



**Identification of Suitable Sites
for Giant clam (*Tridacna maxima*)
in Aow Leuk bay, Thailand**

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**- Suitable Habitat Mapping by use of ArcGIS and Multi Criteria Analysis
to identify Suitable Sites for reintroduction of Giant clam (*Tridacna
maxima*) in Aow Leuk bay, Koh Tao, Thailand-**

**A final thesis written in the frame of the study Animal Management, Major Wildlife
Management, at the Hogeschool Van Hall Larenstein.**

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Picture on Front Page:
Giant clam, *Tridacna maxima*. Chad Scott, Save Koh Tao

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Summary

Identification of suitable sites for reintroduction of threatened species can act as a constructive key to restore and/or preserve species and their environment. A vital tool for this approach is Habitat suitability mapping. This study concentrates on the species *Tridacna maxima*, the Giant clam, and its habitat and relevant threats in a bay of the island Koh Tao, in the southern Gulf of Thailand. The species forms an essential component within coral reefs and is as a consequent affected negatively by their destruction. On Koh Tao this destruction is mainly caused by an increase in the use of coral reefs through tourism. A project initiated by the Save Koh Tao group aims on restoring Giant clam populations in the coral reefs around the island. Until now the bay of Aow Leuk is used as the main nursing and release site. Since sound site selection is critical for the survival of Giant clams, this study focuses on identifying and locating the most suitable sites for reintroduction in the bay of Aow Leuk. An ArcGIS model was constructed by taking into account the factors which form the habitat of Giant clams and combining these with the threats relevant for the species. This model acts as an adaptive model, which can be used for other bays of Koh Tao in the future. The method of stratified random sampling was used to apply 40 transects within the study site and consequently examine 9000m² by using the belt transect method. Data was collected on clam abundance, environmental factors and relevant threats.

By using ArcGIS a Multi Criteria Analysis(MCA) has been conducted to facilitate a ranking of the different habitat suitability classes. The resulting habitat suitability map was subsequently compared with a map presenting the location and level of relevant threats to Giant clams. By this method 53.1 percent of the investigated area was identified as “Not suitable” sites, 1.7 percent as “Less suitable” sites, 39.7 percent as “Suitable” sites and 5.5 percent as “Most suitable” sites for the reintroduction of Giant clams in the bay. By validating the model with the recorded data on clam abundance and clam sizes, it was concluded that the “Most suitable” sites in Aow Leuk bay are the sites which scored the highest amount of points in the MCA. According to the used criteria these sites can be found in a depth of five to ten meters, have a temperature of 29°C to 30°C, a visibility equal to or higher than seven meters, a turbidity of zero to five FTU, a nitrogen concentration of less than 20mg/l, a phosphate concentration of less than 0.5 mg/l, seabed consisting of reef and coral rubble, or sand substrate available for the Giant clam to attach to, and a comparably low threat pressure. These sites are located in the reef areas along the coastal shores of the northern and southern side of the bay. Threats for the Giant clams have been identified as settlement, sediment, buoyancy lines, diving and snorkeling zones and grey water outlets, with settlement areas located in the north west, diving and snorkeling zones, and buoyancy lines located around the reef areas close to the coastal shores of the northern and southern side of the bay, and the grey water outlet lying in the north west of the bay. Threatening amounts of sediment have been recorded mostly towards the middle of the bay within the sandy areas.

Content

1. Introduction	5
1.1 Research objective and questions	6
1.2 Hypothesis.....	6
2. Methods	8
2.1 Study area Koh Tao	8
2.2 Study site Aow Leuk	9
2.3 Study species.....	10
2.4 Study population.....	12
2.5 Data Sampling	13
2.6 Data collection	15
2.7 Data preparation.....	18
2.8 Data analysis – Multi Criteria Analysis	19
2.8.1 Ranking of the criteria.....	20
2.8.2 Validation of the model.....	23
3. Results	24
4. Discussion.....	31
5. Conclusion	34
6. Recommendation.....	36
7. Literature list.....	37
8. Appendices.....	40
Appendix I: Seabed Types	
Appendix II: Steps of data collection and belt transect	
Appendix III: Flowchart	
Appendix IV: Flowchart steps	
Appendix V: Metadata table	
Appendix VI: Maps of different criteria	
Appendix VII: EMP Manual	
Appendix VIII: Multi Criteria Analysis	

List of Abbreviations

EMP	Ecological Monitoring Programme
ENSO	El Niño-Southern Oscillation
MCA	Multi Criteria Analysis
MPA	Marine Protected Area
SST	Sea Surface Temperature
UNEP	United Nations Environment Programme
WCMC	World Conservation Monitoring Centre

List of Tables and Figures

Table 1: Tridacna Maxima picture and taxonomy.	Page: 10
Table 2: Average amount of clams and number of sample spots per seabed type in Aow Leuk.	Page: 14
Table 3: Collected data on clam abundance and environmental factors in the study site.	Page: 17
Table 4: Max. and min. amount of points which can be reached for each criterion in the MCA.	Page: 21
Table 5: MCA criteria for assessing suitable habitat and sites for Giant clams in Aow Leuk.	Page: 21
Table 6: Ranking of the criteria clam size and amount for the validation of the model.	Page: 23
Table 7: Scores for five highest ranked sites for reintroduction of Tridacna maxima in Aow Leuk.	Page: 29
Figure 1: Map of Thailand with the location of Koh Tao.	Page: 9
Figure 2: Study area Koh Tao with the location of the study site Aow Leuk.	Page: 9
Figure 3: Seabed types and sampling points in the bay of Aow Leuk.	Page: 14
Figure 4: Collected data to identify most suitable sites for Giant clams in Aow Leuk.	Page: 15
Figure 5: Visualisation of Navigation to sample spots.	Page: 16
Figure 6: Visualisation of collected data and belt transect.	Page: 18
Figure 7: Visualisation of the resulting maps of the study.	Page: 24
Figure 8: Habitat Suitability Map for Tridacna maxima in Aow Leuk.	Page: 25
Figure 9: Threat Map for Tridacna maxima in Aow Leuk.	Page: 26
Figure 10: MCA Map for reintroduction sites of Tridacna maxima in Aow Leuk.	Page: 27
Figure 11: Map with most suitable sites for reintroduction of Tridacna maxima in Aow Leuk.	Page: 28
Figure 12: Map with highest scored sites for reintroduction of Tridacna maxima in Aow Leuk.	Page: 29
Figure 13: Validation Map of the Suitable Sites model for Tridacna maxima in Aow Leuk.	Page: 30



