ORIGINAL PAPER

Assessing abundance of the giant clams *Tridacna* spp. on shallow reef flats in the gulf of Thailand

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Abstract: The giant clams are sessile reef animals that attract tourists in Thailand and other countries. In the past, giant clams represented an important component of coral communities in the Gulf of Thailand. The present study aimed to examine the population densities of the giant clams *Tridacna* spp. on shallow reef flats in Mu Ko Chumphon, Mu Ko Angthong, and Ko Pha-Ngan, the Gulf of Thailand. The field surveys were conducted at 23 reef sites. Two giant clam species, namely *T. crocea* and *T. squamosa* were recorded. The population of *T. squamosa* occupied all study sites. The highest number was found at Ko Taen (0.96±0.16 ind/m^2), while the lowest was observed at Ko Mattra and Ko Lawa, Mu Ko Chumphon (0.2±0.18 and 0.2±0.17 ind/m^2, respectively). In contrast, *T. crocea* was observed only at 2 study sites, Ao Luek in Ko Tao and Ko Hin Dab in Mu Ko Angthong. There were no records of giant clams at several study sites, particularly in Mu Ko Ang thong and Ko Pha-Ngan. The correlation analysis results indicated that there is a strong negative relationship between giant clam population density and temperature (R = -0.85), while the low positive relationship was found to transparency. The results imply that previous giant clam restoration projects can enhance population densities on natural reefs.

Keywords: abundance, giant clam, Gulf of Thailand, population, shallow reef flat

1. Introduction

The shallow reef flat ecosystem is a large and distinctive habitat on coral reefs (Bellwood et al., 2018). It provides food and refuge for associated reef organisms such as fishes, sponges, crustaceans, and mollusks, as well as providing valuable ecological services. Shallow reef flat is also considered an extreme marine environment because it is under high environmental stress.

Tridacnid clams are commonly called as giant clams, and are the largest living bivalves. They belong to the family Cardiidae, order Cardiida. The *Tridacna* consists of seven species, spread throughout the world, of which three currently exist in Thailand, *Tridacna squamosa*, *maxima*, and *crocea* (Nugranad et al., 1997). According to Thai law, giant clams are an endangered species protected by the Wild Animal Reservation and Protection Act, B.E. 2535, and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES).

Giant clams receive foods and nutrients by filter-feeding on suspended particles in the water but they also have a symbiotic relationship with photosynthetic microalgae, particularly symbiodiniaceae (formerly named Symbiodinium) (Mingoa-Licuanan & Gomez, 2007). These microalgae called zooxanthellae, live in giant clams' mantle and produce its characteristic color variations. The clams provide shelter to the zooxanthellae, while providing the amount of energy and former needs for metabolism and growth (Norton & Jones, 1992; Othman et al., 2010; Mies & Sumida, 2012)

Giant clams play several important roles in the coral reef ecosystem, contributing to reef productivity, providing biomass to predators and scavengers, nurseries and hosts for other organisms, and calcium carbonate producers. Their presence in coral reefs had significant positive effects on the richness and abundance of fish species and various invertebrates. (Neo et al., 2015). Humans benefitted from giant clams throughout the past decades, as most species were exploited for meat consumption while their shells are used for ornaments confection. Besides, the current interest by aquarium trades, due to their bright coloration. (Othman et al., 2010; Van Wynsberge et al., 2016).

In the past, giant clams represented an important component of coral communities in the Andaman Sea and the Gulf of Thailand (Chatrapornsyl et al., 1996; Nugranad & Kittiwattanawong, 2016). Since then, anthropogenic impacts, density dependency individual/ microenvironmental variables, and mortality (disease and bleaching) growingly pressure giant clam populations (Ramah et al., 2017), which are now facing a decrease in abundance and prevalence, especially from global stressors. Rising sea temperatures are also considered as a serious threat to these marine organisms, particularly in the tropical oceans, where bleaching events can occur more frequently and can threaten the symbiotic algae in giant clams.

2. Material and Methods

This study was performed at twenty-three reef sites from five island groups in the Western Gulf of Thailand: (Table 1 and Figure 1). Underwater field surveys were carried out by SCUBA diving, using the belt transect method (English et al., 1997). At each study site, a 30x1 m^2 transect with three replicates was placed in parallel to the shoreline, along the shallow reef flat about 0.5-1.5 meters in depth. The giant clams were recorded, counted, and identified to a species level in situ. The giant clams' densities were then compared between five reef groups.

