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TRANSITION OF SPECIES COMPOSITION, ABUNDANCE AND DISTRIBUTION OF THE GRACILARIOID SEAWEEDS (RHODOPHYTA) IN COASTAL AREAS OF THE UPPER GULF OF THAILAND OBSERVED FROM 2004 TO 2007

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ABSTRACT

Observations of red gracilarioid seaweeds were performed between 2004 and 2007 in several areas along the upper Gulf of Thailand at Ang Sila, Sri Racha harbor and Ko Si Chang in Chonburi, Ban Phe in Rayong, Laem Tien, Laem Sok and Ao Cho in Trat, Bangra Noi in Phetchaburi, Ta Mong Lai and Wanakorn beach in Prachuap Khiri Khan and at Thung Wua Laen beach in Chumphon Province. Changes in species diversity and biomass, as well as environmental factors, were investigated at three-month intervals covering both the monsoon and dry seasons. Eight species of gracilarioids that are distributed on west and east coasts of the upper Gulf of Thailand were identified, including *Hydropuntia edulis*, *Gracilaria changii*, *G. firma*, *G. salicornia*, *G. rhodymenioides*, *G. rubra*, *G. tenuistipitata*, and *G. minuta*. Two unidentified species with forms similar to known species were also found. The first was similar to *Gracilaria* (and named *Gracilaria* sp.) and was collected from Trat Province, while the second was similar to *Gracilariopsis* sp. (cf. *bailiniae*) and was collected from Chonburi Province. The gracilarioids occurred mostly in Chonburi and Trat Provinces. *G. salicornia* was dominant among the collected specimens. The present observations suggest that there have been remarkable changes in the coastal environment along the upper Gulf of Thailand. Most of the study sites had highly turbid and nutrient-rich seawater. The algal biomass decreased when the concentration of dissolved inorganic nitrogen (DIN) and turbidity were extremely high during the dry season. A decrease in seaweed species diversity was observed: in particular species of *Gracilaria* have disappeared from Ban Phe and decreased at Laem Tien, Laem Sok and Ao Cho. The loss of seaweed beds, particularly in Trat Province, was caused by deterioration of the coastal environment.

Keywords: biodiversity, biomass, degradation, Gracilariales, seaweed bed, Gulf of Thailand

INTRODUCTION

In the past, seaweeds in Thailand had been reported as diverse, while coastal environments were still pristine (MARTENS, 1866; SCHMIDT, 1900–1916; DAWSON, 1954; EGEROD, 1971; VELASQUEZ & LEWMANOMONT, 1975; LEWMANOMOUNT, 1976, 1988, 1989; PIRHOMPAKDEE, 1976; YONGRUAN, 1985; CHIRAPART & LEWMANOMONT, 2003). Over the past decades, however, seaweed resources have changed with the degradation of coastal environments. The numbers and diversity of seaweeds have tended to decrease, while some, especially *Gracilaria* species, have disappeared from certain areas. This has been observed on the eastern coast of the Gulf of Thailand (the "Eastern Seaboard") that spans Trat, Rayong and Chonburi Provinces, a large area experiencing deterioration in the quality of its coastal environments.

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There have been many reports of gracilarioid seaweeds from Thailand, most of them dealing with taxonomy (ABBOTT, 1988; ABBOTT *ET AL.*, 1991; LEWMANOMONT, 1994, 1995; CHIRAPART & RUANGCHAUY, 1999; CHIRAPART & LEWMANOMONT, 2002; LEWMANOMONT & CHIRAPART, 2004; CHIRAPART, 2008). A total of 18 taxa were recognized between 1994–2004, including *G. bangmeiana*, *G. changii*, *G. edulis*, *G. eucheumatoides*, *G. firma*, *G. fisheri*, *G. lemaneiformis*, *G. minuta*, *G. percurrens*, *G. rubra*, *G. irregularis*, *G. salicornia*, *G. tenuistipitata*, *G. textorii*, *G. urvillei*, *G. longirostris*, *G. multifurcata*, and *G. rhodymenioides* (LEWMANOMONT, 1994, 1995; CHIRAPART & RUANGCHAUY, 1999; LEWMANOMONT & CHIRAPART, 2004). These taxa are found in several parts of the country, particularly in Pattani, Songkhla and Trat Provinces. Among these, *G. changii*, *G. edulis*, *G. fisheri*, *G. salicornia* and *G. tenuistipitata* are the most abundant and are commonly harvested for human food, agar extraction and abalone feed.

At present, species of *Gracilaria* sensu lato have disappeared from some areas where they were previously recorded as abundant (PENGSENG, 1992; LAEHYEB *ET AL.*, 2011). The decline of these seaweeds has been partly caused by the introduction of the otter trawl into Thai waters in the early 1960s (LEWMANOMONT, 1998), resulting in the continuous disturbance of shallow water sediments. Recently, the proliferation of shrimp ponds has changed the environment of the coastal and mangrove areas, resulting in declines of natural *Gracilaria* populations. Moreover, the over-exploitation of wild stocks of seaweeds and the development of coastal areas for shrimp culture, tourism, and factories have resulted in dramatic decreases in natural production (EKMAHARACHA *ET AL.*, 2005; LAEHYEB *ET AL.*, 2011; PETSUT *ET AL.*, 2012).

The development of many areas along the upper coast of the Gulf of Thailand has resulted in changes in the coastal environment and a decline in *Gracilaria* resources (LAEHYEB *ET AL.*, 2011; PETSUT *ET AL.*, 2012). The disappearance of the gracilarioid species from some areas, particularly in Trat and Rayong, is a result of this problem. Thus, the question remains as to why most of the *Gracilaria* species have disappeared since the development of coastal areas for tourism and shrimp culture. In addition, it is not known if the construction of public aquaria on the coast of Ban-Phe in Rayong has contributed to the decline of the gracilarioids. Though these questions currently have no definite answers, such changes may have caused disturbance and accumulation of shallow water sediments together with changes in water currents. This paper presents field observations for reassessing the distribution of gracilarioids and the possible impacts of environmental changes along the upper coast of the Gulf of Thailand during 2004–2007.

MATERIALS AND METHODS

Study Sites and Field Sampling

The study sites were selected from areas along the upper coast of the Gulf of Thailand. Both intensive and extensive field observations were carried out from June 2004 to May 2005 and from December 2005 to March 2007 along the coasts of Chonburi, Rayong, Trat, Phetchaburi, Prachuap Khiri Khan, and Chumphon Provinces (Fig. 1) where there were notable changes in the coastal environment. The study emphasized collections from Ang Sila, Sri Racha harbor, and Ko Si Chang in Chonburi; Ban Phe in Rayong; Laem Tien, Laem Sok, and Ao Cho in Trat; Bangra Noi in Phetchaburi; Ta Mong Lai and Wanakorn beach in Prachuap Khiri Khan; and Thung Wua Laen beach in Chumphon.