1. Introduction

Coral reefs are diverse ecosystems which provide for food, income, ecological services, and livelihoods for both local coastal communities and its countries (Fonaubert et al., 1996, Yeemin et al., 2001, Chou et al., 2002, Spurgeon et al., 1998). The largest area of coral reefs with 34 percent of the world's total is hold by Southeast Asia and the region is hence regarded as the global centre of tropical marine biodiversity (Tun et al., 2008). Nevertheless, this marine habitat is in a severe state of degradation and in a report about the level of risks of reefs in Southeast Asia submitted by the World Resource Institute in 2002 it is stated that about 77 percent of Thailand's reefs are threatened by human activities. A main impact of these human activities is significant coral bleaching episodes which have been reported within this area. One species being adversely affected by the depletion of coral ecosystems is the Giant clam (*Tridacnidae*). Giant clams live in close association with coral reef and form an essential component contributing to its natural structure (Basker, 1991). Additionally, to their habitat loss due to coral reef degradation, the Giant clams are threatened by other human generated pressures such as pollution and overfishing. Global warming affects the species due to changes in the sea surface temperature which causes severe threats to individual populations. Consequential, several clam-restocking and stock enhancement projects have been carried out at various locations in the Indo-Pacific. One of those projects initiated in order to protect the species and in attempt to restore their populations takes part around the island of Koh Tao, Thailand. This long term project, *the Giant clam Nursery and Restoration Project*, was started in early 2009 when the local government began working with the Save Koh Tao community group and the Thailand Department of Fisheries. It falls under the management of the Save Koh Tao Group while being guided and supervised by the Prechuap Khiri Khan Coastal Fisheries Research and Development Centre. (Scott, 2009)

A main part of this project involves the nursing of juvenile Giant clams *Tridacna maxima* which are placed within cages in the sea. Once the clams have doubled their size they are transplanted onto natural reef sites around the island; until now this is taking place at the reef around Aow Leuk. Since site selection is critical for the survival of Giant clams, and suitable environmental conditions assist the growth and general condition of stocks, (Teitelbaum et al., 2008, Hart et al., 1998, Hart et al., 1999) the identification of most suitable sites for the reintroduction of Giant clams within the area is essential for the ongoing success of the project (Scott 2009).

To identify and locate the most suitable sites, an ArcGIS model was developed which takes into account the biotic and a-biotic factors out of which the habitat of the Giant clams is composed, namely the type of seabed, the substrate, depth, nitrate and phosphate concentration, temperature, turbidity, and visibility, combined with the presence and level of threats. By validating the result with data on the amount and sizes of clams found, the model acts as a reusable form to identify and locate most suitable sites within other bays around Koh Tao in the future. The named environmental factors, the threats and the amount and sizes of clams have been considered as the criteria on which

the model ultimately rests upon. To determine and locate the suitable sites under consideration of these criteria following research objective and questions were used:

1.1 Research objective and questions

The primary objective of the Giant clam Nursery and Restoration Project is to re-establish the Giant clam (*Tridacna maxima*) populations in the coral reefs around the island of Koh Tao. The objectives of this study are to determine and locate (1) **the most suitable sites for the reintroduction of Giant clams in the bay of Aow Leuk**, and (2) **to determine and locate potential threats to the Giant clams in the bay of Aow Leuk**. In order to reach this objective, a habitat suitability map and a threat map for Giant clams in the area of Aow Leuk will be developed.

Therefore the research questions are as follows:

1. What are the most suitable sites for the reintroduction of Giant clams (*Tridacna maxima*) in the bay of Aow Leuk?
 - a) What is the most suitable habitat for Giant clams in the bay of Aow Leuk according to the criteria?
 - b) What threats to Giant clams occur in the bay of Aow Leuk?
2. Where are the most suitable sites for the reintroduction of Giant clams (*Tridacna maxima*) located in the bay of Aow Leuk?
 - a) Where are the areas with the most suitable habitat for Giant clams in the bay of Aow Leuk located?
 - b) Where are the threats to Giant clams which occur in the area of Aow Leuk bay located?

1.2 Hypothesis

It is expected, that most suitable sites for Giant clams will consist of habitat showing the highest suitability according to the requirements of Giant clams which are set by the different criteria, in combination with the lowest threat pressure to the species. It is therefore expected that most Giant clams will occur in such areas.

Thus:

1. Most suitable sites for the reintroduction of Giant clams will consist of the most suitable habitat for Giant clams in combination with the lowest threat pressure.
 - a) Most suitable habitat will consist of the criteria which mostly comply to the requirements of the Giant clam.
 - b) The threats to Giant clams in Aow Leuk bay will be disturbance and pollution of the water caused by tourists and residential areas.

2. Most suitable sites for the reintroduction of Giant clams will be located along the shores of Aow Leuk bay but farther away from human settlements and buoyancy lines, i.e. where the most suitable habitat is found in combination with a low threat pressure.

a) Most suitable habitat will be located along the coastal shores of Aow Leuk bay.

b) Threats will be located along the coastline and around the buoyancies within the bay.



2. Methods

2.1 Study area Koh Tao

Koh Tao is located at 10° 4' 60 N and 99 ° 52' 0 E (www.traveljournals.net) in the southern Gulf of Thailand as it can be seen in figure 1. The island is part of the province Surat Thani and lies about 74 km² off the mainland. It has a size of approximately 21 km² (Flumerfelt, 1999).

