa* (Lamarck, 1801)	•				
	Genus *Coeloseris* Vaughan,1918					
104.	*Coeleseris mayeri* Vaughan, 1918	•	•			
	Family ASTROCOENIIDAE Koby, 1890					
	Genus *Stylocoeniella* Yabe and Sugiyama, 1935					
105.	*Stylocoeniella armata* (Ehrenberg, 1834)	•				
	Family FUNGIIDAE Dana,1846					
	Genus *Cycloseris* Milne Edwards and Haime,1849					
106.	*Cycloseris costulata* (Ortmann, 1889)	•	•			
107.	*Cycloseris somervillei* (Gardiner, 1909)	•				
108.	*Cycloseris cyclolites* (Lamarck, 1801)	•				
109.	*Cycloseris erora* (Doderlein, 1901)	•				
	Genus *Cantharellus* Hoeksema and Best, 1984					
110.	*Cantharellus jebbi* (Hoeksema, 1993)	•	•			
	Genus *Ctenactis* Verrill, 1864					
111.	*Cteanactis echinata* (Pallas, 1766)	•	•			
112.	*Cteanactis crassa* (Dana, 1846)	•	•			
	Genus *Fungia* Lamarck,1801					
113.	*Fungia paumotensis* Stutchbury, 1833	•	•	•		
114.	*Fungia scutaria* Lamarck, 1801	•				
115.	*Fungia corona* Doderlein, 1901	•				
116.	*Echniopora horrida* Dana, 1846	•				
117.	*Fungia concinna* Verrill, 1864	•				
118.	*Fungia danai* Milne Edwards and Haime, 1851	•	•			
119.	*Fungia fungites* (Linnaeus, 1758)	•	•			
120.	*Fungia sruposa* Klunzinger, 1879	•				
121.	*Fungia repanda* Dana, 1846	•				
122.	*Fungia klunzingeri* Doderlein, 1901	•	•			
	Genus *Lithophyllon* Rehberg, 1892					
123.	*Lithophyllon undulatum* Rehberg, 1892	•	•	•		
124.	*Lithophyllon lobata* Horst, 1921	•	•			
125.	*Genus Podabacia* Milne Edwards and Haime,1849					
126.	*Podabacia lanakensis* Veron, 2000	•	•	•		
127.	*Podabacia motuporensis* Veron, 1990	•				
	Genus *Sandalolitha* Quelch, 1884					
128.	*Sandalolitha robusta* Quuelch, 1886	•				
	Genus *Herpolitha* Eschscholtz, 1825					
129.	*Herpolitha weberi* Horst, 1921	•	•			
130.	*Herpolitha limax* (Houttuyn, 1772)	•				
	Genus *Polyphyllia* Quoy and Gaimard,1833					
131.	*Polyphyllia talpina* (Lamaarck, 1801)	•				
	Family FAVIIDAE Gregory, 1900					
	Genus *Diploastrea* Matthai, 1914					
132.	*Diploastrea heliopora* (Lamarck, 1816)	•	•	•	•	
	Genus *Cyphastrea* Milne Edwards and Haime, 1848					
133.	*Cyphastrea serailia* (Forskal, 1775)	•	•	•	•	
134.	*Cyphastrea chalcidicum* (Forskal, 1775)	•	•	•	•	
135.	*Cyphastrea japonica* Yabe and Sugiyama,1932	•	•	•		
136.	*Cyphastrea agassizi* Vaughan, 1907	•				
137.	*Cyphastrea microphthalma* (Lamarck, 1816)	•	•	•	•	
138.	*Cyphastrea ocellina* (Dana,1864)	•				
	Genus *Goniastrea* Milne Edwards and Haime, 1848					
139.	*Goniastrea edwardsi* Chevalier,1971	•	•			
140.	*Goniastrea aspera* Verrill, 1905	•	•			
141.	*Goniastrea retiformis* (Lamarck, 1816)	•	•			
142.	*Goniastrea pectinata* (Ehrenberg, 1834)	•	•			