One way-ANOVA with post hoc Tukey HSD test was performed to determine whether there are significant differences between five island groups. Microsoft Office Excel 2019 was used to perform the correlation between environmental parameters and the density of giant clams.

Table 1. Geographic coordinates of each study sites

Study sites		Geographic coordinates	
		Latitude (N)	**Longitude (E)**
Mu Ko Chumphon	Ko Kula	10°15'35.87"	99°15'20.99"
	Ko Mattra	10°24'6.96"	99°21'5.22"
	Ko Maprao	10°23'25.79"	99°17'31.06"
	Ko Lawa	10°21'43.71"	99°18'28.39"
	Ko Rang Kachiu	10°19'30.31"	99°17'56.81"
Ko Tao	Ao Luek	10°4'12.72"	99°50'27.28"
	Hin Wong	10°6'13.49"	99°50'52.47"
	Hat Sairee	10°7'23.34"	99°50'9.59"
	Ao Muang	10°6'1.69"	99°49'32.95"
Ko Samui	Ko Rahin	9°34'30.25"	100°0'40.27"
	Ko Taen	9°22'2.43"	99°55'55.82"
	Ao Thong Node	9°24'48.59"	99°58'26.65"
Mu Ko Ang Thong	Ko Sam Sao Eastern	9°39'53.40"	99°41'1.32"
	Ko Sam Sao Northern	9°39'16.39"	99°40'54.85"
	Ko Sam Sao Western	9°39'55.32"	99°40'48.46"
	Ko Hin Dab	9° 40' 48.39"	99° 41' 6.46"
	Ko Tai Plao	9°42'22.43"	99°40'33.24"
Ko Pha-Ngan	Ko Chalok Lam	9°47'34.11"	100°0'36.55"
	Ko Kong Than Sadet	9°45'56.49"	100°4'28.09"
	Ao Thong Sala	9°42'18.78"	100°0'2.54"
	Hat Khom	9°47'55.26"	100°0'52.10"
	Hat Thong Lang	9°48'0.58"	99°59'18.34"
	Hat Mae Hat	9°47'50.95"	99°58'43.19"

