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INFLUENCE OF REEF FISH GRAZING ON JUVENILE CORALS

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for the Degree of Doctor of Philosophy Program in Marine Science
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เสธ์ ทรงพลอย : อิทธิพลของการครูดกินอาหารของปลาในแนวปะการังต่อปะการังวัยอ่อน (INFLUENCE OF REEF FISH GRAZING ON JUVENILE CORALS) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: รศ. ดร. สุชนา ชวนิชย์, 89 หน้า.

ทำการสำรวจความหลากหลายและความชุกชุมของปลาในแนวปะการังบริเวณฐานทัพเรือสัตหีบ พบปลาในแนวปะการัง 46 ชนิดใน 17 ครอบครัวโดยมีปลาในครอบครัวปลาสลิดหินเป็นกลุ่มปลาเด่น ตามด้วยครอบครัวปลาผีเสื้อ และปลานกขุนทองตามลำดับ ซึ่งคล้ายคลึงกับการศึกษาในอดีตบริเวณพื้นที่ใกล้เคียง ผลการศึกษายังแสดงให้เห็นถึงความแตกต่างของประชาคมปลาในแต่ละพื้นที่สำรวจ ค่าดัชนีความคล้ายของแจ๊กการ์ดของปลาในแนวปะการังพบมีค่าสูงสุดระหว่างเกาะขามและเกาะเตาหม้อ ซึ่งมีลักษณะการปกคลุมพื้นที่ของปะการังใกล้เคียงกันด้วย เมื่อทราบถึงปลาชนิดเด่นที่พบในพื้นที่แล้ว จึงทำการกำหนดชนิดปลาเพื่อทำการศึกษาพฤติกรรมการกินอาหาร และผลกระทบจากการครูดกินทั้งในภาคสนามและในห้องปฏิบัติการ ได้แก่ ปลาสลิดทะเลแถบขาว (*Siganus javus* (Linnaeus 1766)) ปลานกขุนทองปานดำ (*Halichoeres chloropterus* (Bloch 1791)) ปลานกแก้วสีเพลิง (*Scarus ghobban* (Forsskål 1775)) ปลาสลิดหินเบงกอล (*Abudefduf bengalensis* (Bloch 1787)) และปลาผีเสื้อลายแปดขีด (*Chaetodon octofasciatus* (Bloch 1787)) โดยพบว่าปลาทั้งหมดไม่มีความแตกต่างของพฤติกรรมการกินอาหารในแต่ละช่วงของวัน และอัตราการกัดบนปะการังแตกต่างกันไปในปลาแต่ละชนิด และยังพบว่าขนาดของรอยกัดบนปะการังมีความแตกต่างอย่างมีนัยสำคัญระหว่างชนิดของปลาในการศึกษาภาคสนามพบว่าปลาผีเสื้อลายแปดขีดจะกัดกินบนปะการังมีชีวิตอย่างเดียวเท่านั้น สอดคล้องกับการทดลองในห้องปฏิบัติการที่พบว่าปลาผีเสื้อนี้ชอบที่จะกัดบนก้อนปะการังมากกว่าปลาชนิดอื่น นอกจากนี้ยังพบว่าปลาผีเสื้อลายแปดขีดในการศึกษานี้ชอบที่จะกัดกินปะการังสมอง มากกว่าปะการังกิ่งซึ่งแตกต่างกันหลายการศึกษาในอดีตที่มักพบว่าปลาผีเสื้อมักชอบกินปะการังกิ่งมากกว่า การเปลี่ยนแปลงชนิดอาหารที่ชอบเป็นเรื่องจำเป็นของปลาผีเสื้อเพื่อความอยู่รอดของชีวิต ซึ่งต้องเลือกกินอาหารที่หาได้ง่าย และได้ทำการทดลองครอบกรงเพื่อตรวจสอบสมมุติฐานว่าการป้องกันการถูกครูดกินโดยสัตว์ไม่มีกระดูกสันหลังและปลาจะส่งผลดีต่อการรอดและเติบโตของปะการังที่ถูกนำไปปล่อยคืนสู่ธรรมชาติ โดยมี 3 ชุดการทดลองได้แก่ ชุดควบคุมซึ่งไม่ได้ทำการครอบกรง และชุดครอบกรงที่ป้องกันการครูดกินทั้งจากปลาและเม่นทะเล และชุดครอบกรงที่ป้องกันการครูดกินจากปลาเพียงอย่างเดียว (ใส่เม่นทะเลไปในกรงครอบด้วย) ทำการติดตามอัตราการเติบโตและอัตราการรอดของปะการังเป็นระยะเวลา 4 เดือน พบว่าการเปลี่ยนแปลงของพื้นที่ผิวปะการังเขากวางในกรงครอบที่ป้องกันการครูดกินจากปลาเพียงอย่างเดียวมีค่าสูงกว่าอีกสองชุดการทดลองอย่างมีนัยสำคัญ และในชุดครอบกรงที่ป้องกันการครูดกินทั้งจากปลาและเม่นทะเลพบว่าการเติบโตของปะการังจะได้รับผลกระทบจากสาหร่ายที่มีมากขึ้น ซึ่งแสดงให้เห็นว่าการป้องกันปะการังวัยอ่อนจากการครูดกินจากปลาส่งผลดีต่อการรอดชีวิตของปะการัง นอกจากนี้ยังพบว่าอัตราการเติบโตของปะการังที่มีอายุมากกว่าจะสูงกว่าปะการังที่อายุน้อยกว่าในชุดทดลองควบคุม และจะมีค่าต่ำกว่าในชุดการทดลองครอบกรงป้องกันการครูดกินทั้งจากปลาและเม่นทะเล ซึ่งแสดงว่าการครูดกินโดยสิ่งมีชีวิตในแนวปะการังสามารถลดผลกระทบจากสาหร่ายต่อปะการังได้

ภาควิชา	วิทยาศาสตร์ทางทะเล	ลายมือชื่อนิสิต	....
สาขาวิชา	วิทยาศาสตร์ทางทะเล	ลายมือชื่อ อ.ที่ปรึกษาหลัก	....
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Fish diversity and abundance were investigated at reefs around Royal Thai naval base, Sattahip area. A total of 46 species in 17 families were recorded in the area. The Pomacentridae was the dominant coral reef fish group followed by Chaetodontidae and Labridae similar to previous study in nearby areas. The results also showed that fish assemblages differed significantly among each location. The results from the Jaccard similarity index showed the highest similarity was found between at Ko Kham and Ko Tao Mo. The similarity in fish diversity among these two study sites may be caused by coral compositions and percentages of coral cover. Then, feeding behaviors and effect of grazing by fish on corals studies, field and laboratory experiments were conducted by 5 species those dominant in the area (*Siganus javus* (Linnaeus 1766), *Halichoeres chloropterus* (Bloch 1791), *Scarus ghobban* (Forsskål 1775), *Abudefduf bengalensis* (Bloch 1787), and *Chaetodon octofasciatus* (Bloch 1787)). The result showed that there was no variation of fish feeding behaviors throughout the day and the bite rates on corals of fish varied depending on species. Significantly differentiations of bite sizes on corals were founded between fish species. *C. octofasciatus* clearly bit on live corals (100%). In laboratory experiments, similar to field observations, *C. octofasciatus* preyed on corals more than other fish species. In this study also founded that *C. octofascitus* grazed more on a massive coral, *Platygyra* than branching coral, *Acropora* that different from previous studies. It may be most efficient for the butterflyfish to trade off prey preference and consume available prey during the trails. This way also reduces the mortality risk. Hence, the high consumptions of *Platygyra* by *C. octofasciatus* may reflect the food availability condition. Caging experiments were done for test the hypothesis that the exclusion of large invertebrates and fish would result in increasing outplanted-coral growth and survivorship. Three treatments were set: no cage, fish exclusion cage, sea urchin and fish exclusion cage. Growth rate and survival rate of corals were examined for 4 months. The results showed that percent changes of surface areas of *Acropora millepora* in cage with sea urchins were significantly greater than in either no cage or cage without sea urchin. Without sea urchins in the cages, the *Acropora millepora* growth could be affected by the amount of algal biomass. The result also showed that exclusion of herbivores could increase survivorship of juvenile corals and presence of grazers can reduce the pressure of coral-algal interaction.

Department:	Marine Science	Student's Signature	....
Field of Study:	Marine Science	Advisor's Signature	....
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Chapter 1
Introduction

Due to its role as feeding ground, nursery and shelter for many marine organisms, coral reef is a very important ecology. Coral reef has been a main source of many fishery products. In addition, it is one of the best sites for diving and tourism.

There are 2 major causes of coral reef degradation (Green and Bellwood 2009). First, degradation caused by natural hazard or natural disturbance. Some examples are typhoon, tsunami, low tide, fresh water income, and competition for settlement with algae especially coral bleaching. Coral bleaching event in 2010 causes high degradation on coral reef around Thailand and world wide (Chavanich et al. 2008, Chavanich et al. 2009, Burke et al. 2011). The second reason of degradation is from human impact or anthropogenic threat. For example, fishery, tourism, transportation, and sewage cause coral reef degradation (Edwards and Gomez 2007, Burke et al. 2011).

Due to high rates of reef degradation, reef restoration has become an important conservation topic. Many methods such as coral fragment transplantation can be used to repair coral reefs. Stable substrates from natural or artificial sources may be used to help repair coral damage. Possible sources of coral fragments can come from natural trauma, human error, and separating a coral fragment from its colony. Cement, glue, and cable ties can be used to attach coral fragments to the substrate. In addition to fragment transplantation, sexual reproduction techniques have also been used in reef restorations in Japan as well as Thailand.

In coral reef ecology, the grazing of reef fish on coral reefs may play one of the most important roles. Reef fish feed on algae as they graze which promotes juvenile coral settlement. On the other hand, their grazing behavior could damage corals as well. The variable effects of reef fish grazing behavior is still being debated.

In this study, reef restoration was attempted using a particular sexual reproduction technique in natural reefs. However, studies investigating the survival and growth of corals after transplantation to a natural reef are still required. Reef fish are one of the groups of organisms in coral reefs that affect the survival and growth of juvenile corals. The feeding behavior of many herbivorous fish may benefit or limit the survival and growth of juvenile corals transplanted to a natural reef. The study's aim was to look into the effects of the reef fish's grazing behavior on the survival and growth of juvenile corals transplanted to a natural reef using this sexual reproduction technique.

Objectives

1. To determine the diversity and abundance of reef fish in Samae San area
2. To investigate the effect of grazing behavior of reef fish to survival of juvenile corals and coral fragments those attached to artificial substrate
3. To investigate the effect of grazing behavior of reef fish to growth rate of juvenile corals outplanting to artificial substrate on the reefs

Hypothesis

Grazing behavior of reef fish affects the growth and survival of juvenile corals outplanting to artificial substrate on the reefs.

Chapter 2
Literature review

Reef fish feeding behavior

There are six groups of reef fish behavior classified in this study.

1) Planktontivore: Examples of planktontivore are batfish, some species of damselfish (Barros et al. 2007), some species of butterflyfish (Harmelin-Vivien and Bouchon-Navaro 1983), some species of gobies (Saeki et al. 2005) etc. The prey selection of planktontivore is a result of the water motion. Clarke et al. (2004) showed variety effects of water motion on some planktons feeding in blenny.

2) Coralivore: Examples of coralivore are many species of butterflyfish, some species of wrasse and parrotfish (Rotjan and Lewis 2008). Most of them are diurnal feeding especially middle of the day (Gregson et al. 2008). They prefer to feed on high nutrition coral (Tricas 1989) especially straghorn corals (Graham 2007). Because more nutrition value coral specie, leads to better growth and reproduction cells development (Brooker et al. 2013a). These also related to temporal variation on coral predation because nutrition quality of corals are different in any part of year (Bonaldo et al. 2011).

Coralivore can play a role of bioindicator (Madduppa et al. 2014). Some reef fish choose their habitat primary based on corals complexity. Those that provide good shelters are more preferable than quality of nutrition from hosted coral colonies in some case (Brooker et al. 2013b).

3) Invertebrate feeder: Examples of invertebrate feeder are butterflyfish (Harmelin-Vivien and Bouchon-Navaro 1983), angelfish (Octavio Aburto-Oropezaa

2000), trevally (Silvano 2001), lionfish (Morris and Akins 2009) some parrotfish (Wulff 1997), seahorse (Felício et al. 2006), goby (Hartney 1989) etc. Many fish also feeding on sponge such as some angelfish, cowfish, filefish (Dunlap and Pawlik 1996).

4) Pisceivore: Examples of pisceivore are flatfish (Gochfeld and Olson 2008), stonefish, lionfish (Morris and Akins 2009), trumpetfish (Beukers-Stewart and Jones 2004) etc. They mainly feed on small reef fish like cardinalfish, damselfish (Beukers-Stewart and Jones 2004). Some reef fish such as moon wrasse (*Thalassoma lunare*) are also piscivore which feed only on juvenile fish (Holmes et al. 2012). Hundt et al. (2013) showed that some species of blenny feed on fish's mucus, scale and ray too.

5) Detritivore: Examples of detritivore are some species of surgeonfish, blenny, goby, damselfish and parrotfish (Wilson 2004).