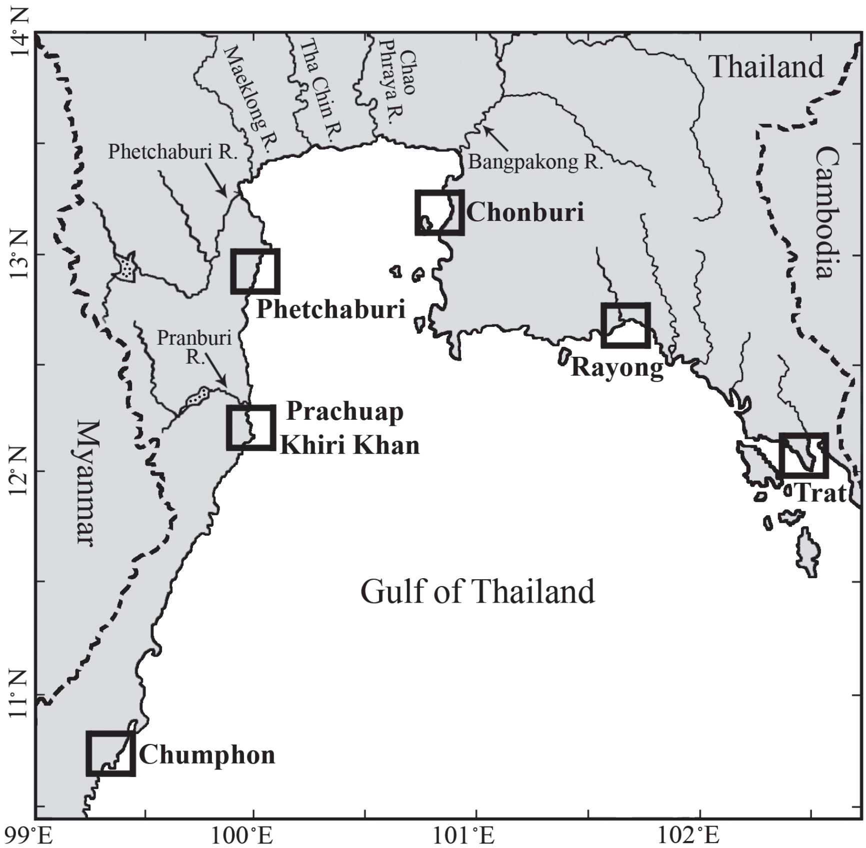

Figure 1. Map of the upper Gulf of Thailand showing study sites of the present study (□) at Chonburi, Rayong, Trat, Phetchaburi, Prachuap Khiri Khan, and Chumphon Provinces. Terrestrial areas shown in gray color. Black lines interior to a coastal line indicate large and medium size rivers flowing into the Gulf. Dotted areas indicate principal reservoirs. Broken lines indicate national boundaries.

Samples were collected by hand or by free-diving in shallow waters. In the near shore, samples were collected at 1–2 m depth below the MTL. Sampling was performed at 3-month intervals covering the wet monsoon and dry seasons. The repeated sampling unit consisted of algal counts undertaken using a 25 × 25 cm quadrat placed randomly in shallow waters on a line transecting each site. The survey encompassed approximately 250 m^2 of area at each study site.

The biomass of collected samples in fresh weight per square meter was determined. Some samples were preserved in a solution of 4% formaldehyde and seawater or as dried specimens on herbarium sheets. All microscopic mounts of the specimens collected were made using 50% corn syrup (Karo Syrup, Corn Products, Inc.) solution in distilled water containing a trace of phenol. Cross-sections were prepared by hand, stained with 1% aniline blue in 25% Karo Syrup and were analyzed under an optical microscope (Nikon, Eclipse E600) at 10×, 20×, and 40× magnification.

Collection of Environmental Data and Laboratory Analyses

At each collection site, several parameters were measured at each sampling interval. In addition, the general environment was observed. Surface seawater temperature, salinity, turbidity, PO_4-P and total dissolved inorganic nitrogen (ammonia+nitrite+nitrate) were determined on each working day as one-point measurements. Water temperature and salinity were measured using an alcohol thermometer and refracto-salinometer, respectively. The turbidity of the seawater was determined and recorded at 420 nm with a spectrophotometer (Shimadzu UV-1601). Ammonia-N content was determined according to APHA, AWWA & WPCF (1980) and PO_4-P, NO_3-N and NO_2-N were measured according to STRICKLAND & PARSONS (1972). Other environmental parameters (e.g. total suspended solids, TSS; water transparency, etc.) were accessed from the Annual Report of Water Quality 2004–2006 published by the Marine Environment Division, Pollution Control Department, Ministry of Natural Resources and Environment (ANONYMOUS, 2004, 2005, 2006).

RESULTS AND DISCUSSION

Ten species of gracilarioids were found, distributed from the west coast to the east coast of the upper Gulf of Thailand: *Hydropuntia edulis, Gracilaria changii*, *G. firma, G. salicornia, G. rhodymenioides, G. rubra*, *G. tenuistipitata*, *G. minuta*, *Gracilaria* sp. and *Gracilariopsis* sp. Nine of them are shown in figure 2. In the specimens collected from Trat Province, an intermediate form (*Gracilaria* sp.) was found (Fig. 2f). As of now, this form has not been identified as any known species. In 2006, another different species of gracilarioid was found among the specimens collected from Ang Sila in Chonburi Province. This species is distinguished clearly in its gross morphology from the other species of *Gracilaria* that have been previously reported in Thai waters. The specimen has been identified as a new unreported species of *Gracilariopsis* sp. (cf. *bailiniae*) for Thai waters (data will be reported elsewhere). Algae of this species were entangled with a large quantity of *H. edulis* found in the reservoir at Ang Sila. Among the observed species, *G. salicornia* was the only dominant species. This species was found at all the study sites, where the differences in abundance and distribution of species were affected by environmental changes at each site. For those of *G. changii* and the intermediate form (*Gracilaria* sp.), plants were found only at Laem Sok and Ao Cho in Trat Province. By contrast, the very rare *G. firma* was found in Laem Tien. Most of the gracilarioids grew in calm water or sheltered habitats of mangrove areas, except for *G. rhodymenioides* which was found along the coast of Ta Mong Lai in Prachuap Khiri Khan and Thung Wua Laen in Chumphon Province where the plants were often exposed to rather strong waves.