143.	*Goniastrea minuta* Veron, 2000	•	•				
144.	*Goniastrea favulus* (Dana, 1846)	•	•				
145.	*Goniastrea peresi* (Faure and Pichon, 1978)	•					
Genus *Oulastrea* Milne Edwards and Haime , 1848							
146.	*Oulastrea crispata* (Lamarck, 1816)	•	•				
Genus Oulophyllia Edwards and Haime , 1848							
147.	*Oulophyllia levis* (Nememnzo,1959)	•	•				
148.	*Oulophyllia crispa* (Lamarck, 1816)	•					
Genus *Favia* Oken, 1815							
149.	*Favia pallida* (Dana, 1846)	•	•	•	•		
150.	*Favia danai* Haime and Milne Edwards, 1857	•	•	•			
151.	*Favia truncatus* Veron, 2000	•	•	•			
152.	*Favia laddi* (Wells, 1954)	•					
153.	*Favia amicorum* (Milne Edwards and Haime,1850)	•					
154.	*Favia maxima* Veron and Pichon, 1977	•	•	•	•		
155.	*Favia fragum* (Esper, 1797)	•					
156.	*Favia matthaii* Vaughan, 1918	•	•	•	•		
157.	*Favia speciosa* Dana, 1846	•	•	•	•	•	
158.	*Favia lizardensis* Veron and Pichon, 1977	•	•	•			
159.	*Favia laxa* (Klunzinger, 1879)	•					
160.	*Favia helianthoides* Wells, 1954	•					
161.	*Favia maritima* (Nemenzo, 1971)	•					
162.	*Favia favus* (Forskal, 1775)	•	•	•	•		
163.	*Favia rotundata* (Veron and Pichon, 1977)	•					
164.	*Favia rotumana* (Gardiner, 1899)	•	•				
Genus *Platygyra* Ehrenberg, 1834							
165.	*Platygyra verweyi* Wijsman-Best, 1976	•	•				
166.	*Platygyra sinensis* (Milne Edwards and Haime, 1849)	•	•				
167.	*Platygyra acuta* Veron, 2000	•					
168.	*Platygyra crosslandi* Matthai, 1928	•	•	•	•		
169.	*Platygyra contorta* Veron, 1990	•	•				
170.	*Platygyra ryukyuensis* Yabe and Sugiyama, 1936	•	•	•	•		
171.	*Platygyra pini* Chevalier, 1975	•	•	•	•	•	
172.	*Platygyra yaeyamaensis* Eguchi and Shirai, 1977	•					
173.	*Platygyra lamellina* (Ehrenberg, 1834)	•	•	•			
Genus *Plesiastrea* Milne Edwards and Haime, 1848							
174.	*Plesiastrea versipora* (Lamarck, 1816)	•	•	•			
Genus *Favites* Link, 1807							
175.	*Favites pentagona* (Esper, 1794)	•	•	•	•	•	•
176.	*Favites abdita* (Ellis and Solander, 1786)	•	•	•	•	•	•
177.	*Favites acuticollis* (Ortmann, 1889)	•	•				
178.	*Favites chinensis* (Verrill, 1866)	•					
179.	*Favites bestae* Veron, 2000	•					
180.	*Favites halicora* (Ehrenberg,1834)	•	•	•			
181.	*Favites flexuosa* (Dana, 1846)	•	•				
182.	*Favites paraflexuosa* Veron, 2000	•					
183.	*Favites stylifera* (Yabe and Sugiyama, 1937)	•					
184.	*Favites micropentagona* Veron, 2000	•	•	•			
185.	*Favites complanata* (Ehrenberg, 1834)	•	•	•	•		