6) Herbivore: Examples of herbivore are parrotfish, wrasse, rabbitfish, rudderfish, surgeonfish, and damselfish. They are diurnal feeder especially on 6-8am (Choat and Clements 1993). Some species also scraped hard substrates during grazed on algae (Miller and Hay 1998).

Diet shift behavior is reported in many reef fish. (Pratchett et al. 2001) reported that damselfish and fusilier shift their diet from their normal food to coral eggs during coral's spawning period. Previous studies found that some species of fish egg (damselfish and blenny egg) are diet for the clingfish. They preferred to take more energy from higher nutrition foods than their normal diet (Hirayama et al. 2005). Type of prey also has seasonal variation. (Feeney et al. 2012) showed that dottyback (*Pseudochromis fuscus*) is mainly feeding on small invertebrate and juvenile fish during summer but only feed on invertebrate during winter.

Fish age also a factor for diet shift behavior, some wrasse play a cleaner role during juvenile and change to coralivore during adult (Cole 2009). Some fish play different role during period of day. For example, juvenile batfish are herbivore during the day but shift to planktontivore at night (Barros et al. 2007).

Herbivorous fish effect on coral reef ecology

At least 9 families of reef fish were identified as herbivorous fish (Choat 1991). Acanthuridae (surgeonfish), Pomacentridae (damselfish), Scaridae (parrotfish), Siganidae (rabbitfish), and Kyphosidae (rudderfish) were among the most important herbivorous families. Green and Bellwood (2009) separated herbivorous reef fish into 4 functional groups.

1) Scrapers or small excavators those feed on epilithic algae turf. They can remove some substrate while feeding. They played a key role as algae cleaner for coral recruitment. This group contains some species of parrotfish.

2) Large excavators or bioeroders those remove larger substrate than scrapers while feeding. They can open large area for new coral colonization. Some species also grazing on live corals. This category include large parrotfish ($\geq$.35 cm standard length).

3) Grazers or detritivores those feed on epilithic algal turf but do not remove reef substratum. They can limit the settlement of macroalgae and growth of them. This group contains most rabbitfish (Family Siganidae), many of surgeonfish (Family Acanthuridae) and small anglefish (Family Pomacanthidae).

4) Browsers those feed on individual algal components. They can limit the growth of macroalgae.

Many studies founded that parrotfish (Family Scaridae) is the main grazer on the reef (Brock 1979, Miller and Hay 1998, Sánchez et al. 2004, Rotjan et al. 2006, Fox and Bellwood 2008, Bonaldo and Bellwood 2009). Some parrotfish could damage coral. The damage varied on size and specie of parrotfish. Parrotfish that mainly feed on coral did more damage than the algal feeder parrotfish (Alwany et al. 2009). The big damaged scars couldn't restore by themselves. The sediment and algae would then cover the scars (Bonaldo and Bellwood 2009). On the other hand, Jayewardene and Birkeland (2006) showed that it took less time for scars to restore for the coral that lived in an appropriated environment.

In Hawaii, some coral are damaged by surgeonfish (Family Acanthuridae) and puffer (Faily Tetraodontidae) (Jayewardene and Birkeland 2006). In addition, grunter (Family Kyphosidae), rabbitfish (Family Siganidae), blenny (Family Blenidae) and damselfish (Family Pomacentridae) were recorded as grazing fish too (Paddack et al. 2006, Tolentino-Pablico et al. 2007). Cabaitan et al. (2008) and Feary et al. (2009) found that reef restoration projects have positive correlation with reef fish community.

Many coral reef threats lead to reef degradation as well as algal phase shifts (Cheal et al. 2010). Most of herbivorous avoid and reversing coral-algal phase shift (Green and Bellwood 2009, Chong-Seng et al. 2014). Most of the studies on the effect of grazing reef fish on coral reef ecology founded that higher abundance of grazing fish cause lower richness of algae (Rogers et al. 1984, Lirman 2001, Paddack et al. 2006, Mantyka and Bellwood 2007). These results support the hypothesis that more grazing fish cause more juvenile coral too (Brock 1979, Rogers et al. 1984, Ruiz-Zárate and Arias-González 2004). In addition, Christiansen et al. (2008) found that grazing of small fish (especially blenny) cannot harm the recently settle juvenile coral. However, Sato (1985) founded that cauliflower coral (*Pocillopora* sp.) is damaged from grazer in reef.

In contrary to the grazing effect from the sea urchin, Korzen et al. (2011) found that herbivorous reef fish mainly played as grazers those remove turf algae. Meanwhile, sea urchin grazing play negative effect to survival of coral recruits. Sea urchins are the competitors for herbivorous fish (Hay and Taylor 1985).

On the other hand, coral reef in Caribbean Sea has different results. Numbers of survival juvenile corals are not related with number of grazing reef fish because positive effect from grazing fish is in the same level of negative effect from area competition with algae (Miller and Hay 1998).

The variable effect of grazing fish and coral juvenile survivorship was described by Trapon et al. (2013). They founded a different effect of herbivorous fish density on coral juvenile survivorship between reef crest and back reef. They concluded that herbivore size and abundance were the reasons. On reef crest, where parrotfish biomass was 5.5 fold greater than back reef, an absent of herbivorous fish lead to high survivorship of coral recruitment. Meanwhile, there was no effect of exclusion herbivorous fish on backreef. Additionally, Chong-Seng et al. (2014) explained how herbivorous fish community differed between high coral cover reef and macroalgal dominated reef. They found grazing herbivores and some browser species dominated on high coral cover reef while many browser species dominated in algal reef.

In term of grazing effect to algae, each species of algae has different tolerance capability to grazing. Lewis (1985) found that algae in genera *Halimeda* spp. produce anti-grazing agents while algae in genera *Sargrassum* spp. and *Turbinaria* spp. cannot produce them. Moreover, some algae, especially group Rhodophyta, could survive after eaten and passed digestive system of herbivorous fish. They could grow and resettle on new substrate (Vermeij et al. 2009).

Evans et al. (2013) showed the important of macroalgal fields those play similar role as seagrass meadows where juvenile marine organism use as nursery grounds.

Coral growth

Many environment factors affects growth rates and survival rates of coral from transplantation (Thongtam 2009). Huston (1985) found that growth rates of some coral species were decreased in deeper sites. Difference of water motion and sediment dynamic also affected coral growth in varied relations (Browne 2012). Temperature is also a very important factor that effected to coral growth (Manzello 2010, Kružić et al. 2012). Effects from temperature and acidification are can varied upon coral species (Manzello 2010).

Some nutrients have a positive effect on coral growth rate such as Phosphate (Dunn et al. 2012). Phosphate can increase number of zooxanthallae and photosynthetic production in corals.

In addition, light is also a key factor that control coral growth. Wijgerde et al. (2012) show an effect of irradiance and light spectrum on growth of coral. They suggested that blue spectrum has a positive relation with coral growth.

Complexity of settlement area is another factor that affects to coral growth. More complexity of settlement area increases the number of colonies and the percentage and diversity of surviving corals (Thongtam and Chansang 1999).

Reef restoration

Reef restoration is very important subject because of reef degradation from the 2010's coral bleaching. Many restoration methods were used such as coral transplantation from coral fragment. The sources of fragments come from either natural hazard or human error. If there is no fragmentation in the area, the fragment separation from coral colony is possible but be not recommended. Stable substrates from natural or artificial can be used. Cement, glue, cable tie are also used to attach the fragment to substrates.

Reef restoration by coral transplantation is widely used. Sources of coral fragment are from natural hazard (Edwards and Gomez 2007, Garrison and Ward 2008), hatchery (Omori 2005, Linden and Rinkevich 2011, Iwao et al. 2014), and collected coral larvae from natural sites (Oren and Benayahu 1997). Most of the studies use straghorn corals in genus *Acropora* (Lindahl 2003, Okubo et al. 2005, Omori 2005) because their growth rate are higher than massive and encrust corals (Dizon and Yap 2005). Large coral fragments are preferred because they have more survival rate than small fragments (Lindahl 2003, Okubo et al. 2005, Forsman et al. 2006, Latypov 2006). In addition, the massive coral in genus *Porites* has low growth rate. It requires many years to use as a source of restoration (Thongtam and Chansang 2008). Rope nursery was also studied to find the most effective method for reef restoration. Levy et al. (2010) found that rope nursery take a very low cost for each fragment (0.11 USD/fragment). They also had high survivorship, low detachment and high growth rates.

Artificial substrate for coral settlement should be used if juvenile colony is founded in the area but settlement area are limiting factor. Type of artificial substrate have been studied (Mundy 2000). Dead coral can also be used as substrate. Planula larvae prefer same species dead coral to settle (Norström et al. 2006). Cauliflower corals (*Pocillopora damicornis*) are dominant juvenile colonies in many areas (Dunstan and Johnson 1998, Glassom et al. 2006, Lee et al. 2009). Concrete mix with 10% coral rubble is more prefer by coral than normal concrete (Lee et al. 2009). In addition, they prefer to settle on substrate that has shelter from current (Petersen et al. 2004).

The development of coral larvae and settlement have been studied (Harii et al. 2002, Kuanui 2008). Coral settlement indicates species and temporal variation (Glassom et al. 2004, Glassom et al. 2006). Competition for settlement area causes low corals settlement rate and their weakness (Dunstan and Johnson 1998, Vermeij et al. 2009). A main reason for mortality of juvenile corals is inappropriate environment (Dunstan and Johnson 1998, Wilson and Harrison 2005, Graham et al. 2008, Nozawa and Harrison 2008). Storm is one of reasons for dead juvenile corals (Williams et al. 2008). However, storm can also get rid of algae, which is a main competitor on settlement areas with corals (Becerro et al. 2006).

Coral farming and gardening are used for the mass sources of reef restoration. In shore aquarium or floating aquarium are used in coral farming. On the other hand, coral gardening is all underwater processes (Heeger 2000, Rinkevich 2000, Mbije et al. 2010). In addition, bio rock method uses weak electric to increase the calcification rate of coral (Hilbertz 1979).

Personal sea water aquarium business needs many corals and thus coral farming can be one method to solve this problem (Delbeek 2001). Nowadays coral degradation is happened in many places. Coral farming become a good source for transplantation in coral degradation areas (Shafir et al. 2009). Floating coral nursery in mid-water is used to avoid from suspend at the bottom water (Amar and Rinkevich 2006, Shafir et al. 2006).

Furthermore, “bio rock” is a method for coral reef restoration. Low pressure electricity is run on metal frames those attached by coral fragments. Electrolysis will increase the speed of calcification (Hilbertz 1979). These lead to the faster speed of coral growth.

Reef restoration by sexual reproduction

Coral restoration by using coral from sexual reproduction as sources is used in case of no coral fragments or coral farm in the area. Coral aquaculture is already succeeded in Japan (Omori 2005, Normile 2009, Iwao et al. 2014). After corals juvenile settled on settlement substrate, they transplanted them back to natural reef (Omori et al. 2007, Okamoto et al. 2012). They found a high survival rates and growth rate of corals after transplantation (Omori et al. 2007). In addition, spawning induction also studied by (Hayashibara et al. 2004), who used H_2O_2 as spawning induce reagent.

Some restoration projects used juvenile corals that settled on special ceramic tiles by leaving tiles in natural reef and waiting for coral larvae settled naturally. They then transferred these tiles to restoration sites (Okamoto et al. 2005, Okamoto et al.

2008). They also found that most of juvenile corals those settled on tiles were belonging to the genus *Acropora*

Coral eggs were also collected from slicks those floated on water surface after coral spawning. Heyward et al. (2002) cultured them in floating ponds until settlement state then moved the pond to preferred substratum.

Effect of reef fish on reef restoration

Sánchez et al. (2004) found that grazing behavior of reef fish in Caribbean is not affected by coral reef restoration projects because successions of restoration are more than damage from grazing. Jayewardene et al. (2009) found that small *Pocillopora meandrina* nubbins (1-2 cm) that transplanted to natural reef were possible to remove by bites from *Arothron meleagris;* while the bigger nubbins were only partially damage.

These results showed varied effects of reef fish on reef restoration. However, there are still a limited number of research on the relation of settlement or growth rates of corals and reef fish feeding (Graham et al. 2011). More research on this is required especially in Thailand.

Reef degradation and restoration in Thailand

Coral bleaching events in Thailand were recorded in 1991, 1995, 1998, 2003, 2005, 2007, and 2010. The most destructive event is in 2010 (Phuket Marine Biological Center 2012). In 2013, more than 80% of coral reefs in Thailand were in bad condition (the live coral to dead coral ration was lower than 1/2). More than 67% of them were degraded from 2010 (Phuket Marine Biological Center 2013). Coral bleaching event in 2010 is one of reasons that caused the mass degradation in Thailand. For example, average live corals coverage percent in inner Gulf of Thailand was 40% but it was reduced to 25% after bleaching event (Prince of Songkhla University 2011).

In 2009, Department of Marine and Coastal Resources released the "Coral Reef Management Plan" to managed usage of coral reef in Thailand (Office of Marine and Coastal Resources Conservation 2009). The year after, they also released "Coral Reef Restoration Plan" that adapted from Edward and Gomez (2007) (Office of Marine and Coastal Resources Conservation 2010) and "Coral Reef Restoration Plan by Artificial Reef" in 2011 (Office of Marine and Coastal Resources Conservation 2011). These 3 plans were guideline for science base reef restoration managements and be a good signal for Thai's coral reefs conservation in the near future.