Changes in Biomass and Number of Gracilarioid Species

The changes in algal biomass observed in this study are shown in Table 1. Algal biomass varied year by year from 2004 to 2007 depending on the environment at the different study sites. Gracilarioids were found mostly in Chonburi and Trat Provinces. *G. changii* had previously been reported in abundance in Trat Province (CHIRAPART *ET AL.*, 1992). Trat gracilarioids had been reported to comprise seven species, including *G. changii*, *H. edulis* (syn *G. edulis*), *H. percurrens* (syn *G. percurrens*), *Gracilariopsis irregularis* (syn *G. irregularis*), *G. firma*,

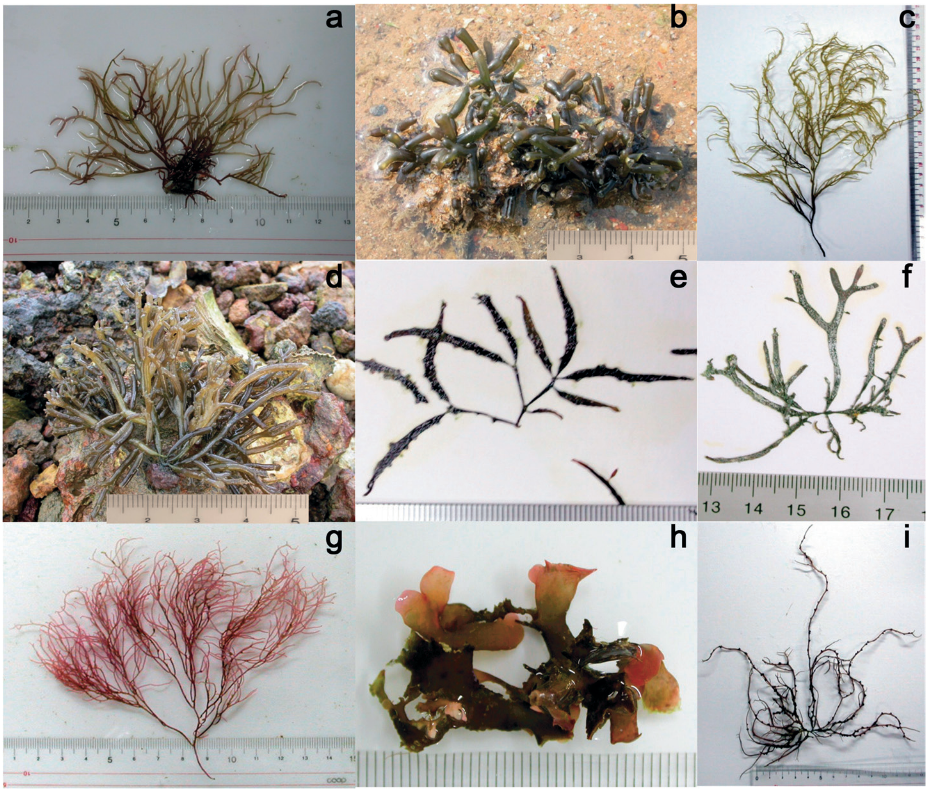

Figure 2. Habit of *Gracilaria* sensu lato collected from different habitats, (a) *H. edulis* collected from Ang Sila, Chonburi Province; (b) *G. salicornia* collected from Sri Racha harbor, Chonburi Province; (c) *Gracilariopsis* sp. (cf. *bailiniae*) collected from Ang Sila, Chonburi Province; (d) *G. firma* collected from Laem Tien, Trat Province; (e) *G. changii* collected from Leam Sok, Trat Province; (f) *Gracilaria* sp. an intermediate form of *Gracilaria* collected from Leam Sok, Trat Province; (g) *G. rubra* collected from Bangra Noi, Phetchaburi Province; (h) *G. rhodymenioides* collected from Thung Wua Laen, Chumphon Province; and (i) *G. tenuistipitata* collected from Bangra Noi, Phetchaburi Province.

G. minuta, and *G. salicornia* (Lewmanomont *et al.*, 1995). In this study, however, only three identified species were found: *G. changii*, *G. firma*, and *G. salicornia,* along with an intermediate form of *Gracilaria*. Of these species, *G. salicornia* was dominant among the collected specimens while the algal biomass of the other three species was rather low. Most samples were obtained from the current study site in Laem Sok, and of these, *G. changii* had the highest average biomass, 0.42 g/m^2 (0.02–1.54 g/m^2) (figures in parentheses give range of values for the sample stations), in the dry season during the hot period in March 2005. However, this decreased to the lowest average value of 0.11 g/m^2 (0.02–0.30 g/m^2) during the monsoon season in July 2005. *Gracilaria firma*, which is very rare, was only collected from Laem Tien but was not found the following year in the same site. Similarly, the intermediate form (*Gracilaria* sp.) was found in August 2004 only in small amounts of 0.18 g/m^2 (0.02–0.46 g/m^2) and 0.09 g/m^2