186.	*Favites vasta* (Klunzinger,1879)	•	•				
187.	*Favites spinosa* (Klunzinger, 1879)	•	•				
Genus *Leptastrea* Milne Edwards and Haime, 1848							
188.	*Leptastrea purpurea* (Dana, 1846)	•	•	•	•		
189.	*Leptastrea aequalis* Veron, 2000	•	•				
190.	*Leptastrea transversa* Klunzinger, 1879	•	•				
191.	*Leptastrea pruinosa* Crossland, 1952	•	•				
Genus *Leptoria* Milne Edwards and Haime,1848							
192.	*Leptoria phrygia* (Ellis and Solander, 1786)	•	•	•			
Genus *Echinopora* Lamarck, 1816							
193.	*Echinopora pacificus* Veron, 1990	•					
194.	*Echinopora lamellosa* (Espper, 1795)	•					
195.	*Echinopora hirsutissima* Milne Edwards and Haime, 1849	•	•				
196.	*Echinopora gammacea* Lamarck, 1816	•					
Family PORITIDAE Gray, 1842							
Genus *Porites* Link, 1807							
197.	*Porites stephensoni* Crossland, 1952	•	•	•			
198.	*Porites compressa* Dana, 1846	•					
199.	*Porites solida* (Forskal, 1775)	•	•	•	•	•	
200.	*Porites lobata* Dana, 1846	•	•	•	•	•	
201.	*Porites murrayeneis* Vaughan, 1918	•	•				
202.	*Porites lutea* Milne Edwards and Haime, 1851	•	•	•	•		
203.	*Porites monticulosa* Dana, 1846	•					
204.	*Porites attenuata* (Nemenzo 1955)	•					
205.	*Porites cylindrica* Dana, 1846	•					
206.	*Porites australiensis* Vaughan, 1918	•					
207.	*Porites rus* (Forskal, 1775)	•					
208.	*Porites densa* Vaughan, 1918	•					
209.	*Porites horizontalata* Hoeffmeister, 1925	•	•				
210.	*Porites sillimaniana* Nemenzo, 1976	•					
Genus *Goniopora* de Blainville, 1830							
211.	*Goniopora lobata* Milne Edwards and Haime, 1860	•					
212.	*Goniopora columna* Dana, 1846	•	•				
213.	*Goniopora minor* Crossland, 1952	•					
Genus *Alveoporade* Blainville, 1830							
214.	*Alveopora catalai* Wells, 1968	•					
Family MUSSIDAE Ortmann, 1890							
Genus *Symphyllia* Milne Edwards and Haime, 1848							
215.	*Symphyllia radians* Milne Edwards and Haime,1849	•	•	•	•	•	
216.	*Symphyllia erythraea* (Klunzinger, 1879)	•					
217.	*Symphyllia recta* (Dana,1846)	•	•	•	•		
218.	*Symphyllia valenciennesii* Milne Edwards and Haime, 1849	•	•	•			
219.	*Symphyllia agaricia* Milne Edwards and Haime, 1849	•	•	•			
220.	*Symphyllia hassi* Pillai and Scheer, 1976	•	•	•			
Genus *Lobophyllia* Milne Edwards and Haime, 1851							
221.	*Lobophyllia hataii* Yabe and Sugiyama, 1936	•					
222.	*Lobophyllia flabelliformis* Veron, 2000	•	•				
223.	*Lobophyllia hemprichii* (Ehrenberg, 1834)	•	•	•			