It has a population estimate of about 1400 inhabitants (Scott, 2009) and the population mainly consists of southern Thais, Sino-Thais, Burmese, northern Thais and Western expatriates or foreigners (Flumerfelt, 1999). The major part of the income is based on the fishing sector and tourism; Koh Tao is well known for scuba diving and snorkeling and receives around 320.000 visitors a year (Scott, 2009). The island is composed of mountains and forests, which are surrounded by coconut plantations, and lined with sandy beaches and rocky coves (Flumerfelt, 1999). There are three main villages namely Mae Haad, Haad Sairee and Chalok Ban Kao, with Mae Haad being the commercial centre located on the western side of the island (Flumerfelt, 1999), as can be seen in figure 1.

Monsoon

The region is characterised as a humid subtropical monsoon area and Koh Tao is affected by both the northeast and the southwest monsoons. During the NE monsoon which dominates from mid October until the beginning of December heavy rainfall can be expected (www.kohtaotoday.com). The average annual temperature is 27°C (Flumerfelt, 1999).

History

During the last century the appearance of Koh Tao has changed. The island was used as a penal colony for political prisoners between 1943 and 1945 but got abandoned by the government and people from the neighbour islands started moving in. Coconut farms got established and the islanders started fishing around the island and relying on subsistence gardening (Flumerfelt, 1999). Until the early 1980s the population has grown up to nearly 500 people and around this time the first tourists started visiting the island. In the beginning only day trips were offered from the larger and more developed neighbour islands Koh Pha Ngan and Koh Samui, and tourism developed very slowly. Finally in 1987 the first dive shop opened on Koh Tao. Today the economy of the island is nearly completely reliant on the dive and tourist industry (Flumerfelt, 1999).

Environment

In a report of the World Resources Institute in 2002 (Burke, 2002) the level of threat for the reefs of Koh Tao was estimated to be medium as can be seen in figure 1. The steady growth in tourism and recreational activities leads to obvious increases in the use of coral reefs for tourism. Negative impacts of such tourism activities can affect the coral reefs of the island through human and anchor damage, and garbage accumulation. Further threats related to tourism are wastewater discharge from hotels and resorts, the collection of shell and ornamental fish, and sedimentation and pollution associated with rapid coastal development (Yeemin et al., 2003, Chou et al., 2002). The severe coral

bleaching in 1998 (the first in the Gulf of Thailand) triggered by the 1997-1998 ENSO event resulted in high mortality rates for several coral species, and typhoons caused patchy coral damages in certain reef sites. Despite this pressure there are no protected areas present around Koh Tao (www.UNEP-WCMC.org).

There are however different laws protecting the coral reefs around Koh Tao. Among others the Fisheries Law of 1947, the National Park Act of 1961 and the Enhancement and Conservation of National Environmental Quality Act of 1975 are mainly enforced by the Department of Fisheries, the Department of Marine and Coastal Resources, and the Natural Parks, Wildlife and Plant Conservation Department. As these bodies encounter problems in enforcing the legislation and regulations, agencies, provincial governments, local district administration authorities and the private sector have in recent years undertaken non-regulatory action aimed at improving coral reef conditions through restoration, preventive measures and raising public awareness.



Figure 1: Map of Thailand with the location of Koh Tao. Source: Burke, 2002.

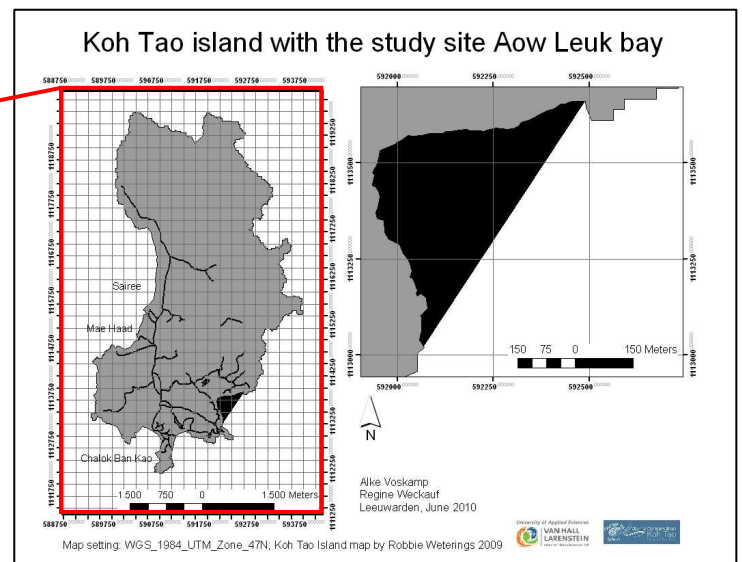


Figure 2: Study area Koh Tao with the indication of the location of the study site Aow Leuk (shown as the black area).

2.2 Study site Aow Leuk


The study site of the research is the bay of Aow Leuk located on the eastern side of Koh Tao, as it can be seen in figure 1. Aow Leuk is characterised by rocky shores to about 4 meters where they turn into a patchy reef with sand bottom and scattered corals that decline in abundance to about 9 meters depth where it turns into a primarily sandy flat bay with a few scattered corals (Chad Scott, pers. comm.). It has a high biodiversity, but relatively low coral coverage (Scott, 2009).

2.3 Study species

Description

The Giant clam (*Tridacna maxima*) is a smaller member of the Tridacnidae family. The species can grow to about 40cm in shell length and the colour of the mantle is extremely variable and ranges from brown to bright blue (Kinch 2002, Isamu 2008). The precise taxonomy and a picture of the species can be seen in table 1.

Table 1: Tridacna Maxima picture and taxonomy, photo taken by C.Scott, 2010.