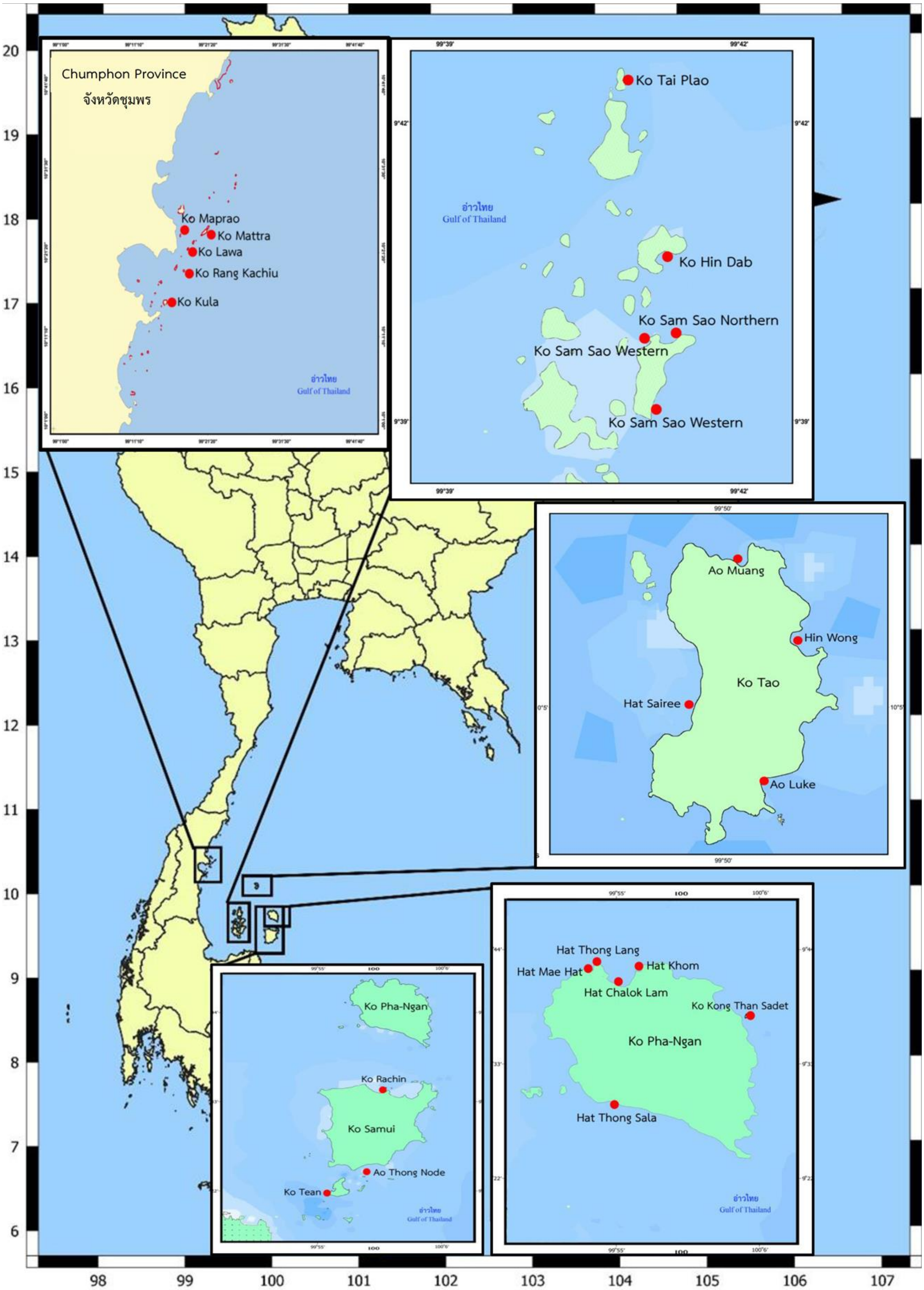

Figure 1. Map of the study sites

3. Results

3.1 Population density

A total of two giant clam species were identified and counted within the study sites, of which 80% were identified as *Tridacna squamosa* Lamarck, 1819 and the rest were *Tridacna crocea* Lamarck, 1819. The population of *T. squamosa* occupied all study sites. The densities of giant clams were relatively high at Ko Taen in Ko Samui (0.96±0.16 ind/m^2) and Hat Sairee in Ko Tao (0.87±0.12 ind/m^2) (Figure 2). However, both sites showed significant differences to the other sites. On the other hand, the lowest densities were observed at Ko Mattra and Ko Lawa, Mu Ko Chumphon (0.2±0.18 and 0.2±0.17 ind/m^2, respectively). *T. crocea* was observed only at two study sites, Ao Luek in Ko Tao and Ko Hin Dab in Mu Ko Angthong, where the density was relatively high in Ao Luek (1.68±0.20 ind/m^2). However, there were no records of giant clams at several study sites, particularly in Mu Ko Ang thong and Ko Pha-Ngan (Figure 3 and Table 2).

3.2 Environmental parameter

The correlation analysis results indicated that there was a strong negative relationship between giant clam population density and temperature (R = -0.85), while the low positive relationship was found to transparency (R = 0.43) (Figure 4).

Table 2. Population densities of *T. squamosa* and *T. crocea* (ind/m^2)

Study sites		Population density (ind/m^2)	
		T. squamosa	***T. crocea***
Mu Ko Chumphon	Ko Kula	0.56±0.49	0.00
	Ko Mattra	0.20±0.18	0.00
	Ko Maprao	0.00	0.00
	Ka Lawa	0.20±0.17	0.00
	Ko Rang Kachiu	0.00	0.00
Ko Tao	Ao Luek	0.64±0.56	1.68±0.20
	Hin Wong	0.67±0.58	0.00
	Hat Sairee	0.87±0.76	0.00
	Ao Muang	0.80±0.52	0.00
Ko Samui	Ko Rahin	0.00	0.00
	Ko Taen	0.96±0.84	0.00
	Ao Thong Node	0.00	0.00
Mu Ko Angthong	Ko Sam Sao (Eastern)	0.00	0.00
	Ko Sam Sao (Northern)	0.00	0.00
	Ko Sam Sao (Western)	0.00	0.00
	Ko Hin Dab	0.00	0.00
	Ko Tai Plao	0.53±0.47	0.00
Ko Pha-Ngan	Hat Chalok Lam	0.48±0.42	0.00
	Ko Kong Than Sadet	0.00	0.00
	Ao Thong Sala	0.00	0.00
	Hat Khom	0.00	0.00
	Hat Thong Lang	0.47±0.41	0.00
	Hat Mae Hat	0.54±0.47	0.00