There are many studies about appropriated restoration methods that should be used in Thailand. Putchim et al. (2008) studied the survival rates and growth rates of some coral species on rope nursery. Yucharoen et al. (2008) studied the survival rates and growth rates of transplanted corals from mid-water nursery to Attims' model (Dauget 1991) artificial substrate. They found high survival rates and growth rates from these methods. The recommended size of coral colonies and fragments for transplantation were also studied by Thongtam and Chansang (2008). Coral fragments transportation method also studied by Thongtam and Panchaiyaphum (1998). Coral fragments should be stored in sea water during transportation.

Increasing settled area for coral larvae is another method that also used in Thailand. In Phuket, Thongtam (2005) used triangle shape substrate for coral settlement. They found that 8 years after starting project, coral reef was recovered. In the same area, coral larvae prefer to settle on these artificial substrates 20-40 times more than natural substrates.

Reef restoration by sexual reproduction in Thailand

Reef restoration by sexual reproduction technique in Thailand was started in 2003. Researchers can hatched coral juveniles and induced coral juveniles to settled on tiles in 2006 (Raksasab 2007). In addition, there are some studies on the development of juvenile corals that settled on tiles (Kuanui 2008). All of these studies were supported by the Plant genetic conservation project under the royal initiative of her royal highness Princess Maha Charkri Sirindhorn, Naval Special Warfare Command, and Department of Marine Science Faculty of Science Chulalongkorn University.

Chapter 3
Diversity of Reef Fish at Thai Naval Base, Sattahip District, Chon Buri Province, Thailand

Introduction

Coral reefs are one of the most diverse natural communities. Reefs have their biologically generated physical complexity, high species diversity, elaborate specialization of component species, and coevolved associations between species. In Thailand, coral reefs are located between 6^{o} N and 13^{o} N, and there are over 300 major reef groups covering an estimated area of 12,000 square kilometers (Chansang et al. 1985, Burke et al. 2002). Thailand ranks the third in total reef area among the Southeast Asia countries, following the Philippines and Indonesia (Craik et al. 1990). Coral reefs in Thailand play a crucial role in the fisheries and tourism industries, and therefore are of paramount importance for the economy.

Fish is a major component in typical reef systems. They play a major role, and act as a herbivore, carnivore, or omnivore in reefs. The diversity and abundance of fish depend on several factors including habitat complexity, food selection, predation, and environments (Luckhurst and Luckhurst 1978, Bell and Galzin 1984, Williams 1991, McCormick 1994, Syms 1995, Green 1996, Munday et al. 1997, Munday 2000, Nanami and Nishihira 2002). In Thailand, there are around 900 species of fish, and their occurrences vary among different locations (Manthachitra and Sudara 2002, Phuket Marine Biological Center 2003, Viyakarn et al. 2008, Songploy et al. 2013).

The compositions of the substrates are shown to influence the fish diversity (Risk 1972, Roberts and Ormond 1987). Some studies also demonstrated that there was a correlation between proportion of live corals and diversity of fish species (Bell and Galzin 1984, Munday et al. 1997, Songploy et al. 2013).

This study addresses the species diversity of fish in various locations in the Royal Thai Naval Base. Many reef fish of Thailand are now heavily exploited in many areas including in the marine protected area. However, in reef areas at the naval base, several activities are restricted and prohibited. This restriction can influence in higher both diversity and abundance of fish. Yet, only few have assessed fish abundance in this area (Viyakarn et al. 2008). This study examined the diversity of fish in the Royal Thai naval base in the upper Gulf of Thailand, and determined whether there was a difference in the diversity of fish outside of the naval base.

Materials and Methods

The study was conducted at the Royal Thai naval area, Sattahip Base, Chon Buri Province, Thailand (Figure 3-1). There were six study sites: Ko Tao Mo, Ko Maeo, Khao Maa Cho, Ko Pla Muk, Ko Kham, and Hin Lak Bet. The surveys were done using scuba diving technique during 2004. At each study, three 50-m line transects were laid parallel to the shore line of each island. Fish within 2.5 m of each side and 5 m above of the transects were visually counted and identified to the species names, except the cryptic species. The transect method was not be able to apply at Ko Maeo, Khao Maa Cho and Hin Lak Bet since the locations are submerged rock and low percent coral cover. Thus, the roving diving technique was applied, covering an area as large as possible between 3-15 m depth at each of the 6 sites. After fish species were identified by fish visual census technique, they were divided into three groups based on English et al. (1994): target species, indicator species, and major trophic families.

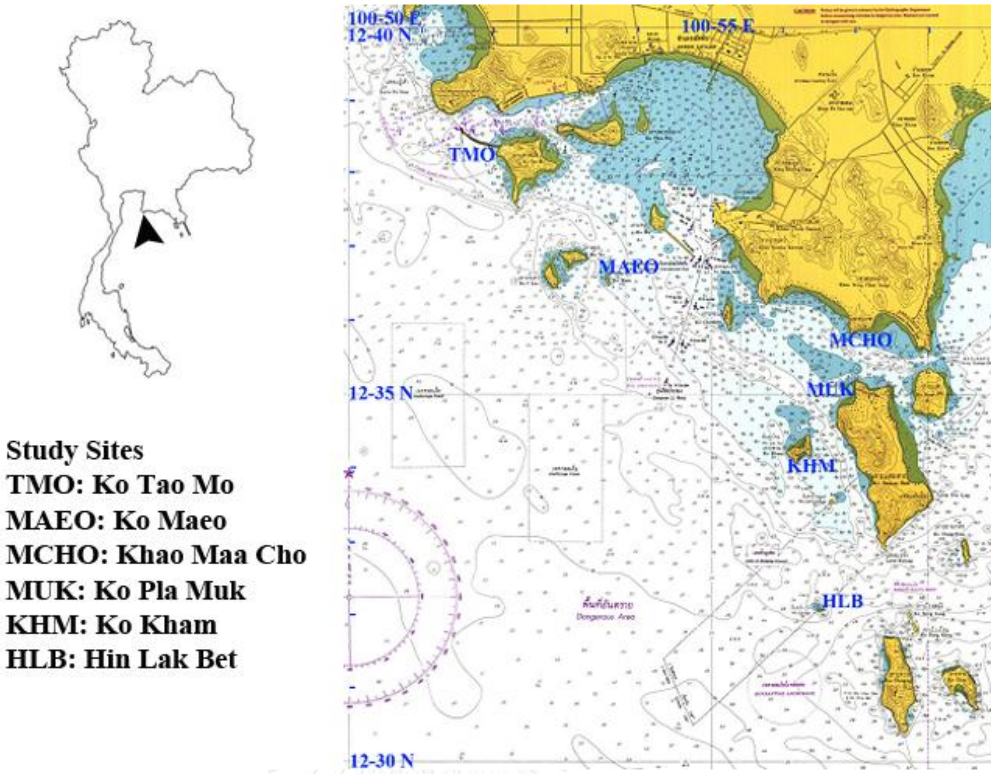


Figure 3- 1 Study sites of reef fish at Thai naval base, Chon Buri province, Thailand.

Results

The results showed that 46 species in 17 families were found in six study sites (Table 3-1). Target species included Family Serranidae, Family Lutjanidae, and Family Haemulidae. Indicator species comprised of Family Chaetodontidae and Family Pomacanthidae. Major trophic families composed of 12 families: Family Pomacentridae, Family Apogonidae, Family Labridae, Family Scaridae, Family Gerridae, Family Holocentridae, Family Nemipteridae, Family Siganidae, Family Pemperidae, Family Mullidae, Family Dasyatidae, and Family Monocanthidae. Hin Lak Bet had the highest number of fish species (32 species) followed by Khao Maa Cho (24 species). The lowest number of fish species was found at Ko Kham (14 species). *Cephalopholis boenak, Chaetodon octofasciatus*, *Abudefduf bengalensis*, *Pomacentrus cuneatus*, *Halichoeres chloropterus*, and *Halichoeres nigrescens* were recorded in every study site.

The results from the Jaccard similarity index showed that the similarity index was ranged between 0.3-0.6. The highest similarity index was found between at Ko Kham and Ko Tao Mo (Table 3-2). From the surveys, the results in the log graph showed that the most abundance families were Family Pomacentridae followed by Family Chaetodontidae and Family Labridae (Figure 3-2).

Table 3- 1 Composition of reef fish at six study sites of Thai naval base, Thailand.

Fish Species	Feeding Type	Study Site [1)]					
		TMO	MAEO	MCHO	MUK	KHM	HLB
TOTAL Species		17	20	24	19	14	32
TARGET SPECIES							
Family Serranidae							
Cephalopholis boenak (Bloch, 1790)	Carnivore	X	X	X	X	X	X
Cephalopholis formosa (Shaw, 1812)	Carnivore		X	X	X		X
Epinephelus fasciatus (Forsskål, 1775)	Carnivore						X
Family Lutjanidae							
Caesio cuning (Bloch, 1791)	Carnivore			X			X
Lutjanus carponotatus (Richardson, 1842)	Carnivore			X			X
Lutjanus russeli (Bleeker, 1849)	Carnivore			X			
Lutjanus lutjanus Bloch, 1790	Carnivore				X		
Lutjanus vita (Quoy and Gaimard, 1824)	Carnivore		X				X
Family Haemulidae							
Plectorhinchus gibbosus (Lacepède, 1802)	Carnivore			X			
INDICATOR SPECIES							
Family Chaetodontidae							
Chaetodon octofasciatus Bloch, 1787	Coralivore	X	X	X	X	X	X
Chelmon rostratus (Linnaeus, 1758)	Carnivore	X		X	X		X
Family Pomacanthidae							
*Pomacanthus annularis (*Bloch, 1787)	Carnivore						X
Pomacanthus sexstriatus (Cuvier, 1831)	Carnivore						X
MAJOR TROPHIC FAMILIES							
Family Pomacentridae							
Abudefduf bengalensis (Bloch, 1787)	Omnivore	X	X	X	X	X	X
Abudefduf sexfasciatus (Lacepède, 1801)	Omnivore			X	X		X
Abudefduf vaigiensis (Qouy *and* Gaimard, 1825)	Omnivore			X			
Amphiprion perideraion Bleeker, 1855	Omnivore	X	X				X
Chromis sp.	Omnivore	X					
Dascyllus trimaculatus (Rüppell, 1829)	Omnivore	X			X		X
Neopomacentrus bankieri (Richardson, 1846)	Omnivore		X	X			X
Neopomacentrus cyanomos (Bleeker, 1856)	Omnivore	X	X	X		X	X
Pomacentrus coelestis Jordan & Starks, 1901	Omnivore		X				X
Pomacentrus chrysurus Cuvier, 1830	Omnivore	X	X		X	X	
Pomacentrus cuneatus Cuvier, 1830	Omnivore	X	X	X	X	X	X
Family Apogonidae							
Ostirhinchus cookii (Maclaey, 1881)	Carnivore		X				X

1) TMO: Ko Tao Mo, MAEO: Ko Maeo, MCHO: Khao Maa Cho, MUK: Ko Pla Muk, KHM: Ko Kham and HLB: Hin Lak Bet.

Table 3-1 (Contd.)

Fish Species	Feeding Type	Study Site [1]					
		TMO	MAEO	MCHO	MUK	KHM	HLB
MAJOR TROPHIC FAMILIES (contd.)							
Family Apogonidae (contd.)							
Ostorhinchus cyanosoma (Bleeker, 1853)	Carnivore	X		X		X	
*Cheilodipterus quinquelineatus*Cuvier, 1828	Carnivore			X			
Family Labridae							
Halichoeres chloropterus (Bloch, 1791)	Carnivore	X	X	X	X	X	X
Halichoeres melanurus (Bleeker, 1851)	Carnivore		X				
Halichoeres nigrescens (Bloch & Schneider, 1801)	Carnivore	X	X	X	X	X	X
Thalassoma lunare (Linnaeus, 1758)	Carnivore						X
Family Scaridae							
Scarus ghobban Forsskål,1775	Herbivore		X		X		
Family Gerreidae							
Gerres sp.	Omnivore						X
Family Holocentridae							
Myripristis hexagona (Lacepède, 1802)	Carnivore				X		X
Sargocentron rubrum (Forsskål, 1775)	Carnivore		X	X		X	X
Family Nemipteridae							
Pentapodus setosus (Valenciennes, 1830)	Carnivore	X	X			X	X
Scolopsis affinis Peters, 1877	Carnivore				X		
Scolopsis ciliata (Lacepède, 1802)	Carnivore			X			
Scolopsis monogramma (Cuvier, 1830)	Carnivore	X		X	X	X	X
Scolopsis vosmeri (Bloch, 1872)	Carnivore	X					
Family Siganidae							
Siganus guttatus (Bloch, 1787)	Herbivore			X			X
Siganus javus (Linnaeus, 1766)	Herbivore				X		X
Family Pempheridae							
Pempheris oualensis Cuvier, 1831	Carnivore		X	X	X	X	X
Family Mullidae							
Upeneus tragula Richardson, 1846	Carnivore	X		X	X	X	X
Family Dasyatidae							
Taeniura lymma (Forsskål, 1775)	Carnivore						X
Family Monacanthidae							
Monacanthus chinensis (Osbeck, 1765)	Carnivore		X				

1) TMO: Ko Tao Mo, MAEO: Ko Maeo, MCHO: Khao Maa Cho, MUK: Ko Pla Muk, KHM: Ko Kham and HLB: Hin Lak Bet.