Giant clam (<i>Tridacna Maxima</i>)	
	<p>Kingdom: Animalia Phylum: Mollusca Class: Bivalvia Order: Veneroida Superfamily: Cardicea Family: Tridacnidae Taxon: Tridacna Maxima (Röding, 1798) Common Name: Small Giant clam</p>

Distribution

Tridacna maxima is the Giant clam species with the widest range, being found in 45 countries from the east coast of Africa to the Red Sea and eastern Polynesia. (Ellis 2000, Wells 1997)

Habitat

Giant clams occur naturally in shallow coral reefs, reef flats and shallow lagoons (www.arkive.org). Since they are able to attach to reefs, rocks or even sand by means of fibrous threads they are also able to live in sandy seabed, coral rubble and on rocks as long as there is shelter close by isolated coral heads or rocks preventing the Giant clam from physical disturbance but still allow enough water movement to prevent siltation and turbidity. Also sea grass beds can be a suitable ground if the turbidity is not too high (Ellis 2000). They live in association with coral reefs and this association makes them an ecologically important part to the health and biodiversity of coral reef where it inhibits the growth of macro algae that can overtake a reef and filters the water from suspended nutrients (Price et al., Munro 1993, Pracuap Khiri Khan CFRDCenter, 2004).

Special requirements:

Depth

The species occurs in depths of 1 to 20 meters (www.arkive.org). A water depth of less than 1 meter or more than 20 meters is lethal for Giant clams. The ideal depth to introduce the Giant clams out of the nursery cages into the open sea lies between 5 to 10 meters (Ellis, 2000).

Temperature

The optimal water temperature for Giant clams is not precisely stated but they appear to grow best in water temperatures of 25 to 30 degrees Celsius (Ellis, 2000, Isamu, 2008). They are able to stand

higher temperatures for a short period of time of 4 to 6 weeks; prolonged exposure to higher temperatures will cause stress and lower the growth rate and can cause more serious effects as bleaching of the mantle and even death (Drone et al., 2003, Ellis, 2000). This temperature sensibility is caused by the close symbiosis they form with zooxanthellae which are highly dependent on sunlight and sensible to changes in water temperature (Pinet, 2004). The example of the El Nino event of 1998 in the Gulf of Thailand shows that most of the corals, which live in the same symbiosis to zooxanthellae as clams, bleached and died following a rise in seawater temperature to 33 degrees (Chad Scott, pers comm.). Normal seawater temperature in tropical waters ranges from 25 to 28 degrees Celsius in colder months and from 28.8 to 32 degrees Celsius in warmer months (Mohsin et al, 1996).

Turbidity

Giant clams are dependent on photosynthesis for their nutrition and therefore require clear water with low turbidity to get enough sun radiation (Ellis, 2000). Turbidity depends on other factors as water quality and water movement to a great extent and changes according to them. Values beneath 25 FTU (Formazine Turbidity Unit) are considered as of a water quality as “clear ponds” (www.h2ou.com).

Nitrate concentration

Nitrate has an indirect influence on Giant clams since high levels of nitrate stimulate the growth of plankton and water weeds (www.h2ou.com). Visibility and turbidity are affected by nitrogen concentration as the excessive growth of algae will lead to an increase in turbidity and decrease in visibility. For marine animals, a maximum concentration of 20 mg NO₃-N/l may in general be acceptable (www.ncbi.nlm.nih.gov). From a certain level nitrate starts to be toxic for marine animals. As the zooxanthellae of the Giant clams need nitrate for their metabolism a rise in nitrate concentration leads to a significant increase in the population density of zooxanthelle (Marubini et al., 1996). Since nitrate is not a limiting criterion for metabolism, as phosphorus is generally the limiting criterion in water bodies, there is no minimum value for the criterion nitrate and every value beneath 20 mg NO₃-N/l may be taken as a suitable concentration (www.h2ou.com).

Phosphate concentration

Giant clams have a limited access to the inorganic phosphate in seawater (Belda et al., 1995). Most phosphate is bound within plankton. The plankton is caught by corals and clams to take in the phosphate and other substances like nitrogen, trace elements and energy (www.aquacare.de). Therefore phosphate dissolved in water does not have a direct influence on Giant clams. Like nitrate too much phosphate in seawater stimulates algae and water weeds to grow and use up large amounts of oxygen (www.h2ou.com). In addition, high phosphate can significantly inhibit calcification in calcareous organisms (kb.marinedepot.com). The maximum level of phosphate in sea water should not exceed 0.5 mg/l in order to not slow down the calcification of the Giant clam (Braley et al., 1992).

Life cycle

The species belongs to the protandric functional hermaphrodites which reproduce by broadcast spawning. The fecundity of the Giant clam is very high (Isamu, 2008).

After the swimming phase the Giant clam gets into the planktonic stage. During this stage the Giant clam inhabits the open ocean for one week before they settle into the substrate followed by the first Byssal attachment (www.arkive.org). For the first several months the foot stays as an effective locomotory organ (Isamu 2008). It reaches full maturity at a size of 11 to 13cm at an age of 5 to 6

years and becomes sessile. Adult Giant clams are completely sessile and are not able to move from their position (www.arkive.org). Giant clams nourish partly through an inhalant siphon which they use to filter seawater for planktonic food (Isamu, 2008). They also get nutrients through the symbiotic relationship with zooxanthelle (*Symbiodinium microadriaticum*) algae. Those algae live in the mantle and support the Giant clam with complex sugars, amino acids and fatty acids, through photosynthesis (Pinet, 2004).

Threats

Giant clams are exposed to a number of human generated threats, such as pollution and habitat loss due to coral reef degradation by for example climate change and unmanaged commercial fisheries. Land-based activities that cause siltation on coral reefs, including deforestation as a result of logging, mining and agricultural development, have been reported as major sources of pollution affecting Giant clam habitat (Blidberg et al., 1999, Wells, 1997). Although fishing by foreign vessels caused much of the depletion of the largest species, Giant clams are now mostly under pressure from subsistence and semi-commercial fishers. Additionally almost all Giant clam populations are exposed to harvest by free divers and not only regarded as a highly valuable food source but also being harvested for their shells and for live export for the marine aquarium trade, with *Tridacna maxima* highly sought after for its colours (Gilbert et al., 2006, Teitelbaum et al., 2008).

Because Giant clams reach a harvestable size before reaching maturity, there is a high probability that individuals will be collected before they have the chance to reproduce (Wells, 1997). Due to these pressures, and their depletion and slow recovery from overfishing, Giant clams are listed under Annex II of CITES (1983), and are considered vulnerable under the IUCN red list of threatened species (1996) (Teitelbaum et al., 2008, UNEP-WCMC Species Database, 2010).