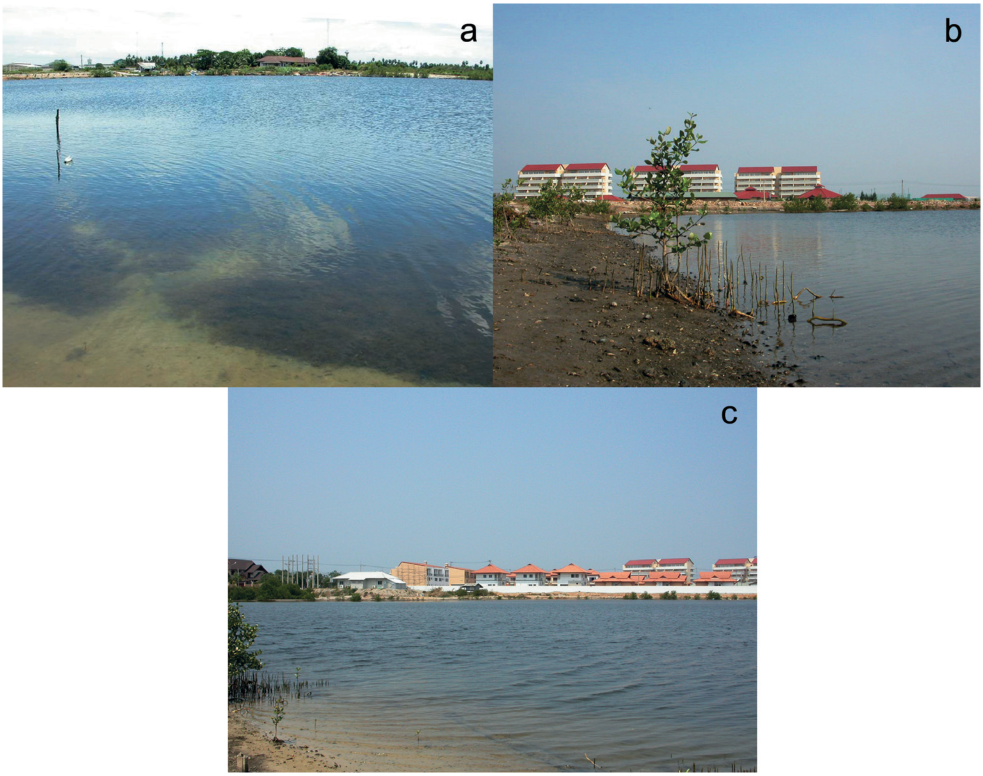

Figure 3. General environment of study site at the seawater reservoir at Ang Sila, Chonburi Province: (a) 7 Aug. 2004, natural shoreline with abundant *Gracilaria*; (b) 30 Mar. 2005, high buildings built around reservoir; (c) 7 Mar. 2006, private village construction.

Figure 4. Degraded environment at a seawater reservoir at Ang Sila, Chonburi Province (24 Mar. 2007).

(0.01–0.26 g/m^2) at Laem Sok and Ao Cho, respectively. However, the biomass of the intermediate form (*Gracilaria* sp.) at Laem Sok decreased to an average of 0.13 g/m^2 (0.03–0.22 g/m^2) in July 2005 and was very rare in 2006.

At the Ang Sila study site in Chonburi Province, the highest biomass was obtained from *H. edulis* (mean 35.80 g/m^2, range 6.04–82.33 g/m^2) collected during the monsoon season in July 2004. In the same year the lowest biomass was obtained from *G. salicornia* (mean 20.75 g/m^2, range 0.17–40.79 g/m^2) during the dry season in November. Both *H. edulis* and *G. salicornia* were found abundantly during the monsoon season in July 2004 but decreased in numbers during the dry season between the cool months (November 2004 to January 2005) to the hot period in March 2005 and 2006. In addition, in March 2006 *Gracilariopsis* sp. was found in low density (0.012 g/m^2), but declined in the following year. The decrease in biomass was thought to be due to deterioration in the general environment (e.g. water quality, bottom sediment) of the study site at Ang Sila; where it gradually declined after March 2005 because of house-construction surrounding the seawater reservoir (Fig. 3). In March 2006, the formerly luxuriant assemblage of algal species in the reservoir had declined, and all had disappeared in March 2007 after the reservoir was filled up with a large amount of trash (Fig. 4, Table 1).

At the other two study sites in Sri Racha harbor and at Ko Si Chang, only *G. salicornia* was found, attached to gravel or to the sandy, muddy bottom of shallow waters in the tidal zone. Changes in the biomass and distribution of *G. salicornia* were also observed during different seasons depending on the habitat and the environment (Table 1). An increase in biomass of *G. salicornia* collected from Ko Si Chang was found (mean 11.13 g/m^2, range 0.79–27.62 g/m^2) during the dry season in March 2005. However, a decrease in biomass of Ko Si Chang algae was observed in the following years, and specimens could no longer be collected. For the Sri Racha algae, a higher biomass of 1.68 g/m^2 (0.14–5.64 g/m^2) was obtained during March 2006 but lower biomass was obtained during the cool period in January 2005. Each year, the algal biomass at Sri Racha harbor tended to be affected by changes in the environment.

In the current observations, very rare algae were observed at Ban Phe in Rayong Province and their biomass could not be estimated. In the past, Pengseng (1992) reported three species of gracilarioids from Ban Phe; including *G. salicornia*, *H. ramulosa* (syn *G. bangmeiana*) and one unidentified species. Another study reported four species: *H. ramulosa*, *H. percurrens* (syn. *G. percurrens*), *G. changii* and *G. salicornia* (Lewmanomont *et al.*, 1995). In the present study, a few specimens of *G. salicornia* and *G. minuta* were found during the dry season in January 2005, and the latter species disappeared altogether from the habitat in the following year. *G. salicornia* plants were found only in tide pools throughout the year. However, in later observations from July 2005 to March 2007, very few specimens of *G. salicornia* were found in the same site.

For those observations in Phetchaburi, Prachuap Khiri Khan and Chumphon Provinces, small numbers of gracilarioids was found (Table 1). Two species of *Gracilaria*, *G. rubra* and *G. tenuistipitata* were found in very small amounts at Bangra Noi in Phetchaburi Province in 2004. These species were distributed along small canals in the mangrove areas, and the plants generally grow on the muddy, sandy bottoms in shallow water. Very rare specimens of *G. rubra* and *G. tenuistipitata* were found during the dry season in 2004, and the algal biomass of *G. tenuistipitata* was 0.65 g/m^2 (0.05–3.18 g/m^2) in July 2005. The biomass of *G. tenuistipitata* reached a higher mean value of 2.06 g/m^2 (0.10–5.24 g/m^2) in April 2006, while the *G. rubra* plants disappeared entirely from the habitat.

At the other study sites in Prachuap Khiri Khan and Chumphon Provinces, three

Table 1. Changes in biomass (g wet wt/m^2) of *Gracilaria* collected from different habitats during monsoon (July and August) and dry season (November–March) from 2004 to 2007.