224. *Lobophyllia corymbosa* (Forskal, 1775)	•						
225. *Lobophyllia dentatus* Veron , 2000	•						
Genus *Isophyllia* Milne Edwards and Haime, 1851							
226. *Isophyllia sinuosa* (Ellis and Solander, 1786)	•						
Genus *Acanthastrea* Milne Edwards and Haime, 1848							
227. *Acanthastrea hemprichii* (Ehrenberg, 1834)	•						
228. *Acanthastrea regularis* Veron, 2000	•	•	•	•			
229. *Acanthastrea echinata* (Dana, 1846)	•						
230. *Acanthastrea brevis* Milne Edwards and Haime, 1849	•	•					
Genus *Parascolymia* Wells, 1964							
231. *Parascolymia vitiensis* (Brueggemann, 1877)	•	•	•	•			
232. *Parascolymia australis* (Milne Edwards and Haime)	•						
Genus *Australomussa* Veron, 1985							
233. *Australomussa rowleyensis* Veron, 1985	•	•					
Genus *Cynarina* Brueggemann , 1877							
234. *Cynarina lacrymalis* (Milne Edwards and Haime, 1848)	•						
Family PECTINIDAE Vaughan and Wells, 1943							
Genus *Pectinia* Oken, 1815							
235. *Pectinia paeonia* (Dana, 1846)	•	•					
236. *Pectinia lactuca* Pallas, 1766	•						
237. *Pectinia alcicornis* (Saville-Kent,1871)	•						
Genus *Echinomorpha* Veron, 2000							
238. *Echinomorpha nishihirai* (Veron, 1990)	•	•					
Genus *Oxypora* Saville Kent,1871							
239. *Oxypora crassispinosa* Nemenzo, 1979	•	•					
240. *Oxypora glabra* Nemenzo, 1959	•	•					
241. *Oxypora lacera* (Verrill, 1864)	•						
242. *Genus Echinophyllia* Klunzinger,1879							
243. *Echinophyllia echinoporoides* Veron and Pichon, 1979	•	•					
244. *Echinophyllia orpheensis* Veron and Pichon, 1980	•						
Genus *Mycedium* Oken,1815							
245. *Mycedium elephantotus* (Pallas,1766)	•						
246. *Mycedium robokaki,* Moll and Borel-Best, 1984	•						
Family MERULINIDAE Verrill,1866							
Genus *Merulina* Ehrenberg, 1834							
247. *Merulina ampliata* (Ellis and Solander, 1786)	•	•	•				
248. *Merulina scabricula* Dana, 1846	•						
Genus *Hydnophora* Fischer de Waldheim,1807							
249. *Hydnophora microconos* (Lamarck, 1816)	•	•	•	•			
250. *Hydnophora exesa* (Pallas, 1766)	•						
251. *Hydnophora bonsai* Veron, 1990	•						
Genus *Scapophyllia* Milne Edwards and Haime, 1848							
252. *Scapophyllia cylindrica* Milne Edwards and Haime, 1848	•	•					
Genus *Phymastrea* Milne Edwards and Haime, 1848							
253. *Phymastrea valenciennesi* Milne Edwards and Haime, 1848	•	•	•	•	•		
254. *Phymastrea colemani* Veron, 2000	•	•					
255. *Phymastrea magnistellata* (Chevalier, 1977)	•						
Genus *Astrea* Lamarck, 1801							
256. *Astrea curta* Dana, 1846	•	•	•				
257. *Astrea annuligera* Milne Edwards and Haime, 1849	•						
Family DENDROPHYLLIIDAE Gray, 1847							
Genus *Turbinaria* Oken, 1815							
258. *Turbinaria peltata* (Esper, 1794)	•						
259. *Turbinaria mesenterina* (Lamarck, 1816)	•	•	•				
260. *Turbinaria reniformis* Bernard, 1896	•						
261. *Turbinaria stellulata* (Lamarck, 1816)	•						
262. *Turbinaria radicalis* Bernard, 1896	•						
Genus *Tubastraea* Lesson, 1829							
263. *Tubastraea* coccinea Lesson, 1829	•	•	•	•			
264. *Tubastraea diaphana* Dana,1846	•						
265. *Tubastraea micranthus* (Ehrenberg, 1834)	•						
Genus *Dendrophyllia* Grey, 1847							
266. *Dendrophyllia robusta* (Bourne,1905)	•	•					
Genus *Rhizopsammia* Verrill, 1869							
267. *Rhizopsammia verrilli* van der Horst, 1922	•						
Genus *Balanophyllia* Wood, 1844							
268. *Balanophyllia bairdiana* Milne Edwards and Haime, 1848	•						
Genus *Cladopsammia* Lacaze-Duthiers, 1897							
269. *Cladopsammia eguchii* Wells, 1982	•						
Family EUPHYLLIDAE Veron, 2000							
Genus *Physogyra* Quelch, 1884							
270. *Physogyra lichtensteini* Milne Edwards and Haime, 1851	•	•					
Genus *Plerogyra* Milne Edwards and Haime, 1848	•						
271. *Plerogyra sinuosa* (Dana, 1846)	•	•	•				
Family CARYOPHYLLIIDAE Gray, 1847							
Genus *Paracyathus* Milne Edwards and Haime, 1848							
272. *Paracyathus stokesi* (Milne Edwards and Haime, 1848)	•						
Total number of species	190	114	44	96	20	69	22
Total number of genera	56	41	22	51	11	23	14
Total number of families	14	13	11	13	4	10	9