2.4 Study population

As study population all *Tridacna maxima* occurring in the study site of Aow Leuk Bay will be regarded. This includes all Giant clams which occur naturally in Aow Leuk bay and Giant clams which were already introduced in Aow Leuk bay.

2.5 Data Sampling

Prior to the data collection the seabed types occurring in the research site in the bay of Aow Leuk and its boundary were determined by use of a Landuse map (2001) created by Robbie Weterings. To a large extent the boundary of the site is naturally given by the coast, the boundary to the sea was determined by identifying the start of the deep sea and creating a straight line parallel to the beach presenting the seaside boundary of the research site.

The different seabed types within the site were identified and vector layers for each seabed type created using the editor tool of ArcGIS. The size of the site and also of each seabed type was calculated within the attribute table.

Sample size calculation

To calculate the necessary sample size which had to be taken within the site, the seabed sizes and the average amount of Giant clams per hectare which are found around Koh Tao were used.

As there is an average of 107 Giant clams per 1 ha found to be around Koh Tao (Scott, 2009) the average amount of clams is given with 1599 clams for the study site Aow Leuk which measures 14.939 ha (149394 m²).

The total sample size was determined by the following formula (Hill et al., 2006):

$$n = \left(\frac{Z \sqrt{f \cdot (100 - f)}}{a} \right)^2 \quad n = \left(\frac{1,96 \sqrt{50 \cdot (100 - 50)}}{10} \right)^2$$

by which a sample size of **n = 97 clams** was calculated under consideration of a 95% Confidence level and a $\pm 10\%$ precision where Z is the Confidence interval, a is the level of precision and f is the percentage of the sample containing the species.

To cover this sample size of 97 clams an area size of 9056m² (=0.906562ha) had to be sampled. It was chosen to cover 1 sample spot by a belt of 5x45m leading to an area of 225m² for each spot. Hence 40 sample spots had to be taken to cover the whole sample area.

For the different seabed types the sample sizes were determined by the following equation:

$$n_h = (N_h / N) * m \quad \text{e.g Reef } n_{\text{reef}} = (381 / 1599) * 40 = 9.53$$

where n_h is the sample size for seabed h , N_h is the average amount of clams for seabed h , N is total average amount of clams, and m is the total sample size ($m=40$). All calculated average amounts of clams, their applying sample sizes, and the resulting amount of sample spots per seabed types have been calculated and can be seen in table2.

Table 2: Average amount of clams and number of sample spots per seabed type in the study site of Aow Leuk.

Seabed	Area Size (m2)	Percent of total area	Average amount clams (0,0107/m2)	Sample Size
Reef	35624	23.8	381	10
Rubble	43243	28.9	463	12
Rock	31639	21.2	339	8
DeepSea	8885	5.9	95	2
Settlement	1127	0.8	12	0
Sand	28605	19.1	306	8
CoconutFarm	271	0.2	3	0
Total	149394	100	1599	40

Sampling method

Stratified random sampling was chosen as sampling method to equalize the amount of samples between the different seabed types and consequently make them comparable. The Hawth tool (Random Point Generation) was used to disperse the samples randomly over the research site, the seabed types respectively, which can be seen in figure 3.

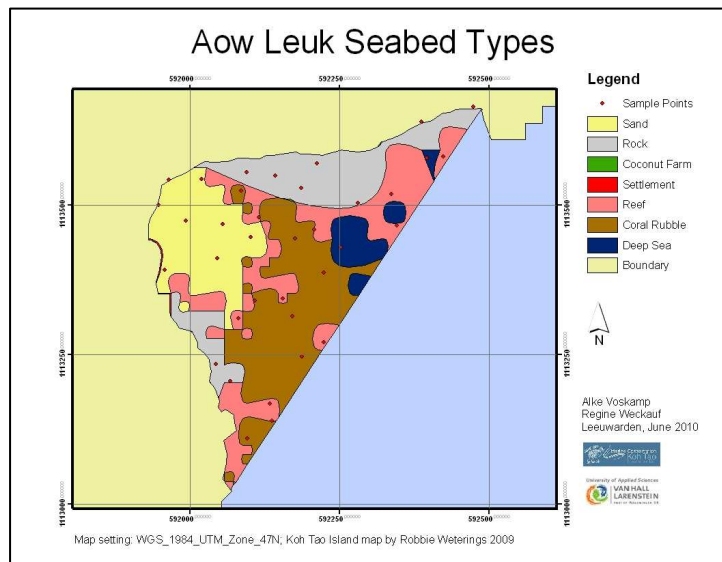


Figure 3: Seabed types and sampling points in the bay of Aow Leuk.

At each of the 40 sample spots the Belt Transect Method was chosen for collecting the data. This method is widely used in marine research where a reference line is laid out on the seafloor and data is taken in reference to that line. A visualisation of a belt transect can be found in Appendix II. This method allowed sampling of a large amount of m² in one dive as the chosen 45x5m transect already provided for 225m², leading to a total examined area of 9000 m² in 40 transects.

Additional data on threats which are present in the bay of Aow Leuk and can have an influence on the Giant clams were collected using the method of qualitative research by applying knowledge of locals and experts in the field of marine biology.

Trial data collection

The time required to cover one sample spot was predetermined in a trial data collection to be 20 minutes. With all seabed types regarded as being equally time consuming the trial data collection was carried out within the study site of Aow Leuk on a randomly chosen transect by the two researches. Under consideration of the time restriction given by the air supply of the tanks it was estimated that during one dive 4 sample spots, transects respectively, can be covered. Thus a minimum of 10 dives would be needed to successfully carry out the data collection; this number varied due to unknown factors as changing weather conditions, bad visibility, equipment failure, navigation problems, any other hazards applying to diving, and the availability of volunteers, as well as the experience of the individual diver and the regarding buddy team.