Year	Species	Study sites								
		Chonburi Province				Trat Province				
		Date	Ko Si Chang	Date	Sri Racha harbor	Date	Ang Sila	Date	Laem Sok	Date
2004	*G. salicornia*		-		ns	3 Jul.	ns	1 Aug.	0.48 (0.61)	1 Aug.
			-		-	21 Nov.	20.75 (13.52)		r	
	G. firma		nf		nf		nf		nf	
	H. edulis		nf		nf	3 Jul.	35.80 (21.88)		nf	
						21 Nov.	13.98 (12.78)		nf	
	G. changii		nf		nf		nf	1 Aug.	0.19 (0.18)	
	Gracilaria sp.		nf		nf		nf	1 Aug.	0.18 (0.16)	
	G. rhodymenioides		nf		nf		nf		nf	
	G. tenuistipitata		nf		nf		nf		nf	
	G. rubra		nf		nf		nf		nf	
2005	*G. salicornia*	22 Jan.	2.83 (3.20)	23 Jan.	1.15 (1.11)	22 Jan.	3.92 (4.42)	21 Jan.	0.29 (0.28)	21 Jan.
		30 Mar.	11.13 (9.90)	30 Mar.	0.60 (0.35)	30 Mar.	2.49 (2.28)	29 Mar.	0.51 (0.57)	29 Mar.
				7 Jul.	0.20 (0.18)	7 Jul.	1.43 (3.27)	9 Jul.	0.39 (0.61)	9 Jul.
	G. firma		nf		nf		nf		nf	
	H. edulis		nf		nf	22 Jan.	6.65 (4.32)		nf	
						30 Mar.	1.97 (1.53)		nf	
						7 Jul.	ns		nf	
	G. changii		nf		nf		nf	29 Mar.	0.42 (0.57)	
							nf	9 Jul.	0.11 (0.09)	
	Gracilaria sp.		nf		nf		nf	9 Jul.	0.13 (0.07)	
	G. rhodymenioides		nf		nf		nf		nf	
	G. tenuistipitata		nf		nf		nf		nf	
	G. rubra		nf		nf		nf		nf	
2006	*G. salicornia*	6 Mar.	0.20 (0.23)	7 Mar.	1.68 (1.41)	7 Mar.	2.95 (3.58)	23 Mar.	0.59 (0.51)	23 Mar.
	G. firma		nf		nf		nf		nf	
	H. edulis		nf		nf	7 Mar.	2.86 (2.67)		nf	
	G. changii		nf		nf		nf		r	
	Gracilaria sp.		nf		nf		nf		r	
	G. rhodymenioides		nf		nf		nf		nf	
	G. tenuistipitata		nf		nf		nf		nf	
	G. rubra		nf		nf		nf		nf	
	Gracilariopsis sp.		nf		nf	7 Mar.	0.012		nf	
2007	*G. salicornia*		nf	25 Mar.	0.81 (0.69)		d	25 Mar.	0.60 (0.81)	25 Mar.
	G. firma		nf		nf		nf		nf	
	H. edulis		nf		nf		d		nf	
	G. changii		nf		nf		nf	25 Mar.	0.11 (0.11)	
	Gracilaria sp.		nf		nf		nf		r	
	G. rhodymenioides		nf		nf		nf		nf	
	G. tenuistipitata		nf		nf		nf		nf	
	G. rubra		nf		nf		nf		nf	
	Gracilariopsis sp.		nf		nf		d		nf	

- = off season; nf = not found; ns = no sampling; d = decay; r = very rare. Numbers in parenthesis represent standand deviation.
Gracilaria sp. = intermediate form *Gracilaria*; *Gracilariopsis* sp. = *Gracilariopsis* sp. (cf. *Gracilariopsis bailiniae*)

Table 1 (continued).

Study sites										
Trat Province (continued)			Phetchaburi Province		Prachuap Khiri Khan Province				Chumphon Province	
Laem Tien	Date	Ao Cho	Date	Bang Gra Noi	Date	Wanakorn beach	Date	Ta Mong Lai	Date	Thung Wua Laen
0.70 (0.68)	1 Aug.	0.10 (0.08)		nf	15 Aug.	0.47 (0.34)	15Aug.	7.27 (6.02)	14Aug.	0.48 (0.38)
ns		-		nf		r		-		ns
nf		-		nf		nf		nf		nf
nf		-		nf		nf		-		r
nf		-		nf		nf		-		r
nf	1 Aug.	0.08 (0.01)		nf		nf		nf		nf
nf	1 Aug.	0.09 (0.14)		nf		nf		nf		nf
nf		nf		nf		nf		nf		nf
nf		nf		r		nf		nf		nf
nf		nf		r		nf		nf		nf
0.50 (0.55)	21 Jan.	2.18 (2.18)		nf		-		-	5 Apr.	0.49 (0.45)
0.82 0.82)	29 Mar.	1.56 (0.92)		nf		-		-		-
0.19 (0.20)		-		nf	21 Jul.	0.44 (0.47)	22 Jul.	2.17 (2.84)	21 Jul.	3.22 (1.76)
r		nf		nf		nf		nf		-
nf		nf		nf		nf		nf	5 Apr.	0.09 (0.05)
nf		nf		nf		nf		nf		nf
nf		nf		nf		nf	22 Jul.	0.68 (1.15)		nf
nf		r		nf		nf		nf		nf
nf		r		nf		nf		nf		nf
nf		r		nf		nf		nf		nf
nf		nf		nf		nf	22 Jul.	2.18 (0.91)	21 Jul.	0.12 (0.09)
nf		nf	22 Jul.	0.65 ± 0.80		nf		nf		nf
nf		nf		nf		nf		nf		nf
0.58 (0.50)	23 Mar.	1.97 (2.04)		nf	4 Apr.	1.79 (1.25)	4 Apr.	0.56 (0.46)	4 Apr.	r
nf		nf		nf		nf				nf
nf		nf		nf		nf	4 Apr.	0.21 (0.27)		nf
nf		0.14		nf		nf		nf		nf
nf		nf		nf		nf		nf		nf
nf		nf		nf		nf	4 Apr.	0.42 (0.49)		r
nf		nf	5 Apr.	2.06 (1.42)		nf		nf		nf
nf		nf		nf		nf		nf		nf
nf		nf		nf		nf		nf		nf
0.13 (0.02)	26 Feb.	0.88 (1.20)		nf		r		r		r
nf		nf		nf		nf		nf		nf
nf		nf		nf		nf		nf		nf
nf		nf		nf		nf		nf		nf
nf		nf		nf		nf		nf		nf
nf		nf		nf		nf		r		r
nf		nf		nf		nf		nf		nf
nf		nf		nf		nf		nf		nf
nf		nf		nf		nf		nf		nf

Table 2. Physical and chemical characteristics of seawater from different study site in wet season from July to August 2004, and dry season from November 2004 to April 2005. Abbreviations of provinces: CB = Chonburi; CP = Chumphon; P = Phetchaburi; PKK = Prachuap Khiri Khan; R = Rayong; and T = Trat.