[A: Natural reef area of North Bay and adjoining area, B: Ship wreck of North Bay, C: Ship wreck of Sinclair Bay, D: Natural Reef area of Sir William Peel Island and adjoining areas, E: Ship wreck of Sir William Peel Island, F: Natural Reef area of Car Nicobar Island, G: Ship wreck of Car Nicobar Island]

Among the wrecks, maximum species diversity (H'=2.91) was recorded at North Bay wreck which is higher than normal optimal level while minimum (H'=1.52) was recorded at Sir William Peel Island wreck (Fig. 2). The species diversity of natural reef areas of North Bay and adjoining areas showed a higher degree of value (H'=3.32) while lower value (H'=2.30) was recorded for natural reef areas of Car Nicobar Island (Fig. 2).

Similarity index was calculated among the four shipwrecks of Andaman and Nicobar Islands. It was seen that maximum similarity (0.41) was recorded between North Bay and Sinclair

Bay shipwrecks (both are steel hulled) while the minimum (0.11) was found between Sir William Island (wooden hull) and North Bay shipwrecks (steel hull) (Table 3). The similarity index of natural reefs and shipwrecks of the entire surveyed regions was also analyzed to hypothesize the correlation between them. It was recorded that natural reef of North Bay and shipwreck of North Bay showed maximum similarity (0.61) in species content being the nearby area while natural reef area of Sir William Peel Island and adjoining areas and nearby ship wreck represented minimum similarity (0.13) (Table 3).

Table 3. Similarity index of scleractinian corals in four wrecks along with the adjoining areas of Andaman and Nicobar Islands

B	C	D	E	F	G	
A	0.61	0.26	0.43	0.17	0.28	0.16
B	0.41	0.40	0.11	0.28	0.22	
C	0.27	0.15	0.24	0.15		
D	0.13	0.16	0.13			
E	0.08	0.23				
F	0.17					

[A: Natural reef area of North Bay and adjoining area, B: Ship wreck of North Bay, C: Ship wreck of Sinclair Bay, D: Natural Reef area of Sir William Peel Island and adjoining areas, E: Ship wreck of Sir William Peel Island, F: Natural Reef area of Car Nicobar Island, G: Ship wreck of Car Nicobar Island]

Discussion

Natural calamities such as cyclone, storm energy, bleaching, tidal waves played a significant role for the destruction of natural reef ecosystems over the period. It was estimated that the 10% of world's coral reef has already been depleted, in addition of 2/3 under the risk of serious decline due to anthropogenic threats (Luoma, 1996). It was also predicted that the loss of coral reef will reach to 70% level by the year 2036 (Reakea-Kudla, 1996). Ecological and species restoration of natural reef along with the development of new reef areas are the prime activities to combat against the depletion of reef areas of the world's ocean. The ideas and implementation of artificial substrate also play a great role for the support of restoration of reef ecosystems. The studies on the artificial reef are have been carrying on with great concern over last two decades with possibilities and impacts (Ardizzone *et al.,* 1989; Aseltine-Neilson *et al.,* 1999; Cummings, 1994; Qiu *et al.,* 2003; Perkol-Finkel and Benayahu, 2005). In 1935, four ships were sunken for the development of artificial reef fishing by the Cape May Wildwood Party Boat Association (Stone, 1974). A number of steel-hulled ships sunk during 2nd world war in the coastal areas of Atlantic and Gulf Coasts and have been showcasing a great place of artificial reef diversity while the steel of steel hulled vessels facing great threats of gradual destruction due to corrosion with the environment clues (Lukens and Selberg, 2004). Environmental catastrophic factor such as hurricane, storm action, tsunami can shift the deployed shipwreck from its original position to new position (Bell and Hall, 1994; Lukens and Selberg, 2004).

An extensive programme on the construction of artificial reef was taken under consideration during 1980s to enhance the reef ecosystem of Malaysia by using thousands of tyres in Peninsular Malaysia and resulted as 37 artificial reefs. Apart from that 9 artificial reefs by using 77 boats and 4 artificial reefs with of 204 concrete pyramidal were established coastal waters of Peninsular Malaysia. A great diversity of corals and associated faunal communities were recorded at the all the artificial reef sites. Thus the artificial reefs developed the species database and aggregation of Malaysia (Hung, 1990). Shipwrecks give a complex integrity of structures for the settlement and development of coral and associated faunal communities. Steel hulled wrecks provide strong substratum in comparison with wood-hulled wrecks as well as the stability of the steel hulled wreck is greater than the wooden one. The natural reef areas of North Bay region showed healthy state of scleractinian diversity at it represented 190 species with the diversity (H') of 3.32.