As only one dive could be followed per day the time of data collection was calculated to a minimum of 10 days, keeping in mind that these days could not be consecutive days as this is dependent on the dive site selection of the day, the availability of equipment, and the capacity of the boat.

Time frame

The sampling was done over the course of 7 weeks during the day in the months April and May which represent the dry season.

2.6 Data collection

To identify the most suitable sites for Giant clams in Aow Leuk, data was collected on the environmental factors, the occurring threats and on the abundance of clams. The details of these criteria can be seen in figure 4.

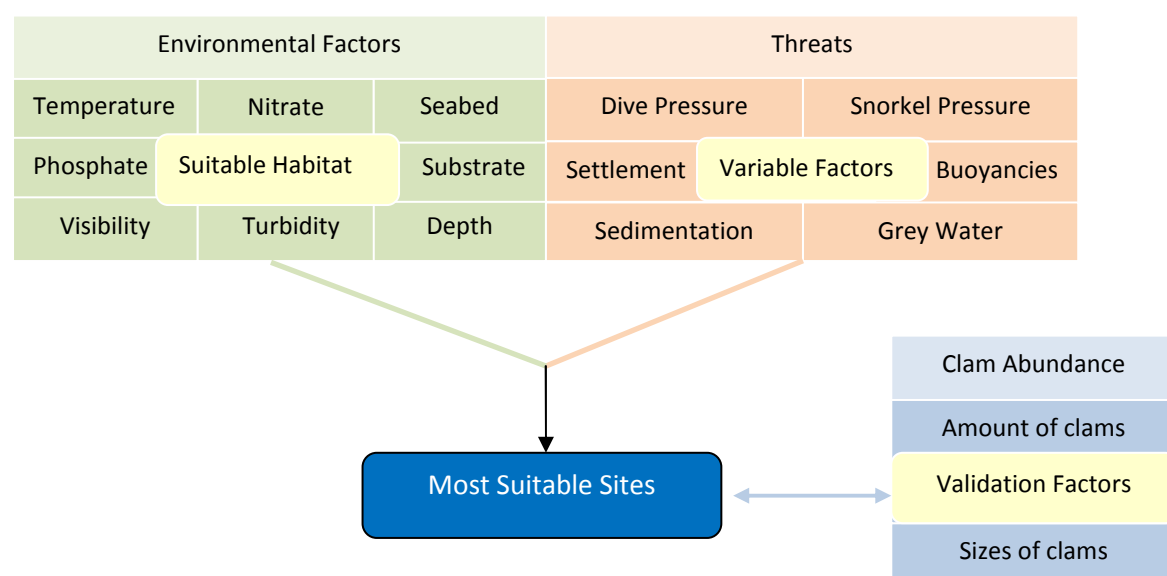


Figure 4: Collected data to identify most suitable sites for Giant clams in Aow Leuk bay.

In the following the method of data collection is explained for the criteria Clam abundance, Environmental factors, and threats.

Clam abundance & Environmental factors

To collect the data on clam abundance and environmental factors in the study site, certain steps had to be followed.

Navigation

To find the individual sample points in the site the coordinates for the spots were taken from ArcGIS and saved into the GPS (Garmin eTrex H). The coordinate of the sample spot which was approached first was taken as reference to navigate to the following sample spots to prevent from errors in accuracy due to the difficulty to navigate on water. These further spots were found by calculating the distance and its bearing in relation to its previous spot and navigating there by counting kick cycles and use of a compass as can be seen in figure 5.

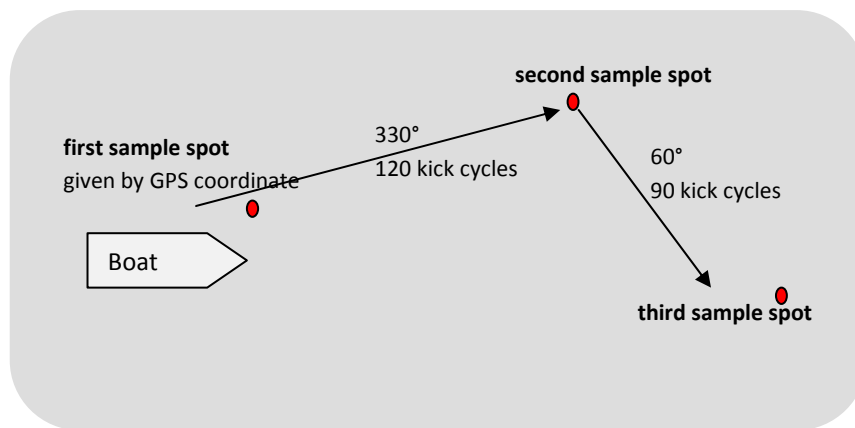


Figure 5: Visualisation of Navigation to fictional sample spots.

For each sample the clam abundance and the environmental factors were taken, as it can be seen in table 3.

Table 3: Collected data on the criteria clam abundance and environmental factors in the study site.

Collected data	Measurements taken
Clam abundance	<ul style="list-style-type: none"> - Amount of clams found - Height of each clam - Width of each clam - Substrate for each clam
Environmental factors	<ul style="list-style-type: none"> - Visibility - Depth - Temperature

	<ul style="list-style-type: none"> - Substrate at begin and end of transect <p><i>Water quality:</i></p> <ul style="list-style-type: none"> - Turbidity - Phosphate - Nitrate
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Clam number, size, and its substrate

On each transect the number of clams was counted. For each clam its height, widths and the substrate it is attached to were noted. The height and width are measured by holding a ruler onto the broadest and the longest part of the clam. The substrate was noted for the place on which the clam settled, the substrate of the immediate surrounding was not considered. The substrate was defined by the method used by the Ecological Monitoring program (hereafter referred to as EMP) (see Appendix VI).

The other environmental factors which have been recorded on the different transects were visibility, depth, temperature, water quality, and the substrate at the start and the end of the transect.

Visibility

The visibility was taken for every transect using a secci disc.

Depth

Depth was taken with a diving computer and noted down. The measurements for depth were taken at the start and at the end point of the transect.

Temperature

Temperature was taken with a diving computer and noted down. The temperature was measured once per transect.