Year	Date	Province/Study site	DIN (μmol/l)	PO_4-P (μmol/l)	Alkalinity ($mgCaCO_3$/l)	Hardness ($mgCaCO_3$/l)	Turbidity (NTU)	Sal. (‰)	pH	Tw (°C)
2004	3 Jul.	CB/Ko Si Chang	2.71	0.29	98	5650	6.7	30	8.2	32
	3 Jul.	Ang-Sila	7.00	2.71	64.9	6992.9	0.49	32	8.3	-
	4 Jul.	R/Ban Phe	4.43	2.20	96	7350	0	33	8	-
	1 Aug.	T/Ao Cho	12.93	1.00	52	2050	338.24	11	8.5	29
	1 Aug.	Laem Sok	7.50	0.55	39	1750	69.46	12	8.1	29
	1 Aug.	Laem Tien	11.29	0.16	37	1350	51.34	12	7.8	28
	14 Aug.	CP/Thung Wua Laen	3.00	0.77	100	4400	21.4	34	8.3	30
	15 Aug.	PKK/Wanakorn beach	1.43	0.45	101	6300	45.3	35	8.3	-
	15 Aug.	Ta Mong Lai	5.79	0.81	58	3150	353.34	34	8.1	29
2004	20 Nov.	R/Ban Phe	5.00	0.55	91	5800	6.98	33	8	-
2005	21 Jan.	T/Ao Cho	9.86	0.29	100	5550	259.92	33	8	30
		Laem Sok	3.93	0.13	100	5300	174.42	32	8	31
		Laem Tien	7.71	0.19	100	5850	37.62	32	8	31
		R/ Ban Phe	16.93	0.55	108	5650	3.42	32	8	30
	22 Jan.	CB/Ko Si Chang	3.14	0.16	102	5850	0	33	8	30
		Ang-Sila*	16.64	1.16	87	6550	0	33	8	31
		Ang-Sila**	33.00	1.00	73	5750	0	34	8	31
		Sri Racha harbor	2.21	31.16	100	5950	0	32	8	30
	29 Mar.	T/Ao Cho	2.00	0.77	92	5950	37.62	34	8	30
		Laem Sok	3.57	2.71	91	6300	3.42	33	8	30
		Laem Tien	7.50	1.26	95	5850	3.42	34	8	30
		R/Ban Phe	11.93	0.97	90	5150	0	35	8	32
	30 Mar.	CB/Ko Si Chang	3.21	0.48	92	5650	304.34	33	8	30
		Sri Racha harbor	6.57	0.71	90	6250	923.4	32	8	30
		Ang-Sila*	17.29	4.49	89	6050	3.42	35	8	31
		Ang-Sila*	37.93	8.36	107	6150	3.42	35	8	31
	4 Apr.	PKK/Wanakorn beach	10.50	7.65	104	5700	13.68	34	8	30
	4 Apr.	Ta Mong Lai	9.64	1.03	102	5800	270.18	35	8	35
	5 Apr.	CP/Thung Wua Laen	7.50	2.78	100	5800	0	34	8	35
	6 Apr.	P/Bangra Noi	5.29	0.94	102	6050	20.52	35	8.1	35
2005	7 Jul.	CB/Ko Si Chang	6.64	0.00	48.5	-	7.27	30	8.08	29
	7 Jul.	Ang Sila	4.71	0.29	48	-	3.64	33	8.19	33
	7 Jul.	Sri Racha harbor	6.57	0.13	55	-	21.82	29	8.14	32
	9 Jul.	T/Ao Cho	12.86	0.32	41.5	-	952.73	24	8	29
	9 Jul.	Laem Sok	8.93	0.16	48.5	-	123.64	25	8.18	26
	9 Jul.	Laem Tien	67.43	0.74	50	-	54.55	12	7.88	29.5
	10 Jul.	Samaesan	6.43	0.29	37	-	14.55	34	8.4	-
	10 Jul.	R/Ban Phe	10.57	0.74	59	-	40	32	7.95	29

Table 2 (continued).

Year	Date	Province/Study site	DIN (µmol/l)	PO_4-P (µmol/l)	Alkalinity ($mgCaCO_3$/l)	Hardness ($mgCaCO_3$/l)	Turbidity (NTU)	Sal. (‰)	pH	Tw (˚C)
	22 Jul.	PKK/Ta Mong Lai	5.21	0.36	59.5	-	50.91	32	8.13	28
	21 Jul.	Wanakorn beach	5.43	0.58	58.5	-	10.91	34	8.16	30
	21 Jul.	CP/Thung Wua Laen	5.57	0.23	57.5	-	14.55	34	8.11	29
2006	6 Mar.	CB/Ko Si Chang	18.14	0.84	6650	21	23.64	30	7.33	29
	6 Mar.	Ang Sila	22.64	3.62	6500	22.5	7.27	31	6.84	31
	7 Mar.	Sri Racha harbor	43.57	1.00	7050	13.5	276.36	32	7.67	31.5
	20 Mar.	Samaesan	23.36	0.65	5800	70.5	30.91	31	7.46	-
	21 Mar.	R/Ban Phe	115.43	0.87	5800	49	5.46	28	6.97	-
	23 Mar.	T/Ao Cho	57.57	0.74	6000	17	1818.2	34	7.7	-
	23 Mar.	Laem Sok	50.79	0.52	5900	16	723.64	32	6.67	-
	23 Mar.	Laem Tien	40.57	0.52	5900	15	121.82	34	7.48	-
	5 Apr.	PKK/Ta Mong Lai	33.00	0.68	5950	61.5	60	35	7.27	-
	4 Apr.	Wanakorn beach	6.21	0.61	5950	62.5	38.18	34	7.77	-
	4 Apr.	CP/Thung Wua Laen	8.29	0.58	6150	61.5	7.27	34	7.82	-
2007	24 Mar.	CB/Ko Si Chang	28.43	0.10	5450	87	169.09	31	8.86	30
	24 Mar.	Ang Sila	113.07	6.46	4350	93.5	41.82	29	7.68	28
	24 Mar.	Samaesan	25.07	0.23	4600	79.5	9.09	32	8.64	32
	25 Mar.	Sri Racha harbor	43.57	0.13	5200	98.5	903.64	34	8.54	32
	25 Mar.	R/Ban Phe	32.43	2.71	4350	82.5	10.91	34	8.61	32
	26 Mar.	T/Ao Cho	32.57	0.19	7700	87.5	321.82	33	8.64	30
	26 Mar.	Laem Sok	54.86	0.10	5250	94.5	1398.2	35	8.54	29
	26 Mar.	Laem Tien	31.86	0.23	4650	80.5	189.09	33	8.21	27
	6 Apr.	CP/Thung Wua Laen	28.86	1.26	4900	86.5	125.46	35	8	27
	7 Apr.	PKK/Wanakorn beach	13.64	0.77	5750	97	96.37	35	8.32	31.5
	8 Apr.	Ta Mong Lai	49.14	0.13	5100	94	123.64	35	8.62	32