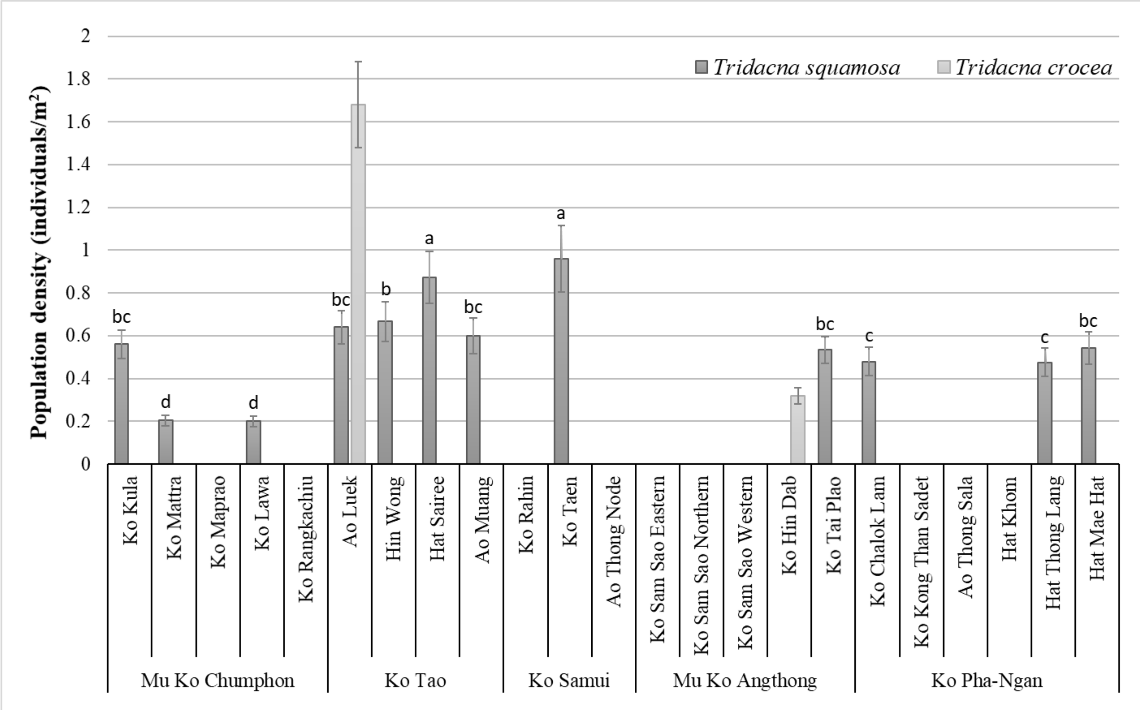

Figure 3. Population densities of *T. squamosa* and *T. crocea* at each study sites. Error bars indicate standard deviation.

Table 3. Environmental parameters at each study site

Study sites		Temp[1] (°C)	Salinity (ppt)	pH	DO[2] (mg/L)	Trans[3] (m)	SS[4]
Mu Ko Chumphon	Ko Kula	29.98	33.70	7.64	7.29	1.40	33.45
	Ko Mattra	31.11	33.96	7.65	7.86	1.20	33.76
	Ko Maprao	30.87	33.29	7.63	7.15	1.00	33.64
	Ka Lawa	30.46	33.73	7.63	7.29	1.00	33.52
	Ko Rang Kachiu	33.54	7.65	7.63	1.20	1.20	30.27
Ko Tao	Ao Luek	28.77	37.09	7.8	6.66	1.30	36.41
	Hin Wong	28.76	37.09	7.62	5.55	1.50	36.41
	Hat Sairee	28.82	37.09	8.21	6.74	1.50	36.3
	Ao Muang	28.69	37.09	8.23	7.17	1.40	36.39
Ko Samui	Ko Rahin	28.76	32.15	6.22	6.82	1.20	32.07
	Ko Taen	28.79	32.15	6.35	7.02	1.30	32.09
	Ao Thong Node	28.84	32.24	6.36	7.02	1.20	32.15
Mu Ko Angthong	Ko Sam Sao (Eastern)	29.49	34.08	7.27	7.11	0.50	33.80
	Ko Sam Sao (Northern)	29.41	34.06	8.17	7.64	0.30	33.78
	Ko Sam Sao (Western)	29.87	33.08	7.24	6.85	0.50	33.80
	Ko Hin Dab	29.88	33.10	7.24	7.11	0.60	33.83
	Ko Tai Plao	29.69	33.07	7.26	7.05	0.60	33.78
Ko Pha-Ngan	Hat Chalok Lam	29.49	37.13	7.92	7.92	1.20	36.46
	Ko Kong Than Sadet	29.49	37.13	7.90	7.89	1.20	36.42
	Ao Thong Sala	29.55	37.14	7.92	7.92	1.30	36.39
	Hat Khom	29.85	37.13	7.92	7.90	1.20	35.96
	Hat Thong Lang	29.91	37.14	7.93	5.46	1.30	35.11
	Hat Mae Hat	29.86	37.14	7.92	7.90	1.20	35.45