Table 3- 2 Jaccard similarity index of six study sites.

Study site [1)]	Jaccard similarity index					
	TMO	MAEO	MCHO	MUK	KHM	HLB
TMO	1	0.3	0.4	0.4	0.6	0.4
MAEO		1	0.3	0.3	0.5	0.4
MCHO			1	0.3	0.5	0.4
MUK				1	0.5	0.4
KHM					1	0.3
HLB						1

1) TMO: Ko Tao Mo, MAEO: Ko Maeo, MCHO: Khao Maa Cho, MUK: Ko Pla Muk, KHM: Ko Kham, and HLB: Hin Lak Bet.

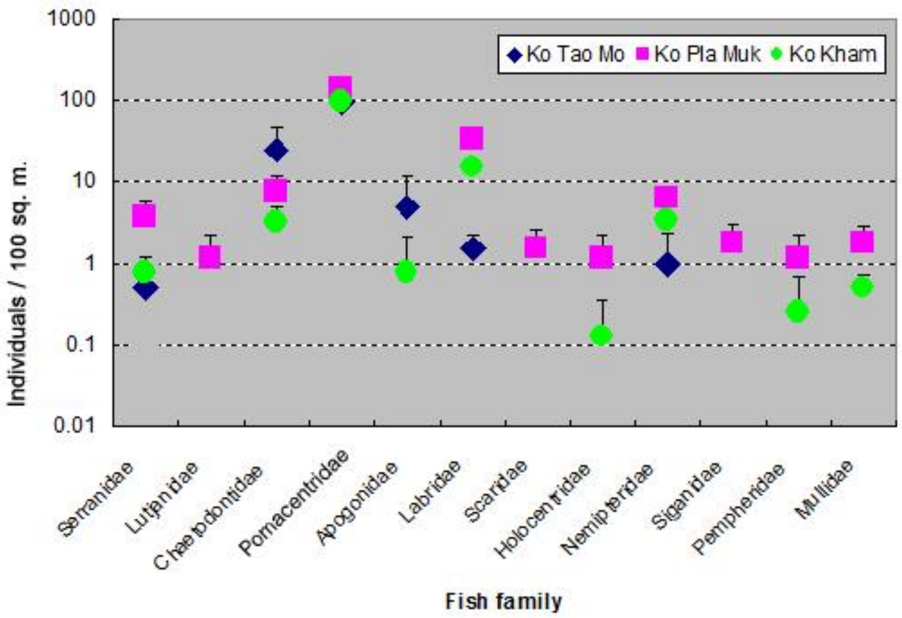


Figure 3- 2 Abundance of reef fish at three study sites at Thai naval base, Thailand.

Chocolate hind

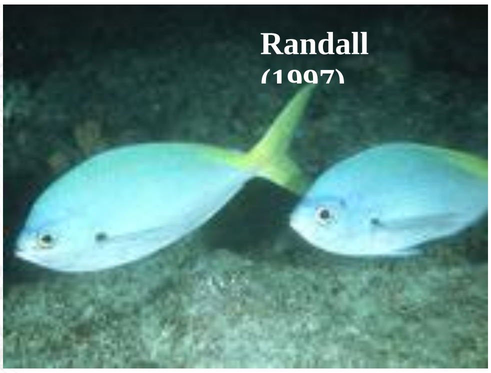
(*Cephalophois boenak*)

Bluelined hind

(*Cephalopholis formosa*)

Blacktip grouper

(*Epinephelus fasciatus*)



Redbelly yellowtail fusilier

(*Caesio cuning*)

Spanish flag snapper

(*Lutjanus carponotatus*)

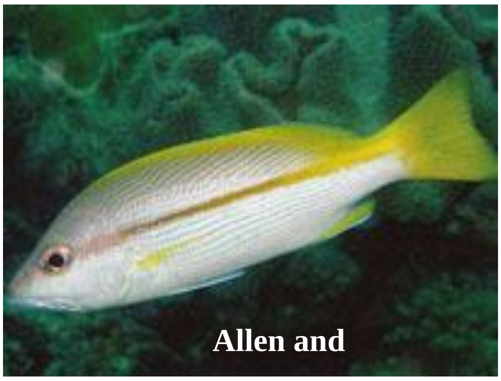
Russell’s snapper

(*Lutjanus russelli*)

Figure 3- 3 Reef fish found in this study

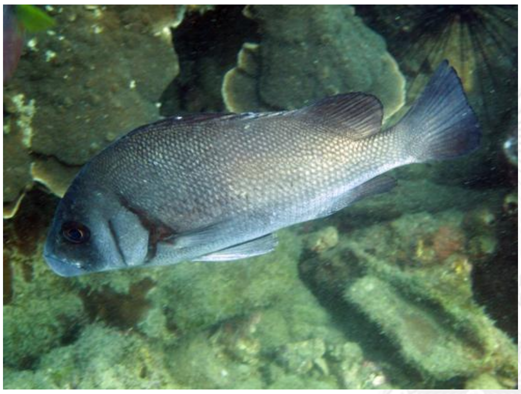
Big eye snapper

(*Lutjanus lutjanus*)



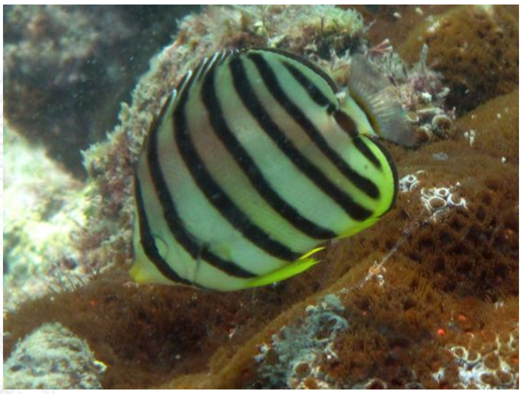
Brownstripe red snapper

(*Lutjanus vitta*)



Harry hotlip

(*Plectorhinchus gibbosus*)



Eight banded butterflyfish

(*Chaetodon octo fasciatus*)

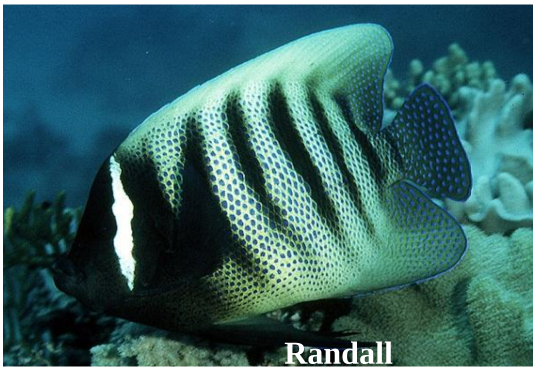
Copperband butterflfish

(*Chelmon rostratus*)

Blue ring angelfish

(*Pomacanthus annularis*)

Figure 3-3 (Contd.)



Sixbar angelfish

(*Pomacanthus sexstriatus*)

Bengal sergeant

(*Abudefduf bengalensis*)

Scissortail sergeant

(*Abudefduf sexfasciatus*)

Indo-Pacific sergeant

(*Abudefduf vaigiensis*)

Pink anemonefish

(*Amphiprion perideraion*)

Damselfish

(*Chromis* sp.)

Figure 3-3 (Contd.)

Threespot dascyllus

(*Dascyllus trimaculatus*)

Chinesse demoiselle

(*Neopomacentrus bankieri*)

Regal demoiselle

(*Neopomacentrus cyanomos*)

Neon damselfish

(*Pomacentrus coelestis*)

Whitetail damselfish

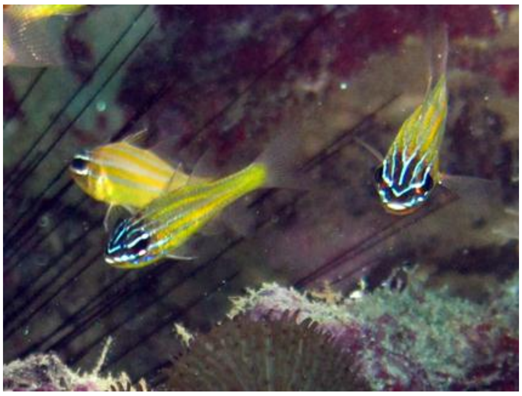
(*Pomacentrus chrysurus*)

Wedgespot damsel

(*Pomacentus cuneatus*)

Figure 3-3 (Contd.)

Cook’s cardinalfish
(*Ostorhinchus cookii*)



Yellowstriped cardinalfish
(*Ostorhinchus cyanosoma*)

Five-lined cardinalfish
(*Cheilodipterus quinquelineatus*)

Pastel-green wrasse
(*Halichoeres chloropterus*)

Tail-spot wrasse (juvenile)
(*Halichoeres melanurus*)

Bubblefin wrasse
(*Haichoeres nigrescens*)

Figure 3-3 (Contd.)

Moon wrasse

(*Thalassoma lunare*)

Blue-barred parrotfish

(*Scarus ghobban*)

Silver-biddy

(*Gerres* sp.)

Doubletooth soldierfish

(*Myripristis hexagona*)

Redcoat

(*Sargocentron rubrum*)

Butterfly whiptail

(*Pentapodus setosus*)

Figure 3-3 (Contd.)

Peters' monocle bream
(*Scolopsis affinis*)

Saw-jawed monocle bream
(*Scolopsis ciliata*)

Monogrammed monocle bream
(*Scolopsis monogramma*)

Whitecheek monocle bream
(*Scolopsis vosmeri*)

Goldined spinefoot
(*Siganus guttatus*)

Streaked spinefoot
(*Siganus javus*)

Figure 3-3 (Contd.)

Silver sweeper

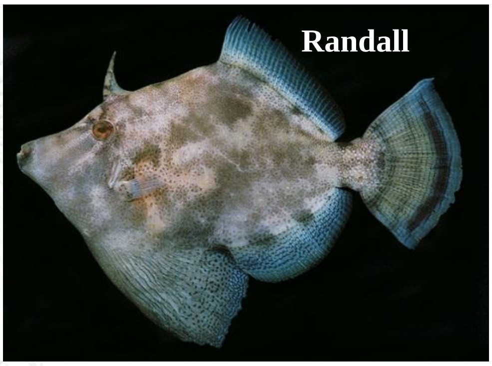
(*Pempheris oualensis*)

Freckled goatfish

(*Upeneus tragular*)

Bluespotted ribbontail ray

(*Taeniura lymma*)



Fan-bellied leatherjacket

(*Monacanthus chinensis*)

Figure 3-3 (Contd.)

Discussion

This is the first report on the diversity and abundance of fish species in the Royal Thai naval base. The results showed that a total of 46 species of fish were found in the area. In the Gulf of Thailand, 353 fish species were recorded (Satapoomin 2002). In Chon Buri Province, Manthachitra and Sudara (2002) found 62 fish species in 25 families. The dominant species were in Families Pomacentridae, Labridae and Apogonidae (Manthachitra and Sudara 2002). Similar to other study, in this study, the Pomacentridae was the dominant group followed by Chaetodontidae and Labridae (Figure 3-2). In the Gulf of Thailand, Manthachitra and Sudara (2002) and Satapoomin (2002) found that the most dominant species for trophic families and target species were *Neopomacentrus cyanomos* and *Cephalopholis boenak.*

From the surveys and statistical analysis, the results showed that fish assemblages differed significantly among each location. The closed similarity in fish assemblages was between Ko Kham and Ko Tao Mo where the low diversity of fish occurred. The similarity in fish diversity among these two study sites may be caused by coral compositions and percentages of coral cover. Both Ko Kham and Ko Tao Mo has similar coral diversity and abundance (Viyakarn et al. 2008). Other study sites, Ko Maeo, Khao Maa Cho and Hin Lak Bet, the substrates were dissimilar to the other two sites. Those three areas either have different percents of coral covers or is a deep submerged rock. Depth may influence the composition and distribution of fish species in tropical reefs (Williams 1991). Higher numbers of fish species are usually attracted by submerged rock due to the higher habitat complexity and high diversity of marine invertebrates. At those three sites, not only the diversity of fish is high, but diversity of coral species recruiting into the areas is also high (Viyakarn et al. 2008). Other than habitat complexity, shelter and food sources also influence the distribution pattern and abundance of reef fish (Sale 1972, Williams 1991). Sale (1972) showed that Pomacentrids in small sizes preferred branching corals for their protection from predators. The different utilization of feeding resources by the fish species should also be taken into account since this can influence the pattern of fish distribution (Scott and Russ 1987).

Physical parameters such as temperatures and depth also had effects on fish diversity (Friedlander and Parrish 1998, Nanami and Nishihira 2002). However, in this study had similar environmental factors. Thus, temperatures and depths were not major causes on differentiating fish diversity in this study.