- no data; *along *H. edulis* area; **along *G. salicornia* area

gracilarioid species were found. These were *G. salicornia*, *G. rhodymenioides*, and *H. edulis*. *G. salicornia* plants were collected from Wanakorn beach and Ta Mong Lai in Prachuap Khiri Khan Province, and from Thung Wua Laen in Chumphon Province. *G. rhodymenioides* and *H. edulis* were collected from Ta Mong Lai and Thung Wua Laen. *G. rhodymenioides* from Ta Mong Lai had a mean biomass of 2.18 g/m^2 (0.66–3.94 g/m^2) in July 2005 and decreased to 0.42 g/m^2 (0.03–1.64 g/m^2) in April 2006, while those of Thung Wua Laen had a lower biomass of 0.12 g/m^2 (0.05–0.18 g/m^2) in July 2005. The *G. salicornia* specimens collected from Ta Mong Lai in August 2004 had the highest biomass at 7.27 g/m^2 (3.49–14.21 g/m^2), and the *G. salicornia* specimens from Wanakorn and Thung Wua Laen had lower values of 0.47 g/m^2 (0.15–0.88 g/m^2) and 0.48 g/m^2 (0.04–0.93 g/m^2), respectively. An increase in the biomass of the Wanakorn samples was observed in April 2006 with value of 1.79 g/m^2 (0.65–4.53 g/m^2). In contrast, those of Ta Mong Lai and Thung Wua Laen tended to decrease from the monsoon season in August 2004 to the dry season in April 2006 and March 2007. This suggested that changes in algal biomass were affected by environmental changes at some sites.

Changes in Seawater Quality and its Effects on Algal Biomass

The physical and chemical characteristics of seawater during the monsoon (rainy) and dry (cool and hot) seasons at the different study sites are shown in Table 2. At each study site, the water temperature varied from 27–35°C, while the salinity varied from 11–35‰.

The chemical characteristics of seawater observed during July 2004 and April 2007 showed a high concentration of dissolved inorganic nitrogen (DIN) at most of the study sites. The highest concentration of DIN was 115.4 μmol/l during the dry season in March 2006 at Ban Phe, Rayong Province and 113.1 μmol/l in March 2007 at Ang Sila, Chonburi Province. The concentration of DIN increased during the dry season and decreased during the monsoon season. However, at Laem Tien, the DIN increased by about six times during the monsoon season from 11.3 μmol/l in 2004 to 67.4 μmol/l in 2005, while at Laem Sok during dry season the DIN increased by fifteen times from March 2005 (3.6 μmol/l) to March 2007 (54.9 μmol/l). Increases in the DIN were also observed at Ao Cho, with a twenty-nine fold increase from March 2005 (2.0 μmol/l) to March 2006 (57.6 μmol/l). A similar trend was found at the other sites in Prachuap Khiri Khan and Chumphon Provinces. The cause of high DIN in the seawater may be due to nutrient loading from shrimp farms as well as from domestic sewage (Fig. 5).

Of all the study sites in the present study, the concentration of orthophosphate of the seawater was highest during the dry season in January 2005 at Sri Racha harbor in Chonburi Province, reaching 31.2 μmol/l. The concentration of orthophosphate in seawater varied depending on the location. Rather high concentrations of orthophosphate of 4.5 μmol/l and 8.4 μmol/l were observed at Ang Sila in March 2005.

It is noteworthy that seawater turbidity was very high in most of the study sites, particularly in Trat Province at Ao Cho and Laem Sok. The seawater turbidity showed maximum values of 1818.20 NTU at Ao Cho and 1398.20 NTU at Laem Sok in March 2006 and 2007, respectively. At the site at Ao Cho, the seawater turbidity rose from August 2004 (338.24 NTU) to March 2006 (1818.20 NTU), though the value dropped to 321.82 NTU in March 2007. This was a trend similar to that seen at the value obtained at Laem Sok. However, this differed from what was observed at the study site at Laem Tien, where lower seawater turbidity was observed. There, the turbidity varied from 3.42 NTU in March 2005 to 189.09 NTU in March 2007. Turbidity of the seawater obtained from the present study corresponded to the report of Marine Environment Division, which showed high values of TSS (148–662 mg/l) and very low transparency (0.1–0.2 m) of the seawater at coast of Laem Sok (Anonymous, 2004, 2005, 2006).

A number of studies have reported that fast-growing algae are typically more affected by nutrient limitation than more slow-growing species (PEDERSEN & BORUM, 1996, 1997; PEDERSEN *ET AL.*, 2010). NEJRUP & PEDERSEN (2010) reported that nutrient limitation may restrict growth and slow down the accumulation of *G. vermiculophylla* biomass at more nutrient-poor sites and/or during periods of low nutrient availability. In the current study, the algal biomass decreased when the concentration of DIN and turbidity of the seawater were extremely high during the dry season. However, other parameters had no clear correlation with the algal biomass and distribution. The nutrient richness obtained at the study sites corresponded to a previous study (FOX *ET AL.*, 2008), which reported that nutrient richness may affect the abundance of *Gracilaria* spp. Dissolved inorganic nitrogen generally influences algal growth (MARINHO-SORIANO, 2012). On the other hand, it has been reported that growth of the *Gracilaria* species increased with increasing light intensity (RAIKAR *ET AL.*, 2001). Other studies reported that seaweeds generally have high growth rates when exposed to environments rich in nitrogen and phosphorous

(Teichberg *et al.*, 2008; Nejrup & Pedersen, 2010; Pedersen *et al.*, 2010). However, they cannot tolerate nutrient rich environments for long periods, which cause reduced productivity (Yu & Yang, 2008). In the present study, high seawater turbidity reduced light penetration into the water column. This likely affected nutrient uptake, contributed to a decrease in a photosynthetic rate, and consequently resulted in reduced growth (Marinho-Soriano *et al.*, 2009; Marinho-Soriano, 2012; Oliveira *et al.*, 2012). Water turbidity and light penetration play a role in controlling seaweed growth (Oliveira *et al.*, 2012). In the present study the resulting high DIN and turbidity of the seawater are thought to have been a significant factor affecting algal resources, diversity and distribution in all study sites.