Among the four shipwrecks, North Bay wreck (steel-hulled) showed a massive productivity in terms scleractinian corals as it harbors a total of 114 species under 41 genera and 13 families with the species diversity (H') of 2.91. The extensive exploration of scleractinian corals from Indian waters revealed that a total of more than 600 species (some species revision is also required) from all the major four reef areas such as Lakshadweep with 156 species of scleractinian corals distributed in 32 sq. km., Gulf of Mannar and Palk Bay region with a total of 139 species of scleractinian corals distributed in 10,000 sq. km area (while Gulf of Marine National Park is with 560 sq. km area), Gulf of Kachchh with 59 species of scleractinian coral in 110 sq. km. area, and Andaman and Nicobar Islands with 588 species (some species revision is also required) of scleractinian corals in 1962 km. long coast line (Tamal Mondal and Raghunathan, 2016,Tamal Mondal *et al.,* 2017). Sir William Peel Island wreck (wood-hulled) represented only 20 species of scleractinian corals. Andaman and Nicobar Islands represents enriched productive area for the scleractinian corals due to its high species diversity and distributional pattern (Tamal Mondal *et al.,* 2015). North Bay wreck shares 19.38% species scleractinian corals of Andaman and Nicobar Islands within an area of about 60x10x10 m^3. The complexity of the structure of the wreck and firm integrity due to steel hull maximizes the scope of coral's larval settlement in presence of biogenic habitat. The island base studies on scleractinian coral reveals that Peacock Island represented 81 species, Avis Island represented 91 species, Ray Island represented 44 species, Curlew Island represented 20 species, Ross Island represented 80 species, Sir William Peel Island represented 65 species, Nicolson Island represented 44 species, Wilson Island represented 49 species, Henry Lawrence Island represented 50 species, Outram Island represented 78 species, Inglis Island represented 48 species, Sir Hugh Rose Island represented 38 species, John Lawrence Island represented 61 species, Neil Island represented 108 species, North Button Island represented 66 species, Middle Button Island represented 32 species, Katchal Island represented 61 species and Trinket Island represented 93 species in Andaman and Nicobar Islands which is lower than the species of North Bay Wreck (Tamal Mondal *et al.,* 2011, 2012, 2013, 2014a,b).

The shipwreck represents high vertical profile which harbours different niche in a limited place to show the species interaction and also provides extensive surface area for epibenthic colonization which develops the lower trophic level biomass at the artificial reef site. Higher rate of coral settlement can be seen on the vertical or inclined surfaces of the wreck in comparison with the horizontal ones, as the sedimentation rate is lower and higher rate of water circulation (Clark and Edwards, 1999; Wendt *et al.,* 1989). The wrecks used to provide alternatives to natural reef sites to carry out recreational diving. Establishment of an artificial reef can alter the physico-chemical attributes of the marine ecosystem by changing natural bottom reef community, water circulation, currents pattern, wave active, rate of sedimentation which may also modify the productivity of the place (Broughton, 2012). It is imperative to improve ample plans for the construction, setting up and deployment of artificial reef with suitable management strategies to enhance the potential of artificial reefs. The long axis of a shipwreck focused on perpendicular to the prevailing current showed higher velocity and energy and lower sedimentation rates and showed more productivity with several invertebrates and organic substances while the middle portion of the ship face less velocity (Baynes and Szmant, 1989; Broughton, 2012). The comparative evaluation on scleractinian corals of natural reef and artificial reef of North Bay implies that the 61% species similarities while rest of the other species larvae were settled in artificial reef area i.e. shipwreck which indicates the great importance of complex wreck area for the successful development of reef building coral for the enrichment of scleractinian diversity in Andaman and Nicobar Islands. The nature of hull substance also play intensive role as settlement of scleractinian corals was greater in steel hull in accordance with the nearby reef area while ship wreck with wooden hull of Sir William Peel Island showed only 13% similarity in species content in comparison with the nearby natural reef areas. Hence the concept of artificial reef and their constructional approach can be taken under consideration for the effective development of reef ecosystem at Andaman and Nicobar Islands with precautionary measures.

Acknowledgements

Authors are grateful to the Director, Zoologicl Survey of India for providing necessary permission and facilities to carry out the coral diversity assessment. The financial assistance provided by Science and Engineering Research Board (SERB), New Delhi and logistic support extended by Department of Environment and Forests, Andaman and Nicobar Administration are duly acknowledged.

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