However, more study are needed to determined what factors may influence the diversity and abundance of fish species in reef areas at Thai Naval Base. It is extremely important to produce basic knowledge in diversity and abundance of local resources in order to understand the system and help in future preservation efforts.

Chapter 4
Feeding behaviors and bioerosion by reef fish

Introduction

Feeding behavior of coral reef fish can be classified into 3 categories, herbivores, carnivores, and detritivores (DeLoach and Humann 1999). A large number of reef fishes are carnivores (DeLoach and Humann 1999). One of the important habits of carnivorous fish is feeding on coral polyps, and because of their diversity, at least 128 species found world-wide, they can have implications for coral compositions (Reese 1981, Cole et al. 2008, Palacios et al. 2014). Corallivores are highly selective, and consume a narrow range of preferred coral species (Pratchett 2007). However, the selection patterns are not well study. In theory, species prefer preys that have high nutritional value, which led to higher reproductive success (Naya et al. 2007). Graham (2007) showed that butterflyfish, *Chaetodon* spp. preferred *Acropora* corals because of its high nutritional value compared to other coral species. Some corallivorous fish such as parrotfish (Scaridae) can be considered as external bioeroders (Bellwood 1995). They are the most abundant fish, and thus, are an important group of bioeroders and sand producer on coral reefs (Bellwood 1995). In addition, their behaviors and their ability to consume different corals are important for predicting the structure change on reefs (Alwany et al. 2009). The damage to reefs can be varied depending on fish sizes and species (Berumen et al. 2005, Berumen and Pratchett 2007). In Hawaii, in addition to parrotfish, corals are damaged by surgeonfish (Family Acanthuridae) and puffer (Family Tetraodontidae) (Jayewardene and Birkeland 2006), while in Egyptian reefs, parrotfish are important agents of marine bioerosion (Alwany et al. 2009). Shantz et al. (2011) found that when corallivorous fish was excluded, coral growth was increased by 20%.

Many herbivorous and corallivorous fish have diurnal patterns of feeding activity (Choat and Clements 1993). However, Gregson et al. (2008) showed that obligate corallivores had a higher feeding rate than facultative corallivores or non-corallivores, and their feeding rates were high during the middle of the day than other times.

Quantitative estimates of fish bioerosions are largely restricted to the Gulf of Thailand. The purpose of this study was to compare and contrast feeding behavior among reef fish at Sameasan Island in the upper Gulf of Thailand. In addition, the study attempted to calculate the bioerosion rate of fish in the Gulf of Thailand by examining fish abundance and feeding activity both in the field and laboratory.

Materials and Methods

Field studies were conducted at Samaesan Island, Chonburi Province, the upper Gulf of Thailand to determine if five species of coral reef fish fed on certain corals as preys by comparing the consumption rates of each coral species. Five fish species (Figure 4-1) commonly found in the site included *Siganus javus* (Linnaeus 1766), *Halichoeres chloropterus* (Bloch 1791), *Scarus ghobban* (Forsskål 1775), *Abudefduf bengalensis* (Bloch 1787), and *Chaetodon octofasciatus* (Bloch 1787). Measures of fish feeding patterns and grazing impact on corals were collected via two methods, in the field and in the laboratory.

Streaked spinefoot

(*Siganus javus*)

Pastel-green wrasse

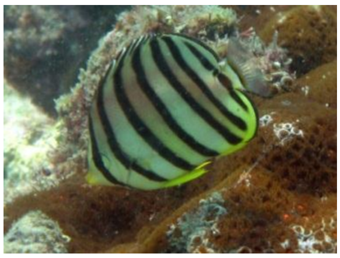
(*Halichoeres chloropterus*)

Blue-barred parrotfish

(*Scarus ghobban*)

Bengal sergeant

(*Abudefduf bengalensis*)



Eight banded butterflyfish

(*Chaetodon octofasciatus*)

Figure 4- 1 Five fish species in this study

Field observations

In the field, the fish community was surveys using three 30 m transect lines. The number of each five species was counted within 2.5 m of each side of the transect line. The transects were established parallel to the shore line approximately 4-5 m depth. In addition, foraging behaviors were quantified by following individual fish for 3 minutes and recording the number of bites taken from scleractinians (hard coral), dead coral, rubble, rock, or others such as shells. After 3 minutes, a new individual was followed. A total of 150 fish from five species were selected haphazardly and observed. The surveys for each fish species were carried out 3 times during the daylight (8.00-10.00 am, 12.00-14.00 pm, and 16.00-18.00 pm). All the data were later combined to calculate for a total number of bites taken by each species in a day.

The bite area or scar size survey was undertaken separately from the foraging behavior surveys. To determine the impact of the feeding by fish, each fish species was followed and size of the scar left by its first bite was measured (Figure 4-2) using a vernier caliper. A total of 50 individuals of fish from five species were examined. All selected fish sizes were ranged between 3-4 cm standard length (SL) (*C. octofasciatus*), 5-7 cm SL (*H. chloropterus*), and 7-10 cm SL (*S. javus, S. ghobban,* and *A. bengalensis*). These sizes were commonly found in the area.

Laboratory experiments

Fish used in the experiments were collected from Samaesan Island and acclimatized three days and starved for two days in aquaria prior to the experimental trials. Feeding preference (no-choice assay) was conducted to examine the rank order of coral preference. Each 27-liter aquaria contained only one fish species and one of four corals species, 1.5-year old *Platygyra sinensis* (Milne Edwards and Haime, 1849), 3.5-year old *P. sinensis*, 1.5 year old *Acropora millepora* (Ehrenberg, 1834) and 3.5-year old *A. millepora*. All experimented corals were from the coral hatchery. This coral hatchery is the place where the larvae of the broadcast spawning corals, *P. sinensis* and *A. millepora*, were raised until either 1.5 or 3.5 years old before using in the experiments. In each fish species, four treatments with five replicates each were employed. Prior to the experiment, experimented corals were photographed. The experiment (Figure 4-3) was run for two days in an ambient seawater temperature (28 °C) and an ambient salinity (32 psu). During the experiments, video was used to record the number of bites and substrates bitten by the fish. The video was run from 6.00 am- 18.00 pm. After two days, the experimented corals were photographed again, and the loss of coral covers were calculated using the Coral Point Count with Excel extensions (CPCe) software (Kohler and Gill 2006). A one-way ANOVA test followed by Turkey's pairwise mean comparison was used to test differences in bite sizes and total bites between fish species.

Figure 4- 2 Bite area measurement

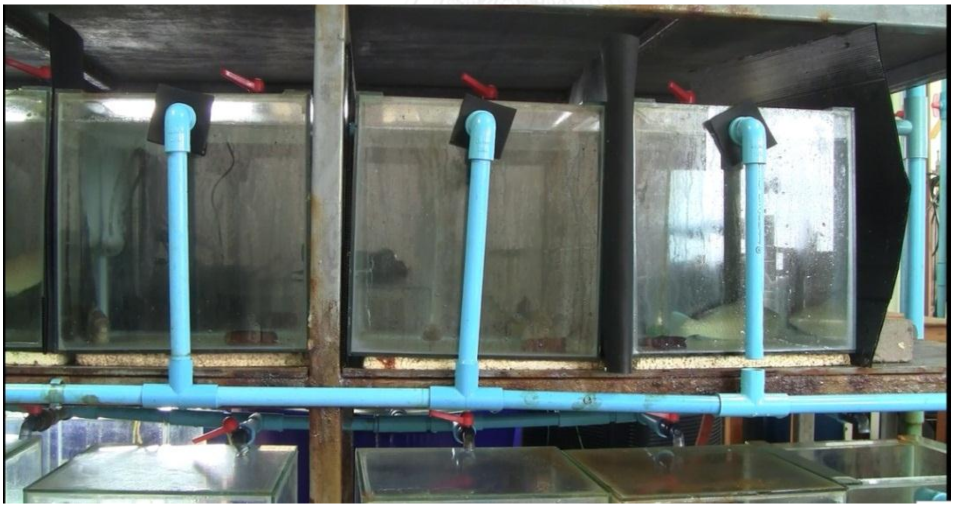


Figure 4- 3 Fish feeding preference experiment

Results

Field surveys and observations

From the field surveys, the most abundant fish species was *Siganus javus* (12.6/100 m^2), followed by *Abudefduf bengalensis* (12.2/100 m^2), *Halichoeres chloropterus* (6.2/100 m^2), *Chaetodon octofasciatus* (4.8/100 m^2), and *Scarus ghobban* (0.4/100 m^2) respectively. The foraging behaviors of five fish species were observed, and the results showed that there was no significant difference in the number of bites between morning, noon, and afternoon times in all fish species. The daily feeding patterns of all fish were relatively constant over the day.

However, when comparing between percent frequencies of bites on different substrates by different fish species, the results showed that *C. octofasciatus* clearly bit more on live corals (100%) than any other fish species (Table 4-1). Other than live corals, fish individuals were observed to bite on dead coral, rubble, and rock (Table 4-1). From the field observations, bite sizes on corals differed significantly between fish species ($p \leq 0.05$) (Figure 4-4). *Scarus ghobban* had the largest bite sizes (0.66 ± 0.03 cm^2), followed by *A. bengalensis* (0.42 ± 0.04 cm^2) (Figure 4-5).

Table 4- 1 Relative frequencies (%) of bites on different substrates by five fish species at Samaesan Island

Fish	Live coral	Dead coral	Rubble	Rock	Others
A. bengalensis	4.7 ± 2.77	46.6 ± 9.33	9.1 ± 1.1	39.6 ± 7.21	0
S. javus	57.2 ± 14.3	35.5 ± 4.2	0	0	7.3 ± 2.8
C. octofasciatus	100	0	0	0	0
S. ghobban	4.1 ± 2.79	49.6 ± 9.92	27.7 ± 7.4	18.6 ± 6.25	0
H. chloropterus	1.5 ± 1.2	31.7 ± 5.76	19.4 ± 3.4	22.3 ± 5.1	25.1 ± 3.7

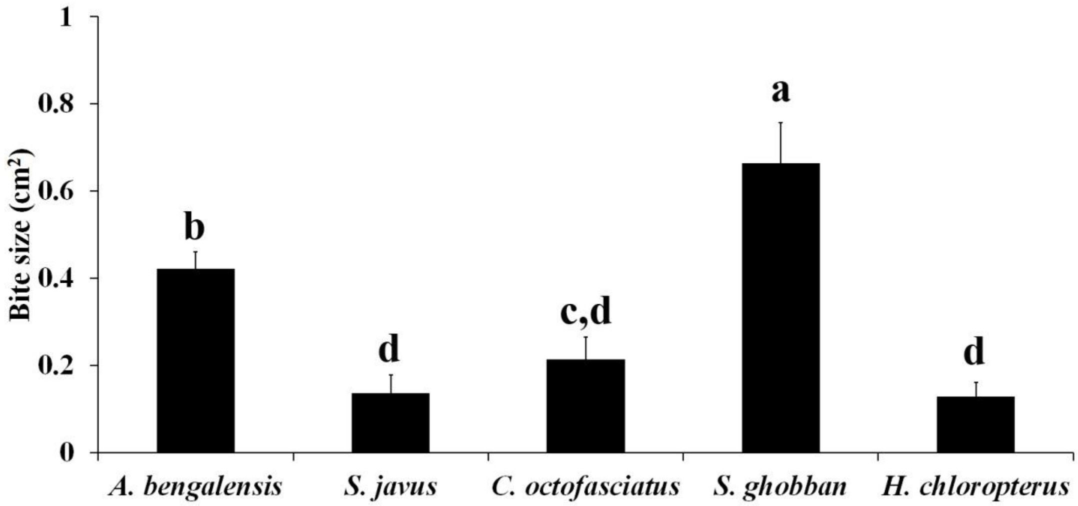
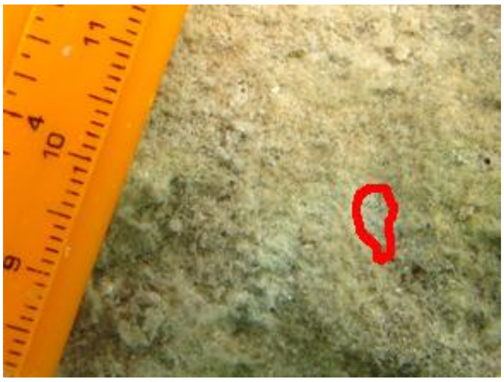
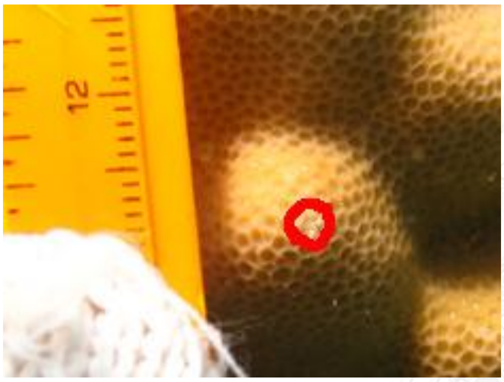


Figure 4- 4 Average bite sizes on corals in each fish species



Abudefduf bengalensis

Siganus javus



Chaetodon octofasciatus

Scarus ghobban

Halichoeres chloropterus

Figure 4- 5 Bite marks of each fish

Feeding laboratory experiments

Laboratory no-choice experiments indicated significant preference of corals between fish species. Similar to field observations, *C. octofasciatus* preyed on corals more than other fish species (Figure 4-6). There were differences in predation (bites tile^{-1}) between coral ages and species. *Scarus ghobban* preferred to feed on *A. millepora* than *P. sinensis* while *C. octofasciatus* grazed more on *P. sinensis* (Figure 4-7). Moreover, *S. javus* tended to bite on the younger coral, *P. sinensis*, than the older ones.

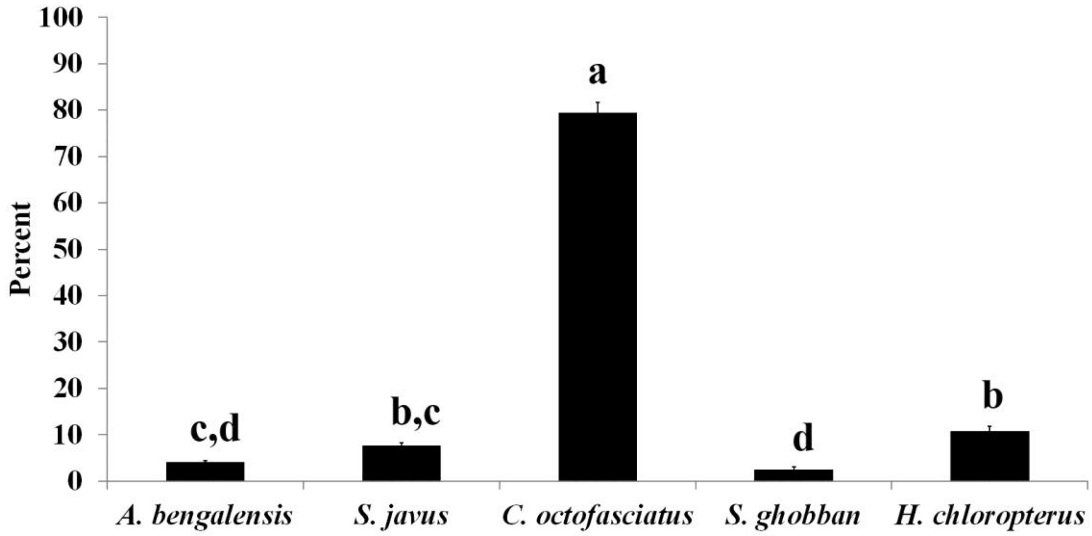


Figure 4- 6 Percentages of total bites on corals in each fish species

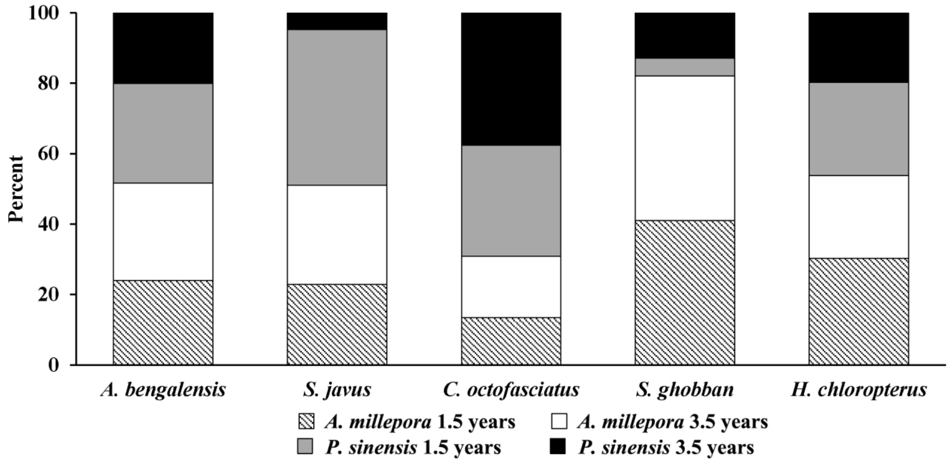


Figure 4- 7 Relative percentage of preyed corals in each fish species

The average bioerosion rates expressed as loss of coral cover are summarized in Figure 4-8. From the experiments, *C. octofasciatus* was the main contributor to overall bioerosion rates. Other fish species, including *S. javus, H. chloropterus*, *S. ghobban*, and *A. bengalensis* exhibited very low or no bioerosion rate.

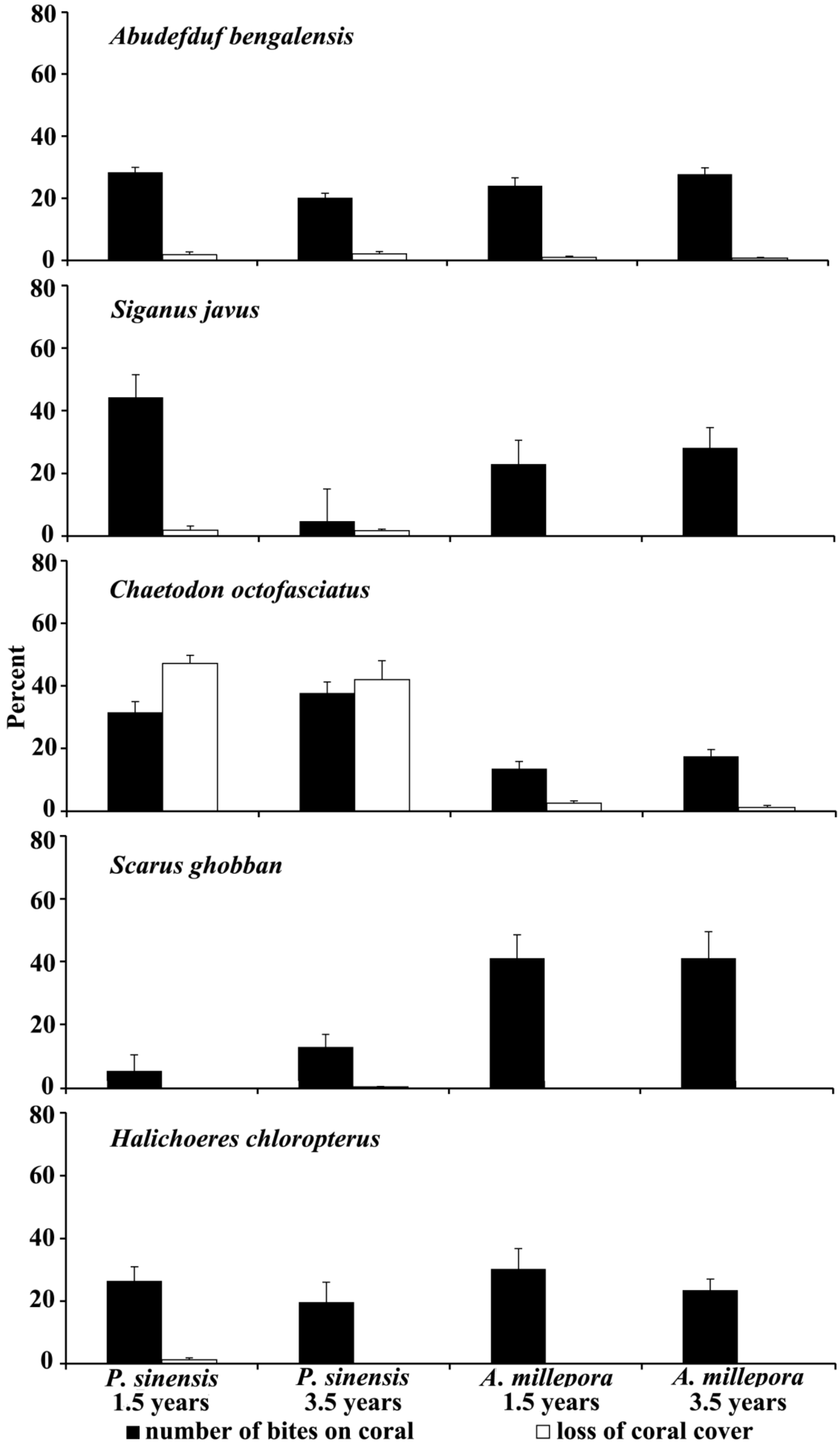


Figure 4- 8 Percentage of total bites on corals and percentage of coral cover loss in each fish species

Discussion

This study on five reef fish species provided the first direct observation of feeding behavior and the potential impact on corals on the upper Gulf of Thailand reefs. To date, such data has been restricted in Thailand. The results from both field and laboratory experiments showed that the density of corallivorous fish bites on reefs did not reflect the abundance of fish, and was not related to coral cover.

Many reef organisms exhibit diurnal patterns of feeding activities (Taborsky and Limberger 1980, Choat and Clements 1993). Some butterflyfish species had their feeding rates varies depending on nutritional benefits (Zekeria et al. 2002). However, in these field observations, there was no variation of fish feeding behaviors throughout the day.

In this study, the bite rates on corals of fish varied depending on species. Tricas (1985) showed that predation on corals by fish was correlated with the nutritional value of corals. Lipid contents in corals can have an influence on food selection and the number of bites of fish; however, corals are considered to be a low quality prey (Tricas 1985). Thus, a higher bite rate is needed for certain fish in order to meet energy requirements (Bottrell and Robins 1983, Pratchett 2007).

Reef eroders include reef fish, urchins, worms, sponges, and gastropods (Scoffin et al. 1980, Reese 1981, Cole et al. 2008). In Indo-Pacific ocean, the bioerosion rates were higher than that of in Carribean sea (Bellwood 1995, Bruggemann et al. 1996). The parrotfish predation is an important factor on reef such as in Great Barrier Reef (Rotjan and Lewis 2008). Nevertheless, our results differed from previous studies in other areas. This may be due to the difference in densities of each fish species. In addition, it has been shown that algal tufts are the preferred food for some parrotfish species (Fox and Bellwood 2007).

Acropora and *Pocillopora* species are usually preferred food for butterflyfish since the corals are fast-growing species while parrotfish prey predominantly on massive corals such as *Porites* and *Platygyra* species (Veron 1997, Bellwood et al. 2010). However, in this study, we found that butterflyfish grazed more on a massive coral, *Platygyra*. To reduce the energy investment for food searching or for starving during the experimental trials, it may be most efficient for the butterflyfish, *Chaetodon octofasciatus,* to trade off prey preference and consume available prey during the trails. This way also reduces the mortality risk (Gilliam and Fraser 1987). Hence, the high consumptions of *Platygyra* by *C. octofasciatus* may reflect the food availability condition.

Our study provided an insight into the feeding behavior of reef fish in the upper Gulf of Thailand, and the important role of the corallivorous fish as bioeroders. More studies are needed to focus on how food is selected and additional factors contributing in selection patterns.

Chapter 5

Effect of reef fish grazing on transplanted corals from sexual reproduction technique

Introduction

Degradation of coral reefs results from human-induced impacts such as dredging, sewage discharge, dynamite fishing, chemical pollution, oil spills, ship groundings, tourist damage and run off sediment, fertilizer and pesticides as a result of changing land use (Brown and Howard 1985, Salvat 1987, Hatcher et al. 1989, Rinkevich 1995, Clark and Edwards 2013). Recognition of the value of coral reefs, the development of marine parks in coral reef areas, and increased efforts focused on reef management have resulted in wide- spread interest in reef rehabilitation using coral transplantation as an aid to management degraded reef areas (Bowden-Kurby 1997, Oren and Benayahu 1997, Lindahl 1998).

The corals to be transplanted have to come from somewhere. In general, transplanted corals are likely to be taken from adjacent undamaged or less damaged reef areas either through asexual or sexual reproduction techniques. The transplantation of corals by using asexual reproduction technique or fragmentation, which has been employed as the primary management tool for reef restoration is now regarded as one of the major conservation measures (Edwards and Clark 1993, Rinkevich 2005, Rinkevich 2008). Studies of transplantation have focused mainly on the fate of transplanted colonies, including their survival and growth rate and their reproductive ability (Yap et al. 1992, Smith and Hughes 1999, Okubo et al. 2006). In addition, some studies focused on the short-term changes in fish assemblage and benthic invertebrates after transplantation (Cabaitan et al. 2008, Yap 2009). Yet, to determine the success of coral transplantation in the areas, other factors such as effects of corallivores and grazers on transplanted corals need to take into account.

Fish corallivores and invertebrate are recognized as having important effects on coral populations and growth (Shantz et al. 2011). Christiansen et al. (2009) demonstrated that grazing of predators had a strong effect on the recruitment success of corals. High numbers of grazers have shown the negative effects on coral recruits, and caused coral mortality at the early stages (Christiansen et al. 2009). Miller and Hay (1998) also showed that disappearance of juvenile corals were from grazing activities. Other non-corallivores such as sea urchin can also have an effect on corals. Sea urchins act as both herbivores and bioeroders in reefs (Bak 1994). While sea urchin grazing removes competitive algae from corals, the excessive high numbers of sea urchins can cause excessive grazing resulting in severe biorosion of corals (Davies and Vize 2008). High densities of sea urchins led to the decrease of coral recruitment, and sometimes decrease of live coral tissues due to their consumption (Bak and van Eys 1975, Davies and Vize 2008).

Other factor that can influence the success of coral transplantation is macroalgae. Even though, macroalgae is an important component in reef communities, its overgrowth can have a negative effect on coral population. An increase in dense of macroalgal mats can lead to direct contact with corals. Corals with close contact with algae can experience in growth and survival reduction (Titlyanov and Titlyanova 2008, Bender et al. 2012). However, the outcomes of coral-algal interaction also depend on the specific coral and algal species, habitat, and water quality (Ceccarelli et al. 2011). To maintain healthy coral reefs, grazing by herbivores is an important process (Hughes et al. 2007). The grazers can minimize algal-coral interaction, and thus enhance in coral growth and survivorship (Bellwood et al. 2004).

At present, the factors affecting juvenile and adult coral survival after outplanting to the reefs are still poorly understood. Only a few studies were conducted to elucidate this (Baria et al. 2010, Trapon et al. 2013). In Thailand, so far no study has been done on monitoring the growth and survival rates of hatchery-reared-juvenile corals after transplantation. The unique of this study was those experimented corals were age-specific, which were cultivated via sexual propagation, and later were transplanted into reefs at Samea San Island, Chon Buri Province, Thailand. Our study was designed to test the direct effect of grazing of fish and sea urchins on outplanted coral growth and survivorship. Our hypothesis was that the exclusion of large invertebrates and fish would result in increasing outplanted-coral growth and survivorship. The purpose of this study was also to compare growth and survival rates of different coral ages that were either caged or uncaged to exclude fish or sea urchins.

Materials and Methods

Experiments were conducted at Samea San Island, Chonburi Province. All corals used in the experimentation were cultured via sexual propagation. Gametes of *Acropora millepora* and *Platygyra sinensis* were collected during the spawning time in February 2010 and 2012 on reefs around Samea San Island. Then, the gametes were transported to the coral hatchery on Samea San Island for further fertilization. After eggs were fertilized and become planulae, cotta tiles were placed in tanks, and used as settlement substrates. The planulae then settled on the tiles within 1 week after the fertilization. Tiles with juvenile corals were maintained in the hatchery with flow-through seawater system until those juvenile corals reach 1.8 and 2.8 years old.

The field experiments were conducted at a fringing reef at Samea San Island. Prior to the experimental trials, 12 concrete blocks in the size of 50X50X50 cm (Figure 5-1) were placed on the reefs approximately 8 m depth. Each block was set about 10 m apart. To test the hypothesis that the exclusion of large invertebrates and fish would result in increasing outplanted-coral growth and survivorship, three treatments were set: no cage, fish exclusion cage, sea urchin and fish exclusion cage. Cages (Figure 5-2) used for fish exclusion and sea urchin and fish exclusion were constructed and covered with mesh plastic nets with 1 cm^2 holes on their sides and tops to prevent grazing from sea urchin and fish. The cages were attached using monofilament line tied with iron bars hammered into the substrates. The difference between fish exclusion treatment and sea urchin and fish exclusion treatment was that for the fish exclusion treatment, sea urchins (*Diadema setosum*) were left in the cages as they were found naturally while for the treatment of sea urchin and fish exclusion, both fish and sea urchins were removed from the cages.

Figure 5- 1 Concrete blocks for coral attachment

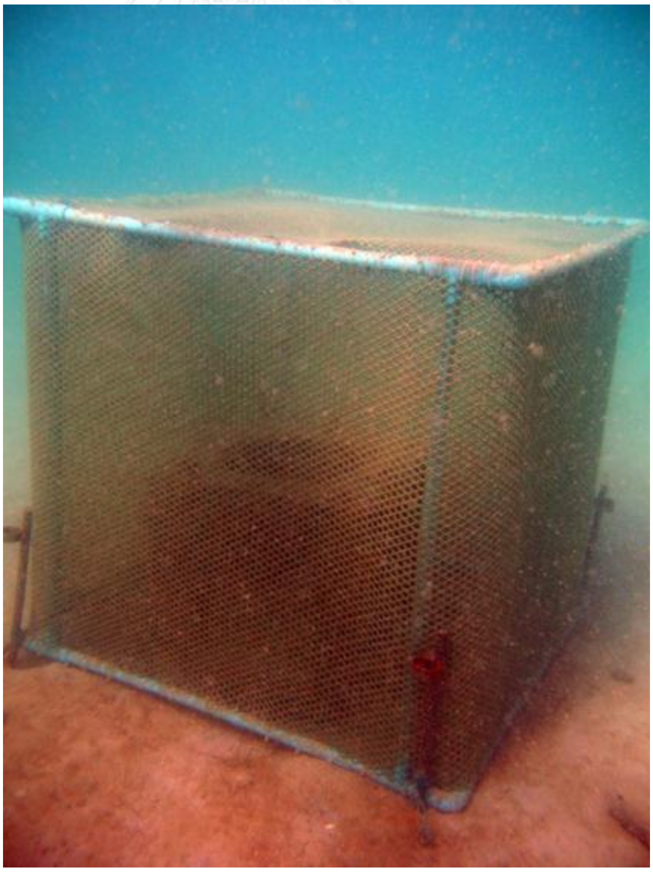


Figure 5- 2 Caged experiment

Prior to setting the cages, tiles with 1.8 and 3.8- year old *Acropora millepora* and *Platygyra sinensis* were randomly allocated to one of three treatments: no cage, fish exclusion cage, sea urchin and fish exclusion cage. The tiles were attached with the concrete blocks vertically by using screws (Figure 5-3). Eight tiles were assigned for each concrete block. The tiles were photographed and re-examined monthly to determine the growth and survival rates. The experiments were run for 4 months. Height, width, and are cover of corals on each tile photograph were analyzed using CPCe (Kohler and Gill 2006). Survival of corals was also examined 4 months after deployment. Two-way ANOVA test followed by Tukey pairwise mean comparison was used to test for a difference in growth and percent cover of corals between treatments.

Figure 5- 3 Coral tiles attached on concrete block

Results

Two-way ANOVA test showed that percent changes of surface areas of 1.8 and 3.8-year old *Acropora millepora* in cage with sea urchins were significantly greater than in either no cage or cage without sea urchin (Fig. 5-4). However, percent changes of surface area of 1.8 and 3.8-year old *P. sinensis* was not significantly affected by any treatments (Fig. 5-5).

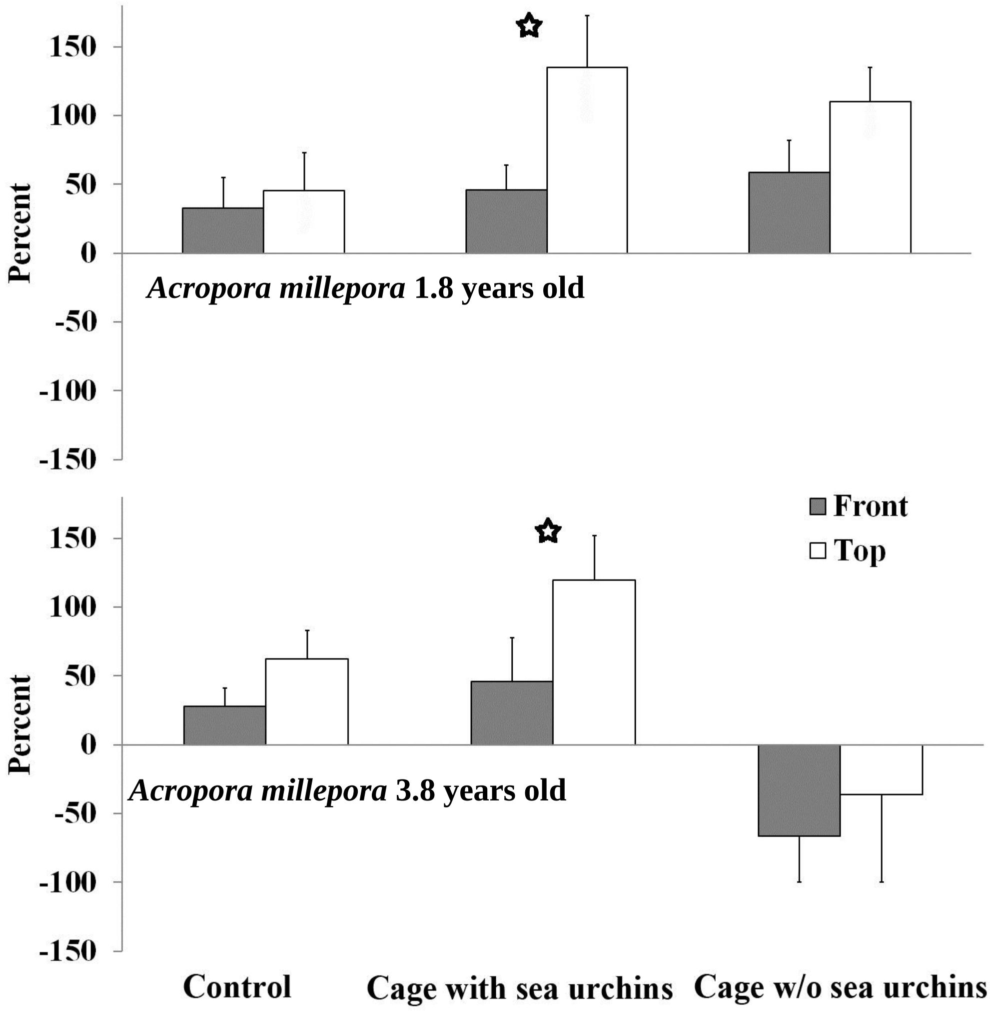


Figure 5- 4 Percent change of surface area in *Acropora millepora*

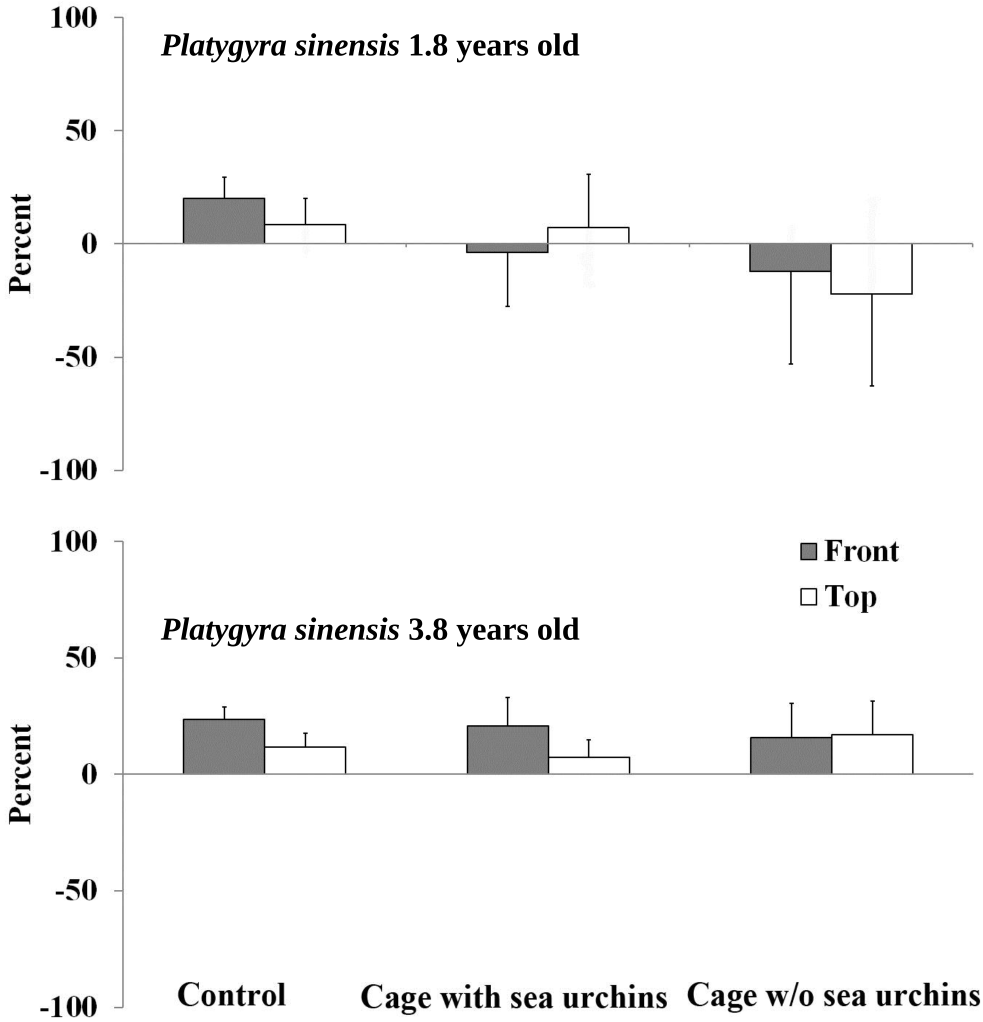


Figure 5- 5 Percent change of surface area in *Platygyra sinensis*

Survival was significantly different among treatments. Corals both *A. millepora* and *P. sinensis* can survive 100% when they were in cages with sea urchins (Table 5-1). However, in the uncaged treatment and without sea urchin caged treatment, the survival rates of *A. millepora* were reduced lower than half. For *Platygyra sinensis*, they survived 100% in all treatments (Table 5-1).