Changing Coastal Habitat and Effects on Algal Biomass and Diversity

My observations have revealed remarkable changes in the coastal environment along the upper Gulf of Thailand. In Thailand, approximately 70% of the population lives within a few kilometers of the coast (Tridech *et al.*, n.d). In this state, many coastal areas have been in decline due to various construction and development projects. Thus, the inappropriate use of coastal land has had adverse impact on coastal resources. Many seaweed habitats along the coasts of Trat, Rayong, and Chonburi have gradually been destroyed while the rock and sand

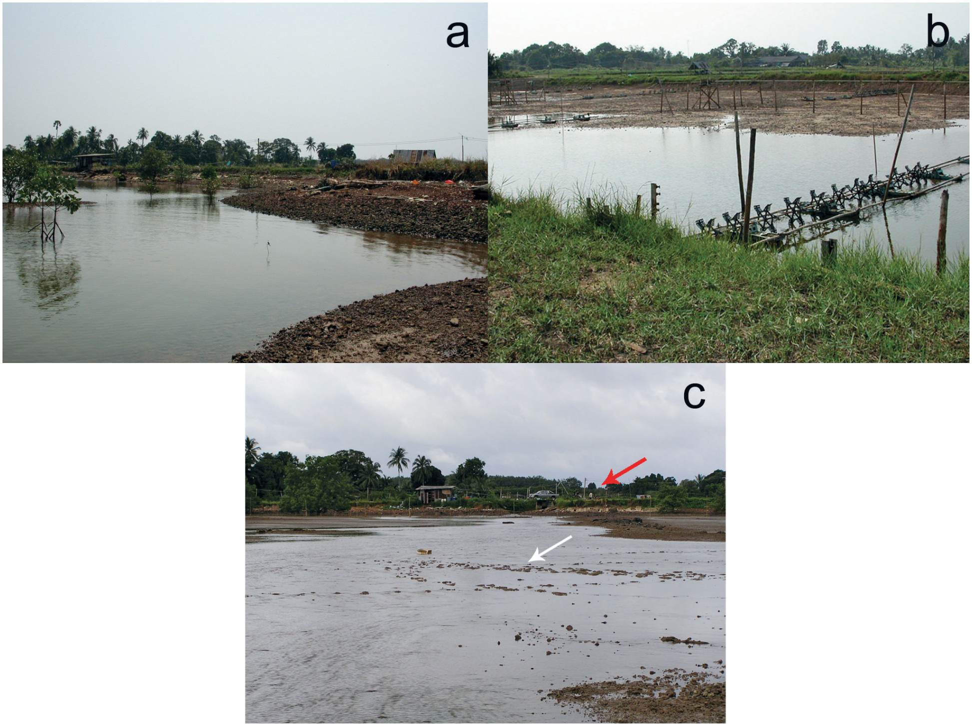

Figure 5. Deterioration of tidal flats and seaweed beds are effects of inappropriate fishery practices: (a, b) shrimp ponds replacing mangrove at Laem Tien in Trat Province; (c) Sewage discharged (white arrow) from the shrimp ponds (red arrow).

Figure 6. Rock and sand beach and mud plains were developed as recreation areas (a), and settlements and wharves (b, c), which has led to the loss of tidal flats and seaweed beds at Laem Sok in Trat Province.

Figure 7. (a) An aquarium at Ban Phe; (b) Rock and sand beach replaced seaweed bed at Ban Phe, Rayong Province.

beaches and mud plains have been developed as wharves, recreational areas, and settlements (Figs. 6, 7). The decline in coastal resources is also the result of inappropriate fishery practices. The overload of organic materials from aquaculture areas such as leftover food and fecal pellets has degraded the quality of the water and the bottom areas in semi-enclosed bays (NAKATA, 1998; EKMAHARACHA *ET AL*., 2005). This has occurred at Laem Tien as well as in other study sites (see also Tables 2). In addition, the construction of marine facilities has led to the loss of coastal nurseries and habitats such as tidal flats and seaweed beds at Ban Phe in Rayong Province (Fig. 7). It is commonly known that tidal flats and seaweed beds are localized zones of high biodiversity where pelagic and benthic ecosystems interact. The loss of tidal flats and seaweed beds, in addition to directly affecting biodiversity and bioproductivity, has exacerbated eutrophication problems because these areas play a significant role in the removal of nutrients and organic materials. It can be seen from Table 2 that the nutrient load was very high after 2004, when the loss of the tidal flats and seaweed beds occurred in the previous years.

The Thai coastal environment, particularly around urbanized areas, has been gradually damaged during the past decade (ANONYMOUS, 2004, 2005, 2006; EKMAHARACHA *ET AL*., 2005). Most areas are suffering from severe degradation of water quality and rapid loss of coastal habitat. As SHARP *ET AL*. (2006) noted, the most extreme case of direct impact on the community is denudation or disruption of the substrate and its associated benthos. Impacts of substrate denudation have been experienced on the coasts of Laem Tien and Ao Cho in Trat Province when people collected *Gracilaria* seed along with their substrates for transplantation. They have also removed all the substrate from the coastal area, causing a rapid decrease in the wild stock of several gracilarioid species from the area. Substrate denudation also occurred at Ban Phe in Rayong Province when various developments and construction projects along the coast of Ban Phe were performed (Fig. 7). The loss of gracilarioid species at Bangra Noi in Phetchaburi Province is also an effect of substrate denudation. The loss of seaweed beds directly caused sedimentation and affected the removal of organic materials in the study sites. As mentioned in a recent report (PETSUT *ET AL*., 2012), the seaweed beds have particularly declined in Trat Province due to the degradation of the coastal environment.

CONCLUSIONS

Many coastal areas in Chonburi, Rayong and Trat Provinces have been developed for tourism and industry. This has had a serious impact on the coastal environment in these areas. The decrease in species diversity of seaweeds was observed in particular through the disappearance of *Gracilaria* species at Ban Phe in Rayong Province and at Laem Tien, Laem Sok and Ao Cho in Trat Province. Notably, *G. salicornia,* a tolerant species that can adapt to various environments, was the only species that could be found at all the study sites. The diversity of the gracilarioids at the study sites in Phetchaburi, Prachuap Khiri Khan, and Chumphon Provinces, located on the west coast of the upper Gulf of Thailand, was less compared to study sites on the east coast. In the present study, environmental changes have also been observed in these areas. Although these changes have not yet impacted the seaweed resources, further work is needed to watch for changes in these areas. Assessment of the impacts and solutions to problems will require the understanding and collaboration of people and the government for sustainable management of the nation's *Gracilaria* resources.

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