[1] Temp: Temperature, [2] DO: Dissolved Oxygen, [3] Trans: Transparency, [4]SS: Suspended Solids

Table 3. Correlation between giant clam density and environmental parameters

Parameters	Temp*	Salinity	pH	DO	Trans	SS
Density	-0.85	0.10	-0.28	-0.31	0.43	0.12

[1] Temp: Temperature, [2] DO: Dissolved Oxygen, [3] Trans: Transparency, [4]SS: Suspended Solids

4. Discussion

Sea surface temperature (SST) anomalies may affect the coral reef and reef-associated organisms such as giant clams (Apte et al., 2019). Based on the results of this study, giant clams showed a strong negative relationship with the temperature. Many studies indicate that rising temperature can negatively affect giant clams and their physiology, impacting on their survival capability under improper environmental conditions, reducing the viability of giant clam populations (Apte et al., 2019; Brahmi et al., 2019; Blidberg et al., 2000)

In 1998 and 2010, severe mass coral bleaching events were observed in the Gulf of Thailand, resulting from sea surface temperature anomalies (Suthacheep et al., 2013). The negative effect of elevated seawater temperature was clearly documented in the mass bleaching of *T. squamosa* and *T. crocea*, in the Gulf of Thailand in 2010 (Junchompoo et al., 2013). The change of seawater temperature did not cause a giant clam sudden death (Apte et al., 2019). Giant clam has been known to rely on the association with the zooxanthellae, and as soon these symbiont algae are lost, the clam will gradually become stressed over time due to their weakened state until they slowly die. Light is also important for giant clams to survive (Rossbach et al., 2019).

Giant clams are now experiencing rapid declines and local extinction in several places throughout the world (Tan & Zulfi gar, 2003; Guest et al., 2007; Neo, 2012a, 2012b; Waters et al., 2013; Triandiza et al., 2019).

Many other countries also have a low stock remaining (Othman et al., 2010) which may result on a great ecological loss to coral reef ecosystems due to their ecological roles. Department of Fisheries of Thailand has successfully worked on aquaculture-based enhancement and restoration of *Tridacna* spp. since 1993. The giant clam restocking programs have been carried out at several sites in the Gulf of Thailand and the Andaman Sea with various levels of success. Most giant clam seed production and restocking programs have been targeted for marine conservation. Department of Fisheries did the restocking programs in collaboration with Department of Marine and Coastal Resources (DMCR). The aquaculture-based enhancement and restoration activities have been conducted with support from local communities, private sectors, and NGOs (Nugranad & Kittiwattanawong, 2016). Our results imply that previous giant clam restoration projects can enhance population densities on natural reefs.

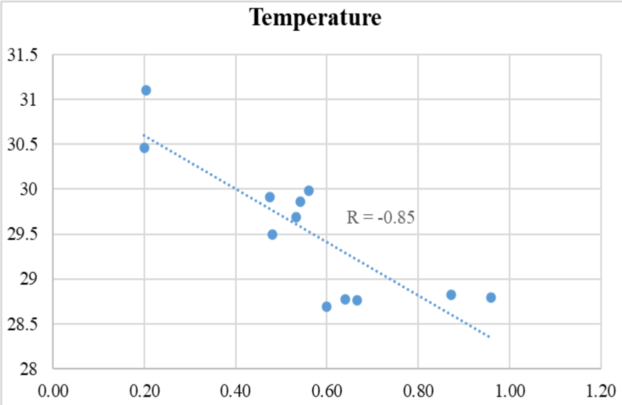

Figure 4. Correlation between giant clam population density and temperature

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