Effectiveness of artificial reefs as alternative dive sites to reduce diving pressure on natural coral reefs, a case study of Koh Tao, Thailand

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Declaration

I hereby declare that this thesis is my own work and effort and that it has not been submitted anywhere for any award. Where other sources of information have been used they have been acknowledged

Signature…….

Date…….

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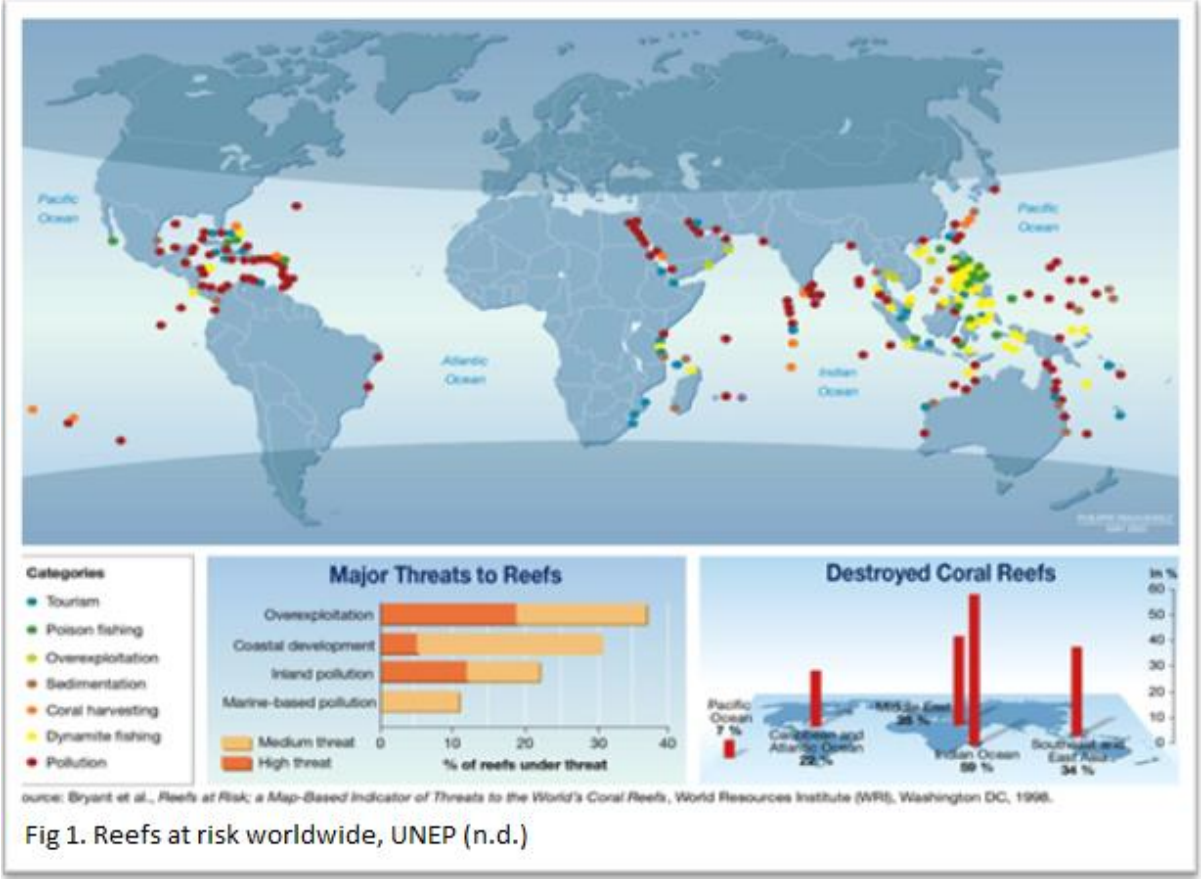
Abstract

Coral reefs are currently in decline worldwide. Mass bleaching events, ocean acidification and more powerful storms are the main destructive factors globally however these are mainly infrequent events which healthy coral reefs may survive and recover from. Other more localised anthropogenic factors such as pollution, sediment run off from development on land and overfishing, put more frequent pressure which inhibits the ability of coral reefs to recover from for example periods of sustained high temperature or storms. Scuba diving is a popular and expanding coastal activity which used to be thought of as a non consumptive and sustainable use of the marine environment. However when areas are intensively dived it causes destruction of structural diversity and overall reef health due to diver contacts, sediment stir up smothering corals etc. which puts corals under constant pressure making them less likely to survive other destructive factors. Artificial reefs are one way to not only provide new habitat for corals and fish, but to provide alternative dive site sites to reduce diving pressure on nearby natural reef. This study looked at the effectiveness of artificial reefs around Koh Tao, Thailand, in this capacity of reducing dive pressure and the reasons why some sites were effective and some sites were not. It was found that around 21% of dives on Koh tao annually are on an AR and 45% of divers visiting Koh Tao will dive an AR. It was found that around 300,000 divers come to Koh Tao each year and with the length of stay of divers and number of divers annually it was likely that some of the more popular dive sites may be receiving 300,000 divers annually. This is far above the hypothetical carry capacity for heavily dived reefs elsewhere and suggests that AR's alone cannot reduce dive pressure to acceptable levels on nearby natural reef sites. The reasons for the success of some AR's and not others were found to be due to a combination of factors shown on fig 6. For example Interactivity, size of AR, distance from dive shops, marine life

Introduction

Coral reefs are one of the world's most diverse and beautiful habitats. They have been around since 225 million years ago in the Mesozoic era, some coral reefs may be up to 2.5 million years old and provide many benefits (Moberg & Folke, 1999), coastal protection, seafood, recreation, new medicines, biodiversity and aesthetic value to name a few (Bryant, Burke, McManus, & Spalding, 1998). Coral reefs are found in all three of the Earth's oceans that have portions in the tropics. These regions include the tropical Pacific, tropical western Atlantic (aka "greater Caribbean"), and the Indian Ocean (including the Red Sea). This distribution is by no means random, coral reef distribution is mainly determined by a particular set of environmental conditions under which the dominant species that build that kind of ecosystem thrive (Jones & Endean, 1973; Yonge, 1963).



ource: Bryant et al., *Reefs at Risk; a Map-Based Indicator of Threats to the World's Coral Reefs*, World Resources Institute (WRI), Washington DC, 1998.

Fig 1. Reefs at risk worldwide, UNEP (n.d.)

Unfortunately in recent years there has been significant declines worldwide, a report published in 2008 by the Global Coral Reef Monitoring Network (GCRMN) found that 20% of the world's coral reefs are currently threatened and predicted to be lost in the next 20 to 40 years and a further 15% critically threatened with a predicted loss in the next 10 to 20 years(Wilkinson & Souter, 2008).

This loss is due to a number of factors both environmental and human. Pollution, overfishing, global warming, ocean acidification and coral diseases are the most prevalent worldwide(Riegl et al. 2009). However when combined other localised factors such as rapid coastal development, loss of forests especially mangroves, increased nutrients in the marine environment, snorkelling and scuba diving damage etc. the extra pressure makes corals less likely to survive bigger threats like sustained periods of high temperatures brought on by climate change(Carilli et al. 2009).

Scuba diving used to be thought of as a non-consumptive and non-destructive sustainable use of coral reefs and to a certain degree it is if done carefully with the proper training(Barker & Roberts, 2004). However with the increasing popularity and accessibility of scuba diving there are problems from unsustainable use and divers damaging coral reefs to a significant extent. This can be through contact with corals causing breakages (Uy et al 2008; Wilkinson & Souter, 2008), stirring up sediment which smothers coral(Barker & Roberts, 2004; Prior et al. 1995; Uy et al., 2008), addition of nutrients through pollution from dive boats (Koop et al. 2001), feeding fish which introduces extra nutrients into the oligotrophic eco system corals require while also reducing the amount of competing algae and sponges eaten by the fish (Koop et al. 2001; Ledlie et al. 2007), use of sunscreen which is linked to coral diseases (Danovaro et al. 2008) and others such as anchor damage from boats (Dinsdale & Harriott, 2004). Coral reefs which are heavily dived can have much less structural diversity/overall productivity/health and biodiversity because of these factors(Prior et al. 1995).

Artificial reefs are one way to alleviate the problem of coral decline by not only providing structure allowing more areas of the ocean to be colonised by corals (Fadli et al. 2012) and protection from predators for small fish(Charbonnel, 2002; Rilov & Benayahub, 1998; Rilov & Benayahu, 2002), but also by providing alternative dive sites reducing the diving pressure on natural coral reefs(Davis & Tisdell, 1996; Feary et al. 2011; Uy et al. 2008). introduction of an artificial reef in a natural reef environment should reduce recreational use of the surrounding natural reefs, all else held constant, as divers and others shift a portion of their use from the natural reefs to the new artificial reef. Artificial reef structures can be sunken ships or vehicles, concrete blocks, metal frames, statues and sculptures, anything which provides extra structure to the benthic environment.

Thailand has an economy which relies heavily on tourism, a large proportion of its GDP is tourism related (Ruggles-brise, 2012), For example between 2010 and 2012 there was a 6.4 million increase in tourists from 15.9 million to 22.3 million visiting each year (Vanhaleweyk, 2013). The islands of Koh Tao, Koh Phangan and Koh Samui, are the three main islands in the Surat Thani province in the gulf of Thailand. Modern day Koh Tao relies on diving and subsequently its coral reefs for income. This makes the health of the reef systems around Koh Tao integral to the economic, social and environmental sustainability of the island (Weterings, 2011). Koh Tao is one of the most popular places to dive in Thailand, the island itself boasts 50 dive schools and 25 dive sites (Rongrongmuang, 2010) .This popularity comes at a cost however and the reefs are under considerable stress from a number of factors including pollution increasing nutrients in the marine environment, over fishing, intensive scuba diving and snorkelling (Weterings, 2011). In the last few decades around 50% of the islands rainforest has been destroyed causing increased sedimentation on the reefs (Weterings, 2011), which is known to smother corals and increase possibility of infection (Babcock & Smith, 2000). Recreational diving and snorkelling is intensive around Koh Tao and known to put pressure on reef systems and cause physical damage to corals (Leujak & Ormond, 2008). Koh Tao already has a number of established AR's including sunken ships, coral nurseries and diver training aids which are well used by dive companies on the island, along with much community involvement in marine conservation with save Koh Tao and branches of that such as the new heaven reef conservation program.

These factors make Koh Tao a prime location for a study on the effectiveness of AR's as alternative dive sites. When it comes to reducing pressure on heavily dived natural coral reefs it is unknown which AR's are being used the most frequently by scuba divers and the opinions divers and dive companies have about them on Koh Tao. This study is aimed at finding out how effective AR's on Koh Tao are at reducing dive pressure by investigating how many people use AR's on Koh Tao, which sites are used the most and the factors which contribute towards AR's successes or failures on Koh Tao. Once this is known their effectiveness at solving this problem may be critically analysed and improvements made for existing AR's and in the planning of new AR's worldwide.

Literature Review

Coral reef ecology and coral biology

Coral reefs are one of the world's most diverse and beautiful habitats. They have been around since 225 million years ago in the Mesozoic era, some coral reefs may be up to 2.5 million years old and provide many benefits (Moberg & Folke, 1999), coastal protection, seafood, recreation, new medicines, biodiversity and aesthetic value to name a few (Bryant et al., 1998). Coral reefs are found in all three of the Earth's oceans that have portions in the tropics. These regions include the tropical Pacific, tropical western Atlantic (aka "greater Caribbean"), and the Indian Ocean (including the Red Sea). This distribution is by no means random, coral reef distribution is mainly determined by a particular set of environmental conditions under which the dominant species that build that kind of ecosystem thrive (Jones & Endean, 1973; Yonge, 1963).

Corals are members of the phylum *Cnidaria* (Jones & Endean, 1973; Yonge, 1963). They are usually colonial, made up of many genetically identical polyps connected by living tissue (called the coenosarc) (Jones & Endean, 1973; Yonge, 1963), although some species, for example mushroom coral (*Fungia fungites)*, consist of a single large polyp (Hoeksema, 1989). Each polyp has a cup like shape with a ring of tentacles surround a central opening known as the pharynx which serves as both mouth and anus. The tentacles are tipped with stinging cells (nematocysts) which are used for catching prey and defence. Corals can be split into two distinct groups, hard corals (*scleractinians)* and soft corals (*gorgonians*) (Jones & Endean, 1973; Yonge, 1963). Hard corals sit on an external skeleton made of the corals secretions of calcium carbonate which forms their structures (Jones & Endean, 1973; Yonge, 1963). There are a number of growth forms different corals take each of which is better suited to different environmental conditions, Foliate or branching corals for example can survive higher sedimentation because sediment falls more easily in between thin blades or branches, whereas large round corals such as brain corals will survive better in areas of strong current where delicate branches might break (Pandolfi & Greenstein, 1997).

Corals are partially carnivorous and use their tentacles to trap zooplankton which they then feed on. Most hard corals only extend their tentacles at night when zooplankton is most abundant. The rest

of their nutrients they gain from a symbiotic relationship with zooxanthellae algae that live within the corals tissue (Jones & Endean, 1973; Yonge, 1963). These zooxanthellae convert carbon dioxide from seawater into sugars and fats some of which are given to the coral, in return the zooxanthellae use the corals waste products for growth and get a safe place to live (Jones & Endean, 1973; Yonge, 1963).

Hard corals are slow growing, some only a few centimetres a year (Hubbard & Scaturo, 1985) and may take a number of years to reach sexual maturity, brain corals (*Diploria labrynthiformis*) for example may take 8 years (Jones & Endean, 1973; Yonge, 1963). Corals can reproduce asexually by budding which is how colonies grow, but to start new colonies they reproduce sexually by releasing gametes (Individual polyps may be male or female or both) (Jones & Endean, 1973; Yonge, 1963). A corals reproductive organs are located inside its body cavity and lie on the mesenteries, the fertilisation of the egg by male sperm may occur internally within the female coral polyp or externally in the water column (Jones & Endean, 1973; Yonge, 1963). Corals which fertilise internally are known as brooders and those which fertilise externally are known as broadcasters (Jones & Endean, 1973; Yonge, 1963). The zygote formed will eventually become a free swimming planula with limited powers of locomotion. Planulae of broadcasting species tend to spend much longer in the water column and therefore travel greater distances than those of brooders, planulae of brooders are released when mature and already contain zooxanthellae. Coral planulae are fed on by many fish species and invertebrates (Jones & Endean, 1973; Lesser, 2004; Yonge, 1963).

The settlement and success of coral planulae is dependent on a multitude of factors. Crustose coralline algae for example is known to not only give off chemicals which cause coral planulae to descend and attach to a surface but also to reduce levels of macro algae which indirectly cause coral recruit mortality (Vermeij et al. 2011). Chemical stimuli from dead coral also cause increased coral recruitment (Kitamura et al. 2007). The waters in which they are situated are more suitable if they are oligotrophic (Hallock & Schlager, 1986), corals are slow growing and in areas of high nutrients they are out competed by macro algae and sponges (Diaz-Pulido et al., 2009; McCook et al 2001; Vermeij et al., 2010). When many coral planulae settle and become sessile they have an optimum level of light which they are attuned to (Coles & Jokiel, 1978; Grottoli & Wellington, 1999; Mundy & Babcock, 1998) if the depth or clarity of the water a coral is situated changes

then light intensity changes which can affect the coral negatively from its optimum rate of photosynthesis, this is an important factor to consider when collecting coral fragments to transplant onto artificial reefs. Most hard corals require stable substrate for recruitment such as hard rock (Jones & Endean, 1973; Yonge, 1963), dynamic environments like sand or small rubble are not suitable.

The health of coral reef ecosystems is important for coral survival, Without stable temperature, pH, light/dark cycles, water flow, salinity, and chemical composition of sea water, coral reefs could not exist, but without a stable trophic cascade, coral reefs could not survive.

Threats to coral reefs

Coral reefs have seen a decline worldwide of around 19% since 1950 (Wilkinson & Souter, 2008) this has been from a combination of natural and anthropogenic factors. In 2004 the largest earthquake in 40 years struck near the island of Sumatra raising some areas of coral reef out of the water and killing them, the resulting tsunamis caused massive damage to coral reefs in surrounding countries. Global coral bleaching events caused by sustained periods of high ocean temperatures, for example those of 1998, 2005 and 2010, have also had devastating effects. In 2005 the heat induced bleaching affected 80% of corals in the Caribbean causing mortality of over 40% in many areas (Wilkinson & Souter, 2008), and in 2010/11 unprecedented high temperatures combined with high storm activity caused a loss of coral cover in Western Australia from 22% to a maximum of 83.9% in some areas (Moore et al., 2012). With the increasing severity and frequency of these heat induced bleaching events it is important that corals and coral ecosystems are healthy and therefore have a better chance at surviving (Anthony et al. 2009).

Increasing levels of CO2 in the atmosphere and subsequent dissolution into the oceans has resulted in a more acidic marine environment with less available carbonate ions for take up by calcifying marine organisms (Kaniewska et al. 2012). Mass coral extinctions in the past have been linked to acidic oceans (Veron, 2008) a concern for corals worldwide. The lack of available carbonate ions means slower bio mineralisation of hard corals, but also drive major changes in gene expression, respiration, photosynthesis and symbiosis of the coral (Kaniewska et al. 2012) negatively affecting its overall health. Acidic oceans also accelerate reef bio-erosion by sponges, sponges erode

and kill corals on a cellular level by a process of bio-chemical dissolution, when the PH of the surrounding water is lower there is less of a PH gradient with the site of dissolution making the process quicker with less metabolic cost by the sponge (Form et al. 2012).

Anthropogenic pollution of the marine environment from nutrient rich sediment, sewage, fertilisers etc. detrimentally effects coral reefs (Hallock & Schlager, 1986; Koop et al. 2001). Corals require an oligotrophic environment to survive and in areas with high nutrients they can become outcompeted by faster growing macro algae (McCook et al. 2001), even in ecosystems with high levels of herbivores nutrient enrichment gives the algae an advantage that can lead to a shift towards a macro algae dominated environment. (Littler et al. 2006;Vermeij et al. 2010) which is a less productive and bio-diverse habitat than a coral reef. Nutrient enrichment can also increase the severity of coral diseases (Bruno et al. 2003). Larger marine pollution such as derelict fishing gear (DFG) can smother areas of coral, break more fragile corals and trap marine organisms resulting in some cases with coral death (Chiappone et al. 2005; Donohue et al. 2001; Yoshikawa & Asoh, 2004).

Over fishing damages the coral reef ecosystem by removing herbivores which predate on algae and act as one form of control on algal growth (Diaz-Pulido et al. 2009) or by removing predators which control the numbers of marine organisms which feed directly on the coral (Dulvy et al. 2004; Verlecar et al. 2007). Coral reefs require a stable trophic cascade and when this is disturbed through the excessive removal of certain species it can negatively impact the ecosystem. Thyresson et al. (2013) Looked at the trade in coral reef fish in Zanzibar and found that traders and hotels preferred larger fish, but locals bought mainly smaller fish meaning both growth overfishing and recruitment overfishing is possible. The trade in larger reef fish is however disproportionally more damaging, for example grazing of algae by parrot fish has been shown to increase exponentially with individual fish size (Thyresson et al. 2013). Recreational fishing on coral reefs also targets larger fish and can significantly damage the population of the species targeted, more so than commercial fishing in some cases (Gao & Hailu, 2011).

Invasive species and population booms of certain species can detrimentally effect coral ecosystems, for example the invasion of the indo-pacific lionfish to reefs across the western atlantic, Caribbean

and gulf of Mexico (Co et al. 2012). Outbreaks of crown of thorns, which can be especially damaging to coral reefs (Kayal et al. 2012), have been linked to increased nutrients in the ocean from anthropogenic activity (Brodie et al. 2005).

Coastal development and destruction of habitat such as mangroves or forest which traps sediment is a concern for many reefs worldwide (Babcock & Smith, 2000; Bonilla et al. 2010; Carilli et al. 2009; Davenport & Davenport, 2006). Coastal development can cause problems from increased nutrients and sediment runoff among others (Davenport & Davenport, 2006;Hawkins & Roberts, 1994; Maragos, 1993). Sediment runoff affects corals by smothering them, meaning corals must use energy to create mucus to remove it, reduces the water clarity and can increase nutrients in the water which leads to excess algal growth and promotes coral diseases (Babcock & Smith, 2000; Bruno et al. 2003; Fabricius, 2005; Haapkylä et al. 2011; Rogers, 1988).

Effects of Scuba diving on coral reefs

SCUBA-diving has been found to be one of the fastest growing coastal tourism activities, and today, there are nine times more certified divers than there were in 1980 (PADI, 2011). There is much research on how intensive scuba diving can detrimentally affect coral reefs (Barker & Roberts, 2004; Rouphael & Inglis, 1997; Uy et al., 2008; Zakai & Chadwick-Furman, 2002). Damage can occur through contacts with divers, which is especially damaging to more fragile branching corals (Leujak & Ormond, 2008). The coral has to use up energy reserves to repair itself making it less likely to survive other environmental stresses (Anthony et al., 2009) and the broken area acts as an opening for coral diseases (Uy et al., 2008; Zakai & Chadwick-Furman, 2002). Divers may also stir up sediment which covers corals making the coral use up energy reserves creating mucus to remove it (Rogers, 1988) and helps coral diseases from the sediment get into broken coral (Babcock & Smith, 2000; Uy et al., 2008). Over time these effects can accumulate decreasing structural diversity of the reef, structural diversity which is important habitat to support the diversity of organisms living on the reef (Rinkevich, 2005). The amount of damage divers actually do, and which type of people are the most damaging has been researched by Walters & Samways (2001) where the most damaging divers were beginners, except when cameras were

involved which increased contacts substantially no matter the divers experience, this was also found in another study by Barker & Roberts (2004). The Morphology of the corals in an area is an important factor when considering how much damage will be done by divers, for example areas with more thin or branching corals will likely be more damaged than areas with mainly thick corals such as brain corals (Rouphael & Inglis, 1997). Diving may cause other detrimental impacts such as the use of sunscreens and other personal care products by divers, which promotes coral diseases (Danovaro et al. 2008), addition of nutrients through pollution from dive boats (Koop et al. 2001), feeding fish which introduces extra nutrients into the oligotrophic eco system corals require while also reducing the amount of competing algae and sponges eaten by the fish (Koop et al. 2001; Ledlie et al. 2007) and others such as anchor damage from boats (Dinsdale & Harriott, 2004).

Artificial reefs

The European Artificial Reef Research Network (EARRN) defines an artificial reef as a submerged structure placed on the substratum (seabed) deliberately, to mimic some characteristics of a natural reef. An artificial reef can be anything which provides extra structure in the ocean environment be it a sunken ship, an oil rig, concrete blocks or metal frames. However Some structures and materials have been found to be better suited to their purpose such as concrete which can be made into multiple shapes and mimics natural rock in many respects (Baine, 2001; Relini et al. 2007). A positive aspect to the development of artificial reefs for non-consumptive purposes is that they can be built in degraded or otherwise unused habitats, thus areas that are relatively unproductive or have poor natural resource development at present may be ideal locations for the construction and deployment of artificial reefs as dive tourism destinations. The use of degraded marine communities for these non-consumptive activities serves to decrease the use and pressures on nearby more productive and pristine habitats while diversifying and increasing the local economic base (Brock, 1994). There is a noticeably higher number of AR's using concrete worldwide however it is important to note for this study that in Koh Tao and Thailand in general metal structures are much more abundant due to concrete AR's being relatively expensive to create and transport (Kheawwongjan & Kim, 2012). Baine (2001) found concrete to be used for most objectives including increasing fish assemblage, lobster habitat and even for prevention of trawling. Artificial reefs made from concrete blocks with

multiple sized holes have been found to be the most effective for generally increasing biodiversity (Relini et al. 2007). It has been found that artificial structures with much more height and structural diversity have much more biodiversity associated with them (Hackradt et al. 2011; G Rilov & Benayahub, 1998; Rilov & Benayahu, 2002). Artificial reefs may also have more biodiversity associated with them than comparative natural reefs (Hunter & Sayer, 2009) and increase the biodiversity of habitats around them (Pickering et al. 1999).

Spieler et al. (2001) states that "*To use artificial substrate effectively in coral reef restoration certain basic knowledge is required: (1) what is the artificial substrate expected to accomplish relative to the goals of the restoration effort and (2) what are the expected interactions of the selected substrate's composition, texture, orientation, and design with the damaged environment and the biota of interest*" For example if your target is increasing fish nurseries then structurally diverse concrete may be your best option, whereas if the objective is reducing dive pressure elsewhere then a sunken wreck or other structures preferred by divers may be more appropriate. Artificial reefs are used for increasing marine biodiversity, preventing illegal trawling, increasing fish stocks, enhancing marine productivity and small-scale coastal fisheries, and developing recreational diving (David et al. 2011; Fabi et al. 2011). Although there is much literature on how to rehabilitate coral ecosystems with AR's (Edwards et al. 2010) there is little current literature on whether coral reefs are successfully meeting their objectives. One such review by Baine (2001) found that out of the 30 case studies in which performance was reviewed only 50% achieved their targets, however current AR's may be performing better.

Effectiveness of artificial reefs with relation to reducing diving pressure has been studied by Polak & Shashar (2012) however their study only took into account one small concrete fish nursery artificial reef which was aesthetically lacking and as a result made little effect on the time spent on natural reef. The study did find that the AR changed the behaviour of learner divers not advanced divers however, a fact important for Koh Tao as it has a high number of learner divers. Leeworthy et al. (2006) studied the effects on recreational use of natural reef after the deployment of a large wreck the "Spiegel Grove" in the Florida keys national marine park, they a found a significant difference of -12.7% divers and -25.7% snorkelers on natural reef after the deployment. There is much literature on the subject of AR's, in particular wrecks, successfully being used to reduce dive pressure

(Davis & Tisdell, 1995; MacDonald et al 1999; van Treeck & Schuhmacher, 1999; Wilhelmsson et al. 1998; Worachananant & Worachananant, 2012).

Study site, Koh Tao, Thailand

Koh Tao is one of a chain of islands near the western shore of the gulf of Thailand approximately 21km^2 in size. It receives around 300,000 visitors annually (Scott, 2009) has over 40 dive shops and was responsible for 46% of all PADI scuba dive certifications in 2009 (Terlouw, 2012). Because of its high numbers of scuba divers and other recreational reef activities almost the entire economy of the island relies on the surrounding coral reefs (Weterings, 2011). Formerly the island was covered in tropical rainforest but has suffered rapid deforestation in the last couple of decades due to rapid development, and as of 2005 only 51% of the forest remained (Weterings, 2011).

Koh Tao's increasing popularity with tourists, scuba divers in particular, has been beneficial to its economy but has caused a number of environmental issues for the coral reefs. Waste water and sewage from coastal development leading to eutrophication and increased algal cover in some areas; Inexperienced snorkelers and divers physically damaging corals; Soil erosion caused by deforestation and development which has led to sedimentation on coral reefs (Weterings, 2011) and overfishing of the surrounding waters disturbing the ecosystem balance (Terlouw, 2012).

There have been two major bleaching events affecting Koh Tao in the past 15 years. In 1998 global bleaching caused mass mortality on the reefs surrounding Koh Tao, however it was found that coral recovery was high in most areas except those experiencing additional stresses such as waste water and sedimentation (Terlouw, 2012). In 2010 Koh tao suffered another such event with temperatures rising to 31-33 degrees Celsius in April-June, and the worst affected sites on Koh Tao having around 98% bleaching and 70% mortality (Terlouw, 2012).

Koh Tao has a number of conservation organisations including the community based save Koh Tao marine branch, which in conjunction with a number of the islands dive shops have implemented projects to restore damaged reefs and reduce diving pressure, such as many coral nurseries and AR's for alternative dive sites (Marine conservation Koh Tao, website).

Method

To assess effectiveness of artificial reefs as tools for the reduction of diving pressure on natural reefs in Koh Tao two general aspects were studied:

1. The number of divers using AR's in comparison to total number of divers and the relative amount of use for each of the six main AR's around Koh Tao (2 wrecks, three aimed at increasing corals/biodiversity, and one designed as a playground for learner divers).
2. The opinions of divers and dive company's on the AR's around Koh Tao; whether they enjoy diving AR's, whether they would contribute to future projects, etc.

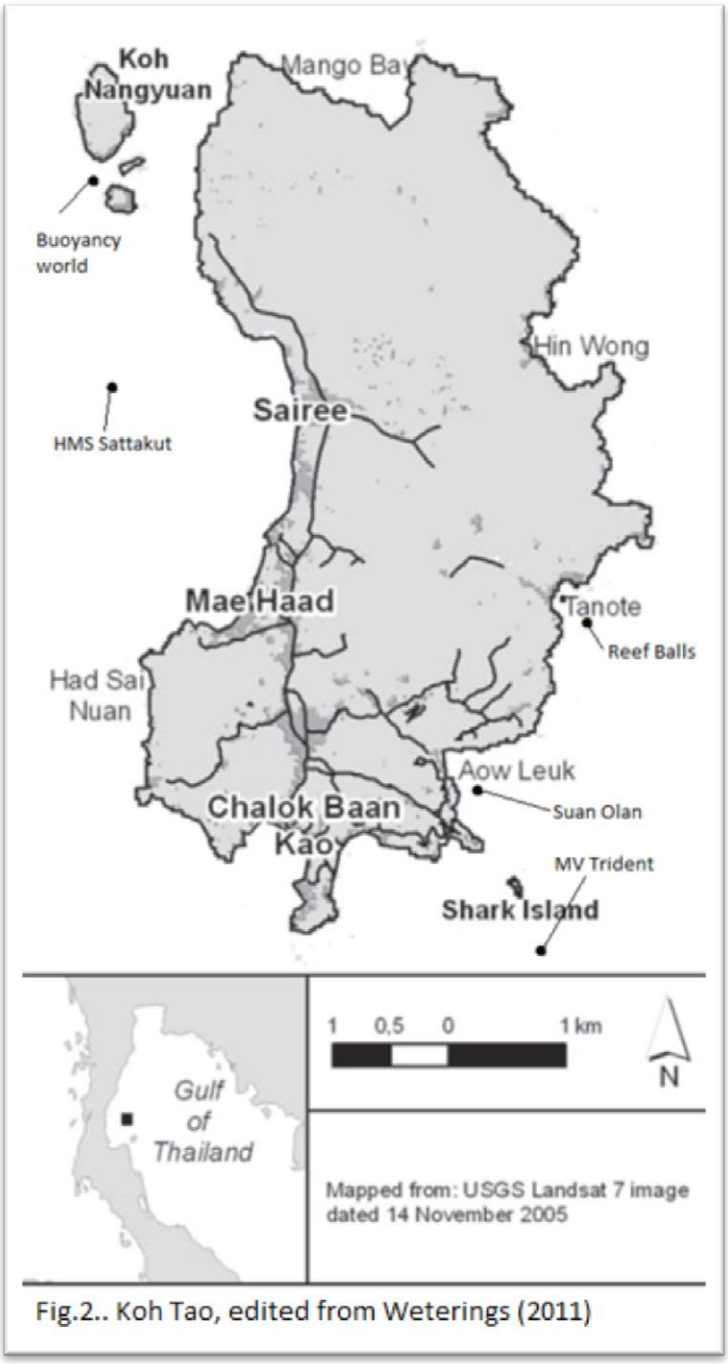


Fig.2.. Koh Tao, edited from Weterings (2011)

The study site of Koh Tao in Thailand (fig 2.) was chosen due to its high number of divers, established artificial reefs and its highly active conservation organisations. For this study the help of one such organisation the "New heaven reef conservation program" was involved in the development of surveys, and gave credibility when approaching divers and dive shops with said surveys. A three month internship with the new heaven reef

conservation program, starting June 2nd 2012 finishing August 20th 2012, was used to gain in depth understanding of the artificial reefs around Koh Tao, how well they are working and the efforts involved in their successes, with the objective of being better able to analyse any results gained and their context. In this time period surveys were distributed and collected. The map of Koh Tao, shown in fig 2., shows the location of Koh Tao and the 6 Artificial reefs of specific interest to this study; HMS Satttakut, MV Trident, Suan Olan, Tanote reef balls, The Biorock and Bouyancy World. Locations shown on Fig 2.

Artificial reef study sites

Plate 1. HMS Sattakut.
Chad Scott 2012

HMS Sattakut and MV trident

The HMS Sattakut (sunk June 18th 2011) and MV trident (sunk September 2010) were both sunk with the intention of creating new dive sites and promoting the health of the marine environment by creating new underwater habitat. Wrecks are known to be favourites of divers, and therefore more likely to be used as dive sites, which is why these two wrecks were chosen for this study. It is important to note that the MV trident is deep, lying at 29 to 36 metres and has occasional strong currents, making it unsuitable for beginner divers. However Koh Tao's dive shops offer many advanced diving courses including tech diving, wreck diving and nitrox, in which the MV trident would be useful. The HMS Sattakut is closer to the main body of dive shops on the west of the island and lies at a shallower 18 to 30 metres, making it more accessible for beginner divers.

Buoyancy World

Plate 2. Bouyancy world, Koh Tao
Chad Scott 2012

Built in conjunction with save Koh Tao marine branch and 8 dive schools in 2009, buoyancy world is designed as a buoyancy training site for beginner divers and coral/fish nursery. Buoyancy world contains a number of structures including art and sculptures, buoyancy training swim throughs, fish and coral nurseries, etc. Buoyancy world is located next to the highly used "twins" dive site, which allows non learner divers who are not practicing diving skills to spend part of their time on buoyancy world and part on coral reef.

The Biorock

Plate 3. Biorock, Koh Tao
Chad Scott 2012

Completed in 2009, the Biorock artificial reef structure uses low voltage direct electrical current to stimulate calcium carbonate deposition, hereby strengthening the coral skeleton and increasing coral growth rates. It has had difficulties however due to the costs involved with fixing any problems with the technology, and at the time of the study was not functioning and had not been functioning for a number of months. The site has much marine life nearby and the Biorock itself is interesting for divers, however the lack of a mooring line for dive boats, distance from other natural reef dive sites making it too far for one combined dive and amount of boat traffic nearby may make it unpopular as a dive site. The site is focused more towards coral growth and rehabilitation rather than a dive site.

Suan Olan

Plate 4. Suan Olan, Koh Tao
Chad Scott 2012

Suan Olan, located in Ao leuk bay, is a mixture of coral nurseries and artificial reef structures designed for coral transplantation/ diver training aids, along with other structures such as the concrete mini where aggregations of fish can be found. Recently joining up the different structures of the site are bottle nurseries, concrete blocks with empty bottles set in and covered with coral fragments. It has some pristine shallow coral reefs nearby and the site itself is perfect for learner divers and has concrete tubes for swimming through. However it is located far from the majority of dive shops, it has only very recently got a dive boat mooring line and the bottle nurseries,

making it easy to navigate, are also very new and at the time of the survey no accurate map was available for dive guides.

Tanote bay reef balls

Tanote bay suffered excessive sedimentation due to actions on land and the Tanote reef balls were set up, as part of the save Koh Tao coral nursery program, to provide more hard structure for corals to grow on and fish to use as shelter. The site consists of 146 hollow concrete hemispheres with numerous corals attache. The reef balls are quite barren, however there are many juvenile sweetlips, a favourite for divers, and good shallow natural reef nearby. The site is located relatively far from the main body of dive shops which are on the west of the island. It is aimed at coral reef and fish rehabilitation rather than as a dive site.

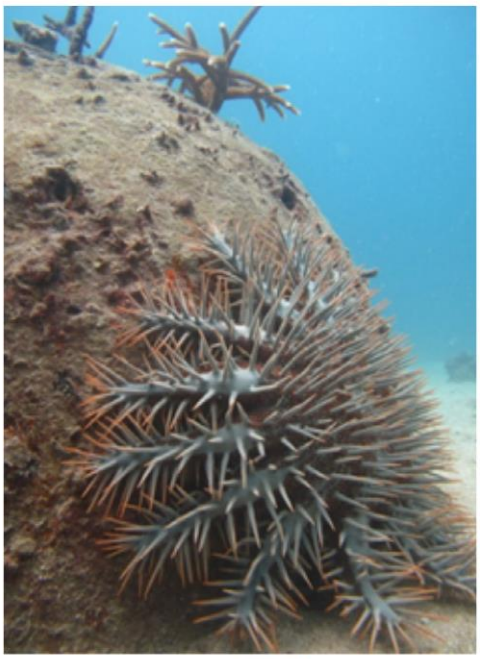


Plate 5. Tanote reef balls
Chad Scott 2012

These 6 sites were chosen because they are the main artificial reefs around Koh Tao and provide examples of AR's built specifically for divers, specifically for coral/fish rehabilitation and some with aspects of both. There are a number of confounding factors which may make a purely numerically based value of effectiveness of these sites unreliable, for example some are further from the main body of dive sites meaning the majority of dive shops will save money on fuel by visiting nearer dive sites, some don't have mooring lines for dive boats and any number of other unknown factors. Also factors such as dive shops willingness to fund and diver's enjoyment of the AR's may count towards effectiveness as a tool for reducing dive pressure. For these reasons questionnaires were designed to asses numerical value

of use of the AR's as dive sites and other aspects for example divers enjoyment of AR's and what dive shops and divers think matters for them with relation to AR's.

Two separate questionnaires were designed, one for divers and one for dive shops to gain numerical values of divers use, opinions and preferences. The dive shop surveys were distributed to every dive shop possible considering time and transport constraints, with all the largest dive shops prioritised. The diver surveys were handed out to some of the larger dive shops which agreed to help, mainly on the west side of the island. In total 29 of the 43 dive shops were surveyed.

Questionnaires can have problems due to; questions which lead the responder towards a more favourable answer, responders giving more favourable responses than they would in reality act upon, giving the socially acceptable response, rather than their true feelings on the subject, not concentrating on answers when surveys take too long to complete. For these reasons surveys did not include the save Koh Tao logo, were short and straight forward and designed so that questions did not lead the responder on as much as possible. High season (Dec to Feb and June to end of august) and low season (the other 6 months) having very different numbers of divers were separated in the survey.

A database was created, total count from the survey results analysed and percentage figures extrapolated from results. Written survey data was put into the database and linked to the numerical results found. A copy of the survey forms used in the study is shown in appendix I. Completed survey forms (in database form) used in the generation of data and its subsequent analysis are presented in the electric resource in Appendix II.

Results

Dive company survey results

Twenty nine dive shops were questioned and from that the total number of divers annually around Koh Tao was found to be in the region of 299,390 and

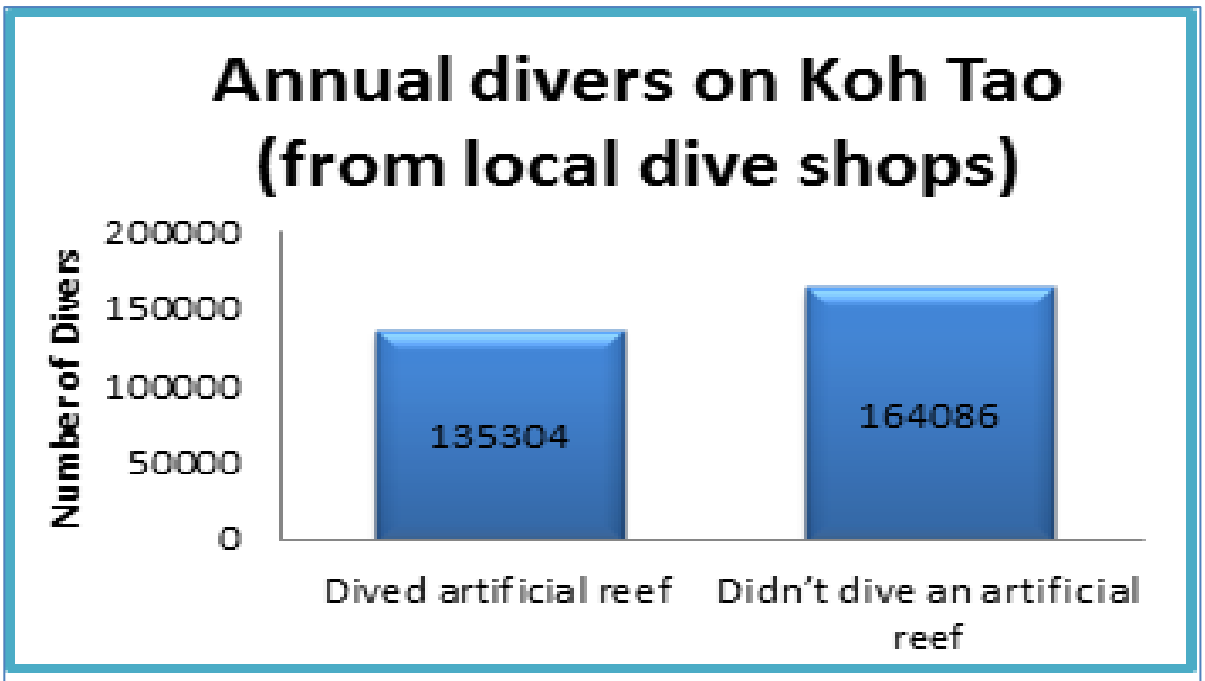


Fig 3. Annual divers on Koh Tao
Data from appendix II

that around 45% of those divers had dived on an artificial reef or spent part of their time on one. If each of the divers spent an average of 7 days on Koh Tao (Scott 2013), doing 2 dives a day (a day's fun diving on Koh Tao generally involves 2 dives) and spent 21% of dives (found from diver surveys) of their dives on an AR, then that is around 880,207 dives in which AR's are used instead of natural reef sites annually.

Of the divers on AR's it was found that 41% were recreational dives and 59% were taught courses. A high number of taught courses was expected however the reason for a relatively high number of recreational divers may be due to HMS Sattakut, which was found to be the most visited artificial reef, as wrecks are known to be popular with recreational divers (Davis & Tisdell, 1995; MacDonald et al 1999; van Treeck & Schuhmacher, 1999; Wilhelmsson et al. 1998; Worachananant & Worachananant, 2012).

Willing to contribute	manpower		money		materials	
Companies divers per week	yes	no	yes	No	yes	no
1 to 50	64%	36%	18%	82%	36%	64%
51 to 250	86%	14%	57%	43%	71%	29%
251 or more	100%	0%	45%	55%	55%	45%
total	83%	17%	38%	62%	52%	48%

Table 1. Willingness to contribute of Dive comapanies on Koh Tao Data from Appendix II

Of the dive shops surveyed 90% felt like they had benefited from the artificial reefs around Koh Tao. Willingness to contributed Manpower was relatively high no matter the number of divers per week (and therefore economic wealth of the dive business) however a general increase in the number of dive shops willing to contribute was observed with an increase in number of divers. One of the notes on one of the smaller businesses survey stated that their small team may make it difficult to help with AR projects which may go towards explaining this result as some small businesses may have been answering more realistically than others. When it came to willingness to pay money towards future AR projects there was a general increase in those who would contribute with an increase of economic wealth however the relationship was not linear, a higher percentage of the dive shops designated as middle income were willing to contribute money. Of the top 6 dive shops with the highest number of divers three were willing to contribute money and three were not. It should be noted that the three of those willing to pay have the most divers by a significant margin. The same pattern is observed when willingness to provide materials is asked, with the middle sized dive businesses having a much higher willingness to contribute. This result will be due to other factors such as the individual disposition of dive shop owners towards marine conservation.

To the question of which type of artificial reef is most important to dive companies 36% answered fish nurseries, 36% answered coral nurseries and 28% answered training aids. This shows nothing definitive of which is most important but suggests that a compromise of all three, such as in the case of buoyancy world, is most appropriate.

Of the 6 artificial reef sites usage questioned Buoyancy world and HMS Sattakut stood out with 391 and 416 dive boats being taken by Koh Tao dive companies to these sites each month, accounting for 41.1% and 43.7% of the total use of the 6 AR's surveyed. The next most used AR was Suan Olan which was visited 79 times (8.3% of the total usage), then Tanote 33 visits (3.5% of total), MV Trident 23 trips (2.4% of total) and lastly Biorock with 10 trips (1.1%). This suggests that out of these 6 AR's, Bouyancy world and HMS Sattakut are the most effective at reducing diving pressure as they are the most used by dive companies.

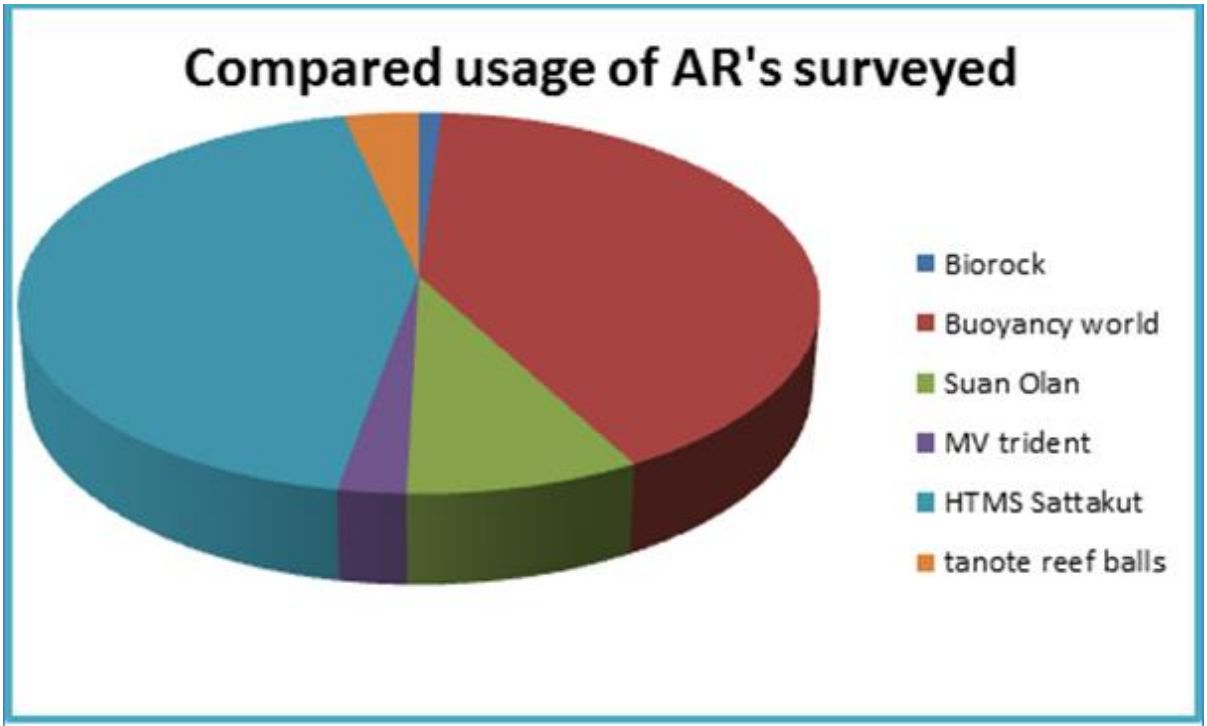


Fig 4. Comparative usage (percentage) of AR's on Koh Tao
Data from Appendix II

Notes from Dive company surveys

One of the dive shops stated that wrecks were the most important to them, a statement which links to the result of HMS Sattakut being the most well used of the AR's surveyed. Another statement was that Suan olan is too small for fun divers and courses can just go to Buoyancy world which is closer, the results show buoyancy world as one of the highest used sites and this statement suggests its location may be an important factor for this. MV Trident was described as "too deep and bad current", MV trident was found to be one of the least used dive sites and this may be an important factor why. Tanote reef balls was stated as "too small for fun divers and courses, and too far", Tanote reef balls were found to be one of the least used sites, it is located on the opposite side of the island to the main body of dive shops which would suggest this statement has significance. Another statement was that "Artificial reefs should be near natural reef as fun divers don't want to spend all their time on an AR" most of the AR's surveyed are near some natural reef so whether or not this links in with the data is unknown however.

Diver survey results

Of the 28 divers surveyed the most common dive qualification was instructor or higher, the average total dive count was 538, the average dive count on Koh Tao was 354 and the average number of dives on AR's on Koh Tao was 73. This is because almost all of the surveys ended up in the hands of employees of the dive shops rather than the customers, therefore these surveys should be considered mainly the opinions of the employees of Koh Tao's dive companies. Accordingly 79% of the dives on AR's were found to be scuba courses and only 21% found to be recreational dives, which makes sense as most instructors will be teaching rather than simply leading dives. The high number of divers that have dived buoyancy world, which is designed for teaching divers, can be explained by the significant number of instructors surveyed.

Of those surveyed 85% said their experiences of AR's were "good" or "very good" and 96% said they would like to dive an AR again. This suggests that in general Koh Tao's AR's are performing well when it comes to user satisfaction. When asked whether they would pay for a dive solely on an artificial reef only 40% answered yes, however when asked if they would pay for a dive with only part of the time spent on an AR 84% answered yes. This suggests AR's should be near natural reef so that it is possible to switch

between the two surroundings and links in with the dive company survey notes in which the same statement was made by a dive instructor.

Interactive structures (wrecks, swim throughs etc.) were found to be the most favoured for 65.2% of surveys. Coral/fish nurseries and sculptures were equal with 17.4% of surveys each favouring them. Buoyancy world and HMS Sattakut are highly interactive in nature and were found to be the most well used, which links in with these results. Of those surveyed 80% had dived HMS Sattakut and 48% had dived buoyancy world, the highest number, with the third most used dived site being Suan olan at 38%. This fits in with the order of use of AR's from the dive company survey.

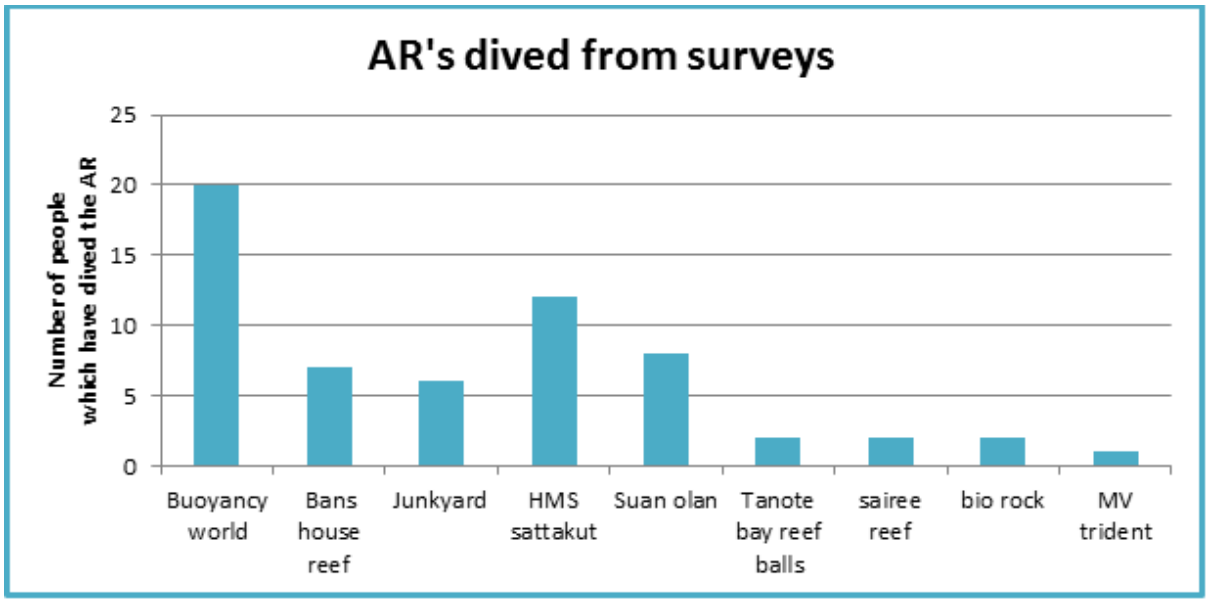


Fig 5. Comparison of AR's dived from diver surveys
Data in Appendix II

When asked which improvements to artificial reefs were most wanted the most frequent answer was more corals (38.9% of surveys) with increased fish life being second (27.8%). Of the two most frequently dived sites HMS Sattakut has only a few young corals but a lot of fish life and buoyancy world has a small number of coral covered structures but is lacking in fish life which may link in to those results. Maintenance and more interesting structures were the next most answered result at 17.4% of surveys each.

Notes from diver Surveys

One diver stated that he would only dive large AR's, a statement which links in with the dive company notes where Suan olan and Tanote reef balls were both described as being too small to dive. Another diver stated that the wreck was not very good due to bad visibility. Koh Tao sometimes has very pronounced Thermoclines which can be full of sediment making it difficult to see up to a metre ahead, this may be the reason for this statement. Another

survey in which only HMS Sattakut had been dived stated specifically the thermocline was the issue, which may confirm this.

When asked what they liked best about AR's a common answer was "it's something different", however common answers when asked what was disliked most was "it gets boring" and "lack of marine life". This suggests that to make people want to dive again and therefore increase effectiveness of AR's as tools for reduction of dive pressure elsewhere, AR's must focus on becoming more diverse and interesting not only to look at but with regards to the marine life on them.

One comment stated that "it should all be at 12m" in reference to two of the AR's dived, Suan olan and buoyancy world. 12m is the maximum depth to which complete beginner scuba divers doing, for example, PADI discover scuba can go. Novice divers are some of the most damaging to natural reef as they lack buoyancy control. This 12m depth may be impractical to implement however. Lack of maintenance of current AR's was another issue raised in a number of surveys, including fishing vessel damage.

Fig 6. Reasons for success of artificial reefs as alternative dive sites derived from survey data
Data found in Appendix II

Discussion

Around 299,390 people dive Koh Tao annually from this survey, however due to the fact that a small number of Koh Tao's dive shops were not involved in this survey and that many dive boats come from Koh Samui and Koh Phangang and are therefore not included in this survey, the number will be considerably higher. It has been previously found that Koh Tao has over 300,000 visitors annually (Scott, 2009) and that most of the tourism and economy of the island is dive based (Weterings, 2011) therefore this result is unsurprising. Carrying capacity of coral reefs for diving is difficult to assess but an important concept for conservation, previous studies have found that after a certain number of dives damage to corals increases greatly and that the sustainable number of guided dives per site is around 5000 annually (Harriott, Davis, & Banks, 1997; Julie P. Hawkins et al., 1999; Zakai & Chadwick-Furman, 2002). It can be assumed that divers coming to Koh Tao will dive a number of sites and that the most popular sites may have 300,000 divers on them annually, about 50,000 guided dives per year if it is assumed that each guided dive involves 6 people, far above the proposed sustainable level of diving for other areas (Harriott et al., 1997; Julie P. Hawkins et al., 1999; Zakai & Chadwick-Furman, 2002). Studies have found that novice divers are some of the most likely to damage corals and stir up sediment due to their lack of buoyancy skills (Barker & Roberts, 2004; Harriott et al., 1997; Walters & Samways, 2001) therefore due to Koh Tao's high number of divers it is proposed that all dives involving novice divers are required to dive an artificial reef and be allowed on areas of natural reef only when their buoyancy is to an acceptable standard that it is felt they will not accidently cause damage to corals. However for this to be feasible Koh Tao's artificial reefs must take into account this surveys notes and become larger, more interesting, have more marine life and become more numerous so that novice divers on scuba courses enjoy their dives and do not become dissatisfied with diving AR's.

45% (135,304 annually) of divers on Koh Tao were found to have dived an artificial reef on Koh Tao, and from diver surveys 21% of total dives were on an AR. This means that Koh Tao's artificial reefs divert around 21% of all dives from natural reef dive sites annually. This figure may be different due to the unknown site use and number of divers coming from neighbouring islands however. A similar study by Leeworthy et al. (2006) found after the deployment of AR's 34% of all dives in the area were on an artificial reef, the lower figure of 21% on Koh Tao may be

due to only 2 of the AR's surveyed being highly visited and Leeworthy et al's. (2006) study site in the Florida keys having a significantly lower number of divers annually, perhaps making limited space for divers and dive boats on mooring lines a key issue for Koh Tao's AR's. 21% is a substantial percentage of the total dives, however as Koh Tao's number of dives per site is way above the hypothetical carrying capacities found in other studies, increasing the number of AR dive sites may not be effective enough to reduce pressure to sustainable levels. If this is the case then reducing the impact of divers through proper training so that zero contacts occur in combination with AR's for mitigation effects and training uses may be essential for Koh Tao. A study of conservation dive briefings effect on contacts with corals by Camp & Fraser (2012) found that receiving a higher level of conservation education did influence diver behaviour in the water and reduce the frequency of diver contacts with corals. There are numerous dive companies on Koh Tao currently offering marine conservation courses and PADI ecological diver qualifications including the New heaven reef conservation program which helped significantly with this study. It may be that training and marine conservation education promoting diving which does not negatively impact corals should be a pre-requisite of being allowed to dive on Koh Tao, and worldwide, if coral reefs are not to degrade from intensive diving.

The two sites found to be the most used, and therefore most effective to reduce diver pressure elsewhere, were Buoyancy world and HMS Sattakut. Wreck diving is known to be a favourite for recreational divers therefore the result is unsurprising in the case of HMS Sattakut. MV Trident however was found to be one of the least used AR's. The reasons for this being its depth, strong currents and, to a small degree, its further distance from the main body of dive shops on the west of Koh Tao. One dive company survey stated that it is only visited for "specialist dives". Because of these factors MV Trident is therefore ineffective at reducing dive pressure. Buoyancy world has a number of factors found in this survey to be important for AR's as dive sites; it is close to the main body of dive companies, it is close enough to a popular natural reef dive site that one dive may incorporate both AR and reef, it has numerous interactive structures which was found to be the favourite aspect of AR's and it is shallow enough for beginner divers in most areas.

Suan Olan was the third most used of the AR's surveyed but had substantially less use by divers although it shares many of the

characteristics of buoyancy world. The difference in results may be due to Suan Olans increased distance from the main body of dive shops in comparison to buoyancy world, a factor found to be important, and its relatively small size, another negative factor surveys found to be important. At the time these surveys were done Suan Olan did not have a mooring line directly over the AR and an accurate map (with angles, depths and distances) was non-existent making it difficult to use. Suan Olan may have got a small percentage more usage if the dive shops in less easily accessible areas of the island on the east coast of Koh Tao had been surveyed. When Suan Olan is improved for diver use then it may be used much more frequently and therefore be a much more effective tool for reducing dive pressure. Especially by the dive shops on the south and east coasts of Koh Tao, which will increase their use of AR's for Scuba courses as the other main alternative, buoyancy world, is saturated with divers and further away than Suan Olan.

Biorock and Tanote reef balls have similar issues with lack of size, mooring lines etc. Because these two sites are aimed at environmental restoration rather than as dive sites it may be apt to judge them on their ecological benefits which this study does not address. However as tools for reducing dive pressure both these sites are ineffective.

The structures on AR's found to be most favoured were interactive structures such as swim throughs, wrecks etc. Buoyancy world and HMS Sattakut are both highly interactive, which may be one factor as to why their usage is so high. This is important to note because the more enjoyable diving an AR is the more likely it is to be used by divers and therefore reduce diving on other sites. From this it is recommended that existing and future AR's designed primarily as dive sites become as interactive as possible to maximise user enjoyment. However as the results of dive companies surveys show increased marine life being the most wanted, a compromise of multiple structures some designed for corals and fish nurseries and some designed to be interactive for divers would be most suitable. Buoyancy world has this, however many of the negative factors of Koh Tao's AR's were found to be lack of corals/marine life and boredom of divers and as one of the most used sites it is likely in reference to buoyancy world. To increase enjoyment, and therefore use by divers, structures may need to be more innovative in the way they can be interacted with and those structures designed for coral transplants be better designed, maintained and more numerous to substantially increase

marine life. This is recommended for all AR projects (apart from Wrecks) which are designed for teaching scuba courses.

If this investigation into the effectiveness of AR's was repeated again then a number of refinements would be made; As the average length of stay of divers on Koh Tao is around 7 days (Scott 2013) then asking dive shops the number of divers per month or per annum would be more appropriate, at the time of the survey it was assumed the average was less than a week and therefore asking divers per week would be simpler for dive shops to answer immediately. Instead of asking number of visits per site at the 6 artificial reefs surveyed, divers per site per month should be asked because the dive shops have significantly different sized dive boats, some which hold 10-20 divers some 50+ therefore visits per site gives less accurate results. Due to the significant difference in use between sites however results may not differ dramatically and are still relatively good representations of use. Number of divers visiting one of the popular natural reef sites per month/annum, should have been included to give a comparison to judge the accuracy of estimated number of divers on popular sites and to compare usage with the AR's. When asking what type of artificial reef is most important, wrecks should have been included, which would have significantly altered this questions results, as a wreck was the most used AR.

Concern has been raised in the past as to whether artificial reefs help fisheries by increasing fish stocks or whether they cause aggregations of remaining resources which are then more easily over exploited (Bohnsack & Sutherland,1989;Sata,1985) leading to arguments against the implementation of artificial reefs. However if artificial reefs are used for recreational diving it would provide economic incentive to discourage their use in commercial fishing and allow them to help increase fish numbers in the surrounding waters. The results from this study could help with making diving AR's in such areas more appealing to divers and therefore more feasible as dive sites.

Recommendations for future work would be; Work out how effective ecological diver qualifications are at reducing the damage done to corals, how these courses can be improved and whether they have enough of an impact to make the large number of divers on Koh Tao sustainable by comparing new rates of damage to those found in similar surveys of regular divers such as Walters & Samways (2001) and Barker & Roberts (2004).

Use recommendations on AR's from this survey for example making them bigger, more interactive, better maintained with more marine life, close to dive shops, relatively shallow etc., and repeat surveys to see if there is a significant increase in usage of AR's. A study by Leeworthy et al. (2006) looked at the numbers of divers on nearby natural coral reef sites before and after the introduction of an AR, then worked out the reduction in divers its introduction caused along with any economic factors indicating the increase in business gained from the new AR. Using this approach to show both the mitigation effect and cost versus benefit is recommended. This could then be used to guide planning of future AR projects worldwide.

AR's have multiple purposes the majority of which are to increase marine fish/invertebrate stocks or growing corals. They may however serve a dual purpose as dive sites to reduce dive pressure and possibly earn money from diving/sports fishing/snorkelling to pay some of the costs of creating them and create jobs for local people. Using recommendations from this survey may help increase the use of these AR's for recreational diving and produce greater economic benefits from these AR's. How damaging activities such as sports fishing, snorkelling and diving are to AR's are should be looked into however. Due to the number of recently transplanted broken corals and fallen fragments on Koh Tao's AR's it is difficult to tell the damage done specifically by divers without following multiple guided dives and recording contacts as has been done in other studies (Barker & Roberts, 2004; Walters & Samways, 2001).

In general dive companies on Koh Tao feel they have benefited from AR's (90% of dive companies surveyed) and future projects on Koh Tao have a large base of dive companies willing to contribute money, manpower and materials. With 83% of dive shops surveyed willing to contribute manpower, 38% willing to contribute money and 52% willing to donate materials. This makes future AR projects on Koh Tao feasible even without outside investment. However alternative sources of income could possibly be found from governments and NGO's. Companies may also contribute money, for example Suan Olan was partially funded by car company MINI and contains a concrete mini. Scuba equipment companies in particular as marine conservation is important to many of their customers, or companies which are seen as negatively effecting the environment such as oil companies which make substantial financial hand outs to environmental projects to try to mitigate negative opinion of them.

There are many places worldwide where the combination of intensive diving and concern for unsustainable diving practices make conditions which suit the introduction of artificial reefs as alternative dive sites, and subsequently would benefit from the findings in this study. Eilat in the northern red sea for example has a similar problem of coral reef degradation due to the level of divers being far above the carrying capacity for the natural reef dive sites (Rinkevich, 2005) with some of the more popular dive sites receiving in the region of 30,000 dives per year, less than Koh Tao but unsustainably damaging. Artificial reefs have also been used around Eilat, for example Polak & Shashar (2012) studied the effects of one small artificial reef on the behaviour of divers and its effect on reducing time spent on natural reef, finding that it had only a small effect. They concluded that its small size and lack of taking into account diver preferences may have been the main factors for its relatively small effect. Results of diver preferences and aspects of successful sites from this study of Koh Tao may help improve AR's in cases like this. They also found that the more information on marine conservation given to divers before a dive the greater care was taken by divers to avoid contact with corals, which links into recommendations from this study of Koh Tao about there being mandatory ecological diver qualifications due to AR's not having enough of an effect in reducing dive pressure in areas of very intensive diving.

Conclusion

AR's on Koh Tao take a significant number of divers off natural reef (around 21% of dives, 59% of which are scuba courses which are likely beginner diver therefore most damaging) and can be considered effective at reducing dive pressure. However due to the large number of scuba divers visiting annually, around 300,000, it is impossible for AR's on Koh Tao to mitigate the negative effects of intensive scuba diving and other solutions to reducing diver damage in combination with AR's must be found.

The most effective AR's at reducing diving pressure on Koh Tao were the wreck of HMS Sattakut and the AR designed for training divers called Buoyancy world, accounting for 43.7% and 41.1% of the total use of the 6 AR's surveyed. The reasons for their success being; their relatively short distance from the main concentration of dive shops surveyed and popular dive sites, which cuts time and fuel costs for dive companies. Their depth and current being within acceptable levels, buoyancy world is mainly for beginner divers and is relatively shallow, HMS Sattakut is deeper but still within the 30m maximum for relatively simple diving. MV Trident is similar to HMS Sattakut but is 29m to 36m in depth and has strong currents making it much more difficult to dive, which significantly negatively affected its use. The interactive nature of Buoyancy world and HMS Sattakut, with many areas to swim through and structures to practice buoyancy control, a factor surveys found to be the favourite part of diving AR's. The relatively large size compared to other AR's on Koh Tao, a factor found to be important for AR's to be used as dive sites in the survey notes.

Areas for improvement of AR's to increase diver usage and therefore increase effectiveness at reducing dive pressure are; A combination of more interesting and interactive structures, survey notes found boredom of diving AR's to be an issue and that interactive structures were the most favoured. More marine life, many of the AR's on Koh Tao have only a couple of structures with thriving numbers of corals and others such as buoyancy world have few fish in the immediate area, these were found to be the main improvements wanted in the diver surveys. The relatively small size of some AR's was found to be an issue in the survey notes, there needs to be natural reef nearby to go to for part of the dive, having natural reef nearby being another factor found to be important in the survey notes, however if AR's were

improved with recommendations from this study then having natural reef nearby may not be an issue.

In general dive companies on Koh Tao feel they have benefited from AR's (90% of dive companies surveyed) and future projects on Koh Tao have a large base of dive companies willing to contribute money, manpower and materials. With 83% of dive shops surveyed willing to contribute manpower, 38% willing to contribute money and 52% willing to donate materials. Therefore future AR projects on Koh Tao are highly feasible and likely to involve help from much of the dive community on the island.

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Appendix

Appendix I.

Dive Company Survey, artificial reefs around Koh Tao

1. Company Name _____

2. On average, how many divers per week

high season_____

low season _____

3. On average, how many divers spend time on an artificial reef per week

High season_____

Low season_____

4. On average how many of those are

Fun dives_____

Courses _____

5. On average how often do you visit these AR's per month

Hin fai biorock_____

Bouyancy world (twins)_____

Suan Olan (Hin ngam)_____

MV Trident_____

HTMS Sattakut_____

Tanote reef balls_____

6. Which type of artificial reef is more important (circle appropriate)

Fish nurseries : Coral Nurseries : training aids : underwater sculptures

7. Do you as a company feel you benefit from artificial reefs around Koh Tao? Y/ N

8. If future artificial reef projects arise would you as a company be willing to contribute

manpower Y/N

Money Y/N

Materials Y/N

Diver survey, Koh Tao

1. What is your current highest scuba qualification?
2. Total Dive count?
3. Total dive count around Koh Tao
4. Total dives on artificial reefs around Koh Tao (even if only for a short part of your dive)?
5. Which artificial reef sites have you dived around Koh Tao?
6. How would you rate your experience on the artificial reef

   Very good|Good| Average|Bad|Very bad
7. What was your favorite structure on the artificial reef you dived?
8. Would you dive on an artificial reef again? Y/n
9. What improvements would you most like to see on the artificial reef you dived?

A. More Fish

B. More corals

C. More interesting structures

D. Other _____

10. What did you like best about diving the artificial reef?
11. What did you like least about diving the artificial reef?
12. Would you pay to dive solely on an artificial reef? Y/n
13. Would you pay for a dive in which part of the time is on an artificial reef? Y/n

14. What was the purpose of your dive on the artificial reef? (Fun dive or learning/ course)
15. Have you ever heard of Biorock technology? Y/n

Appendix II.

Electronic resource.