Water quality

For the environmental factors turbidity, nitrate and phosphate a water sample was taken on each transect. Those water samples have been tested afterwards on concentrations of phosphate, nitrate and the turbidity by using a colorimeter machine.

Substrate

The substrate was noted down at the start and the end point of the transect by use of the EMP method (see Appendix II).

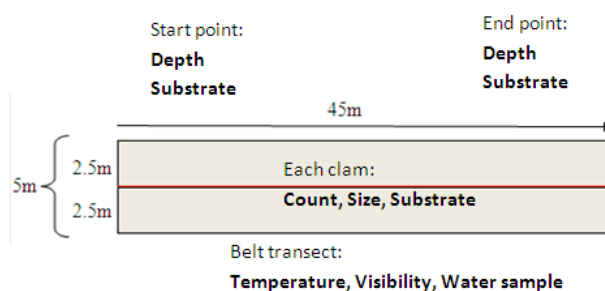


Figure 6: Visualisation of the collected data and its location of collection on the belt transect.

As volunteers were taking part in the data collection, a list of data collection steps, the needed equipment, the visualisation of the Belt transect, and the data to collect was developed which can be found in Appendix II.

Seabed

The different seabed types in the research site were assessed by constructing a Marine use map in ArcGIS by aid of the Landuse map (2001) and visually defining the seabed types.

This Marine use map was used as base map to project the other environmental factors, the abundance of clams and the occurring threats to the Giant clams in the bay.

Threat

The criterion Threat was determined by interviewing individuals knowledgeable about the bay of Aow Leuk; Several Dive Instructors, individuals belonging to the Save Koh Tao conservation group, and the project coordinator of the New Heaven Conservation Courses were asked to point out the relevant threats. Additionally information obtained from a report on Threats around Koh Tao (Weterings, 2009) were used. For the zones of sedimentation, diving and snorkeling a zoning map was developed which was then manually transferred in the Marine use map. For the threats buoyancies line, settlement, and grey water outlet GPS coordinates of their location in the bay were taken and loaded into the map.

2.7 Data preparation

The data which was collected during the field work was stored in an excel file. The file contains the information about found substrate, temperature, depth, turbidity, visibility, nitrate, phosphate, amount of clams and clam size. From this data base separate excel tables were developed for each criterion. Each table contains the recorded values of the criteria per transect, and its coordinates. From these excel tables raster? layers for each criterion were produced within ArcGIS 9.3. For this the sample spot locations were loaded into the program and via the export data function copied eight times. For each criterion its excel table was joined with the join table tool to one sample location layer and the resulting layer (containing the information of the sample spot locations and the recorded values) was named after this criterion. Resulting layers were created within ArcGIS for the criteria substrate, temperature, depth, turbidity, visibility, nitrate, phosphate, amount of clams and clam size. The layers of amount of clams and clam size layer will be used later on for the validation of the GIS model. The other layers (i.e. substrate, temperature, depth, turbidity, visibility, nitrate, phosphate) are used to conduct a Multi Criteria Analysis (hereafter referred to as MCA). To prepare the layers of substrate, temperature, depth, turbidity, visibility, nitrate, and phosphate for the MCA, they were interpolated. The resulting values were reclassified according to the ranking values chosen in the MCA. For the interpolation the ArcGIS Spline tool was used as this produced the results which fitted visually best to the natural shape of the bay. (Chad Scott, pers. comm.) The Spline tool interpolates a surface from points to polygon by using the exact recorded values. For the criteria seabed the Landuse map (2001) was used. The shape of Aow Leuk has been clipped out of the Landuse map and the different occurring seabed types have been visually defined. The information about the occurring threats was added to the map by visual locating and adding their coordinates. An individual layer was produced for buoyancy lines, settlement, grey water, sedimentation, diving and snorkeling. For the buoyancy lines, settlement and grey water a buffer

was created around the source of the threat since these threats do not only affect the exact place they occur but also the surrounding area. The buffers around the buoyancy lines were set to 20 meters as the disturbance by divers and by the buoyancy line itself occurs locally around the line. The buffers for the settlement and the grey water were set to a 50 meter radius as their influence on the water spreads further.

2.8 Data analysis – Multi Criteria Analysis

To analyse the data a Multi Criteria Analysis was conducted, which is an analysis facilitating a ranking of large numbers of criteria (Carsjens et al., 2002). This approach allows several criteria to be considered at one time and hence assigns the possible habitat suitability classes based on how closely each of them meets those criteria. Since the 1990s, the combination of MCA and GIS has been promoted for use in solving spatial problems in urban planning, forest conservation and site determination (Phua et al., 2005). Within the GIS of this study the MCA presents a visualisation of the classes by providing a picture of the suitability across the study site Aow Leuk.

The criteria have been selected by literature review and personal communication with the Project Coordinator and other experienced individuals.

Further individual weights have been assigned by this method to each criterion to calculate weighted summations distributed over the study site and guarantee a more objective way of assessing the suitability by breaking the levels in smaller portions (Saaty, 2008).

The eight criteria which were used for the MCA of the suitable habitat map are:

1. Seabed (Sand, Rock, Reef, Rubble, Deep Sea)
2. Depth (m)
3. Temperature(C°)
4. Visibility (m)
5. Nitrate
6. Phosphate
7. Turbidity (m)
8. Substrate Clam (Sand, Hard Coral, Coral rubble, Rock, Silt)

A ninth criteria was added to identify the most suitable sites in the bay.

9. Furthermore the relevant threats which occur in the study site have been taken into account and were later added to the MCA to identify the most suitable sites. Threat (Dive Pressure, Grey Water, Snorkelling, Sedimentation, Settlement, Buoyancies)

To conduct the MCA the different criteria need to be ranked individually, the ranking will be given per criteria in the following.

2.8.1 Ranking of the criteria

The ranking for the different criteria is done by using their limiting values, in relation to the positive or negative effect on the Giant clam. For each criterion the points are awarded according to the suitability of the value. The ranking is subdivided in “Most suitable” (3), “Suitable” (2), “Less suitable” (1) and “Not suitable” (0). For each criterion the recorded values which are lethal for the Giant clams are ranked with 0 (“Not suitable”).