Table 5- 1 Percent survival of transplanted coral

	Control	Cage with sea urchins	Cage without sea urchins
A. millepora 1.8 yrs.	50	100	91.67
A. millepora 3.8 yrs.	94.12	100	50
P. sinensis 1.8 yrs.	100	100	100
P. sinensis 3.8 yrs.	100	100	100

There was no significant difference in growth rates between treatments in any coral species (Fig. 5-6 and Fig. 5-7). However, the growth rate of 3.8 year-old corals in uncaged treatments was significantly higher than younger corals. In addition, the growth rate of 1.8 year-old corals in a cage without sea urchins was significantly higher than older corals (Fig. 5-8).

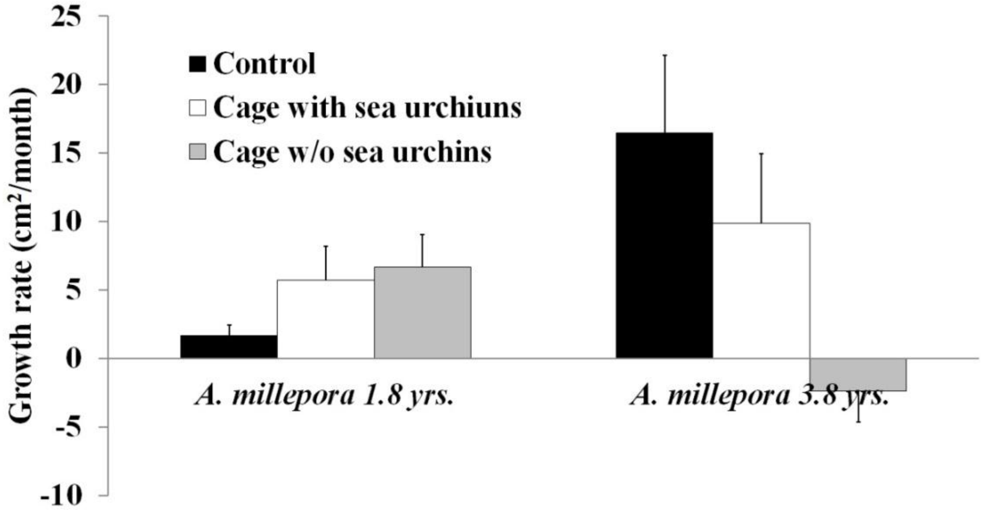


Figure 5- 6 Growth rates of *A. milepora*

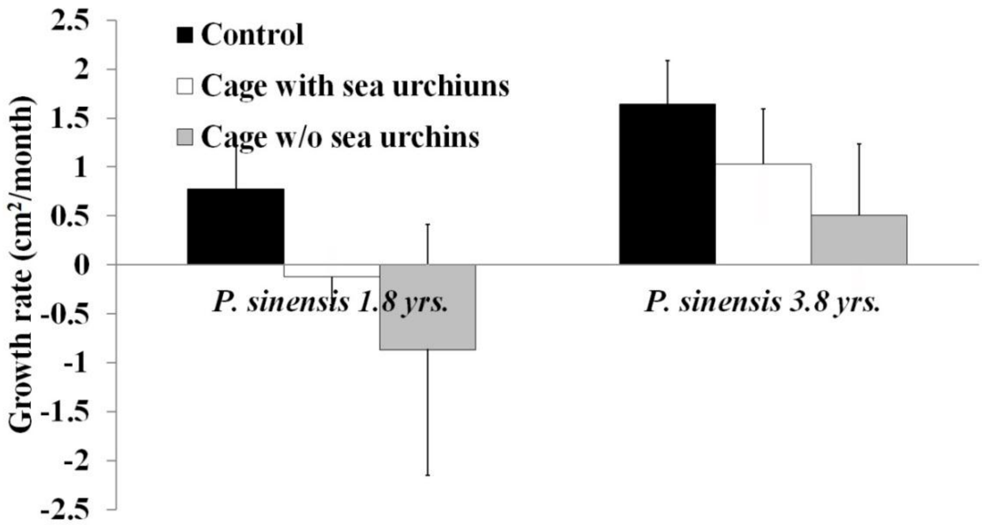


Figure 5- 7 Growth rates of *P. sinensis*

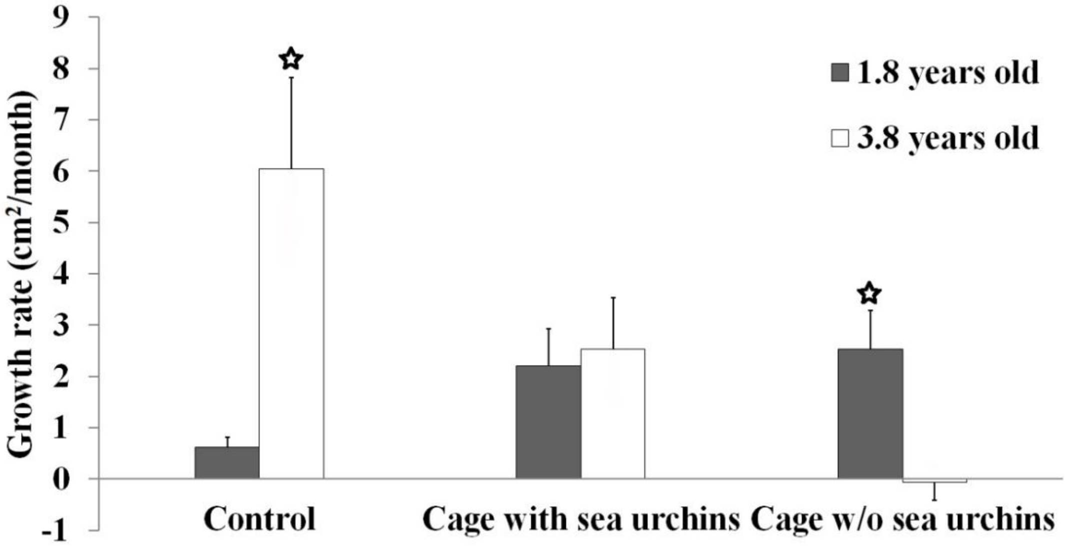


Figure 5- 8 Growth rates of corals

Discussion

Our study clearly showed that exclusion of fish had a positive effect on the survival of corals. Factors affecting juvenile and adult coral survival after outplanting to reefs can be both from grazers and algal biomass. Even though, the cage prevents grazers, the caging treatment is a mechanism to increase the algal biomass. In this study, without sea urchins in the cages, the results showed that the *Acropora millepora* growth and survival could be affected by the amount of algal biomass. Several studies have demonstrated that algal competition can inhibit the growth of corals such as acroporid species (Tanner 1995, Miller and Hay 1996). However, some coral species such as *Pocillopora damicornis* showed no effects of macroalgal competition on their growth rate (Tanner 1995). Similar to Tanner (1995), in this study, *Platygyra sinensis* did not show the difference in growth and survival rates between caged and uncaged treatments. Thus, the susceptibility of corals to increased algal competition can be species-specific.

Grazing is an important process in reefs (Green and Bellwood 2009). The presence of grazers is known to reduce the pressure of coral-algal interaction, limit the development of algal turf, and enhance coral recruitment (Mumby et al. 2007, Mumby 2009). However, several studies have shown that newly or young corals had high mortality rates due to the incident of grazing (Miller and Hay 1998, Davies and Vize 2008, Christiansen et al. 2009). The exclusion of herbivores could increase survivorship by over 50% in some coral species (Trapon et al. 2013) same as this study. Fish predators are often cited as a major cause of juvenile coral mortality (Trapon et al. 2013). In the area where fish predators are high, grazing can be intense, while at low density, fish predators have been proved to increase the survival rates and densities of juvenile corals (Hoey and Bellwood 2007, Hoey et al. 2011).

Coral morphology can also have an influence on the effect of coral-algal competition. Tanner (1995) and Hughes (1989) found that corals with high perimeter-to-area ratio such as encrusting forms were more affected by the increase of algal biomass than that of in branching or massive forms. In this study, the growth by mean of increase of surface area of *P. sinensis* were negatively affected by increasing algal biomass, whereas percent change of areas of massive *P. sinensis* were not affected.

To enhance coral survival following outplaning to the reefs, the caging method to exclude macroinvertebrate grazers and fish is an option. Several studies reported survival rates of uncaged juvenile corals outplanting to reefs ranging between 0 to 17% (Wilson and Harrison 2005, Nozawa et al. 2006, Villanueva et al. 2006). When caging was deployed, the survival rates could be up to 33% (Baria et al. 2010). Thus, the caging seems to be beneficial to coral survival and growth. The results from this study and previous studies also showed that fish and sea urchins contributed to survival and growth of corals; however, the effect of grazing and the consequence of the algal biomass increase can be species-specific. Therefore, for corals outplanting for reef rehabilitation purpose, rearing juvenile corals in cages for awhile may allow them to increase in sizes faster, but how to control the algal biomass while caging needs to be considered.

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Chapter 6
Conclusion

Fish diversity and abundance were investigated at reefs around Royal Thai naval base, Sattahip area. A total of 46 species in 17 families were recorded in the area. Hin Luk Bet had the highest number of fish species (32 species) while the lowest number of fish species was found at Ko Kham (14 species). The most abundance families were Pomacentridae followed by Chaetodontidae and Labridae. The results from the Jaccard similarity index showed that the similarity index was ranged between 0.3-0.6. The highest similarity was found between at Ko Kham and Ko Tao Mo. The similarity in fish diversity among these two study sites may be caused by coral compositions and percentages of coral cover

To compare and contrast feeding behavior among reef fish at Samaesan and to determine the effect of grazing by fish on corals, field and laboratory experiments were conducted by 5 species those dominant in the area (*Siganus javus* (Linnaeus 1766), *Halichoeres chloropterus* (Bloch 1791), *Scarus ghobban* (Forsskål 1775), *Abudefduf bengalensis* (Bloch 1787), and *Chaetodon octofasciatus* (Bloch 1787)) were investigated. The results showed that there was no significant difference in the number of bites between morning, noon, and afternoon times in all fish species. The daily feeding patterns of all fish were relatively constant over the day. The results showed that *C. octofasciatus* clearly bit more on live corals (100%) than any other fish species. Other than live corals, fish individuals were observed to bite on dead coral, rubble, and rock. Significantly differentiations of bite sizes on corals were founded between fish species. In laboratory experiments, feeding preference (no-choice assay) was conducted to examine the rank order of coral preference. 1.5-year old *Platygyra sinensis* (Milne Edwards and Haime, 1849), 3.5-year old *P. sinensis*, 1.5 year old *Acropora millepora* (Ehrenberg, 1834) and 3.5-year old *A. millepora* were used in this experiment. Similar to field observations, *C. octofasciatus* preyed on corals more than other fish species. In addition, *C. octofasciatus* was the main contributor to overall bioerosion rates. Other fish species, including *S. javus, H. chloropterus*, *S. ghobban*, and *A. bengalensis* exhibited very low or no bioerosion rate. The result also showed that butterflyfish grazed more on a massive coral, *Platygyra* than a branching coral, *Acropora* that different from previous studies. To reduce the energy investment for food searching or for starving during the experimental trials. It may be most efficient for the butterflyfish, *Chaetodon octofasciatus,* to trade off prey preference and consume available prey during the trails. This way also reduces the mortality risk. Hence, the high consumptions of *Platygyra* by *C. octofasciatus* may reflect the food availability condition

To test the hypothesis that the exclusion of large invertebrates and fish would result in increasing outplanted-coral growth and survivorship, caging experiments were done at a fringing reef at Samea San Island. Three treatments were set: no cage, fish exclusion cage, sea urchin and fish exclusion cage. 1.8 and 3.8- year old *Acropora millepora* and *Platygyra sinensis* were used in this study. The experiments were run for 4 months. Growth rate and survival rate of corals were examined. The results showed that percent changes of surface areas of 1.8 and 3.8-year old *Acropora millepora* in cage with sea urchins were significantly greater than in either no cage or cage without sea urchin. Without sea urchins in the cages, the *Acropora millepora* growth could be affected by the amount of algal biomass. However, percent changes of surface area of 1.8 and 3.8-year old *P. sinensis* was not significantly affected by any treatments. In addition, corals both *A. millepora* and *P. sinensis* can survive 100% when they were in cages with sea urchins. However, in the uncaged treatment and without sea urchin caged treatment, the survival rates of *A. millepora* were reduced lower than half. This result showed, exclusion of herbivores could increase survivorship of corals. Meanwhile, *Platygyra sinensis*, they survived 100% in all treatments. There was no significant difference in growth rates between treatments in any coral species. However, the growth rate of 3.8 year-old corals in uncaged treatments was significantly higher than younger corals. In addition, the growth rate of 1.8 year-old corals in a cage without sea urchins was significantly higher than older corals. These results showed the important of grazing process in reef. The presence of grazers can reduce the pressure of coral-algal interaction.

In conclusion, reef fish can have effects on coral growth and survivals. To restore and rehabilitation reefs, several factors including grazing and fish predators need to be considered. From this study, the results showed that fish contributed to survival and growth of outplanted corals. The effects of reef fish grazing on coral reefs seen in this study could be applied to the knowledge base to enhance coral reef management and restoration plans around this region.

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APPENDIX

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