A criterion which is ranked as “Not suitable” will cause that the whole area in which it occurs will be ranked with 0 points in total. That means that this area falls directly into the class “Not suitable”. For the other areas, which achieved a “Less suitable” to “Most suitable” (1 to 3 points) per criterion, the reached points will be summed up to a final score. This means that the more points an area scores during the MCA the higher is the suitability of this area as a site for the introduction of Giant clams.

The MCA was used two times in total. First, without taking the threats into account, to develop the “Most suitable” Habitat map for the Giant clams. Second, taking into account the environmental factors and the threats, to develop the “Most suitable” Sites for reintroduction of Giant clam map.

During the first use of the MCA for the “Most suitable” habitat map the maximum score which is possible to reach is 35 points. The minimum amount is 16 points. The final ranking of the total score reached by the different areas is as follows:

30 - 35 points = “Most suitable”

23 - 29 points = “Suitable”

16 – 22 points = “Less suitable”

≤ 15 points = “Not suitable”

After finishing the MCA for the “Most suitable” habitat, the same MCA is used again but now the threats are included. With this MCA the “most suitable” sites map is produced. As threats give a highest possible amount of 3 points and a lowest possible amount of 1 point the maximum score which is possible to reach is 38 points. The minimum amount is 17 points. The ranking for the second MCA looks as follows:

33 - 38 points = “Most suitable”

25 - 32 points = “Suitable”

17 – 24 points = “Less suitable”

≤ 16 points = “Not suitable”

The MCA model is generated to make it applicable to any bay around Koh Tao. Therefore it generally measures the suitability of an area for the reintroduction of Giant clams. That makes it possible that no area in the bay of Aow Leuk will be awarded with the maximum number of 35 points (100%). The

possible minimum and maximum amount of points which can be reached for each criterion can be seen in table 4:

Table 4: Maximum and minimum amount of points which can be reached for each criterion in the first MCA for the “Most suitable” habitat and the second MCA for “Most suitable” sites.

1st MCA	Seabed	Depth	Temperature	Visibility	Nitrate	Phosphate	Turbidity	Substrate	Total possible Points
Max	9	6	6	3	2	3	3	3	35
Min	3	3	3	1	2	3	1	0	16

2nd MCA	Seabed	Depth	Temperature	Visibility	Nitrate	Phosphate	Turbidity	Substrate	Threats	Total possible Points
Max	9	6	6	3	2	3	3	3	3	38
Min	3	3	3	1	2	3	1	0	1	17

The following table (Table 6) shows the MCA, taking into account the individual weighting of the criteria and the points given for each value per criterion. More detailed information on each criterion and its applied weights can be found in the Appendix (VII).

Table 5: MCA criteria for assessing suitable habitat and sites of Giant clams in the bay of Aow Leuk.

Criteria	Seabed		Depth (m)		Temperature°C		Phosphate(mg/l)		Nitrate(m/l)		Substrate		Visibility(m)		Turbidity(FTU)		Threats	
Weighting	3		2		2		1		1		1		1		1		1	
	Values	Pts.	Values	Pts.	Values	Pts.	Values	Pts.	Values	Pts.	Values	Pts.	Values	Pts.	Values	Pts.	Values	Pts.
	Deep Sea	0	0 - 1	0	≤ 22	0	< 0,5	3	< 20	2	Silt	1	0	0	0-5	3	Zone: Diving, Snorkeling, Sedimentation	1
	Sand > 5	0	1 - 4	1	21-27	1	≥ 0,5	0	≥ 20	0	Rock	2	0-1	1	5-10	2	Buffer: Grey water, Buoyancies, Settlement	2
	Coral Rubble > 5	0	4 - 5	2	28	2					Hard Coral	2	2-6	2	10-25	1	No buffer or Zone	3
	Sand < 5	2	5-10	3	29-30	3					Coral Rubble	3	≥ 7	3	≥ 25	0		
	Coral Rubble < 5	2	10-11	2	31	2					Sand	3						
	Rock	2	12-20	1	32	1												
	Reef	3	>20	0	≥ 33	0												

The resulting GIS model for the selection of "Most suitable" Sites for the reintroduction of Giant clam was validated to test its effectiveness. The criterion of clam abundance was chosen for validation and the following factors used:

1. The found amounts of Giant clams (*Tridacna maxima*)
2. The size of the found Giant clams

2.8.2 Validation of the model

After conducting the MCA by using the program ArcGIS 9.3 the resulting model needs to be validated to test if the model functions correctly. This is done by use of the collected data on the abundance and the size of the Giant clams. The layers which contain the information about the amount of clams and the clam size are loaded into the final map. The results of the MCA are compared to the findings about the clams and show if the highest amount of clams and the largest clams are found within the areas classified as "Most suitable" , and if there are no clams in the areas which have been found as "Not suitable" (Lethal). To produce those layers and to make the MCA results and the two chosen factors for validation better comparable also these two factors "Average Amount Clams" and "Clam size" were ranked which can be seen in table 7.

Table 6: Ranking of the criteria clam size and clam amount for the validation of the model.

Criteria	Average Amount Clams		Clam size (cm)	
Weighting	2		1	
	Values		Values	
	0 -2	1	≤ 11	1
	3 - 10	2	12	2
	≥ 10	3	≥ 13	3

3. Results

The following paragraph shows the results which have been found during the study. The connection of the resulting maps can be seen in figure 7.. Figure 8 shows the map of most suitable habitat in Aow Leuk bay, figure 9 the map of threats occurring in the study site. In figure 10 the final MCA result is given, including the environmental factors as well as the threats. This map was dissolved to classify the most suitable sites for the reintroduction of Giant clam, the map can be seen in figure 11. Table 7 holds information about the individual scores of the highest ranked sites which are subsequently visualised in the map shown by figure 12. Figure 13 shows the validation of the GIS model. Detailed maps for the distribution of the individual factors can be seen in Appendix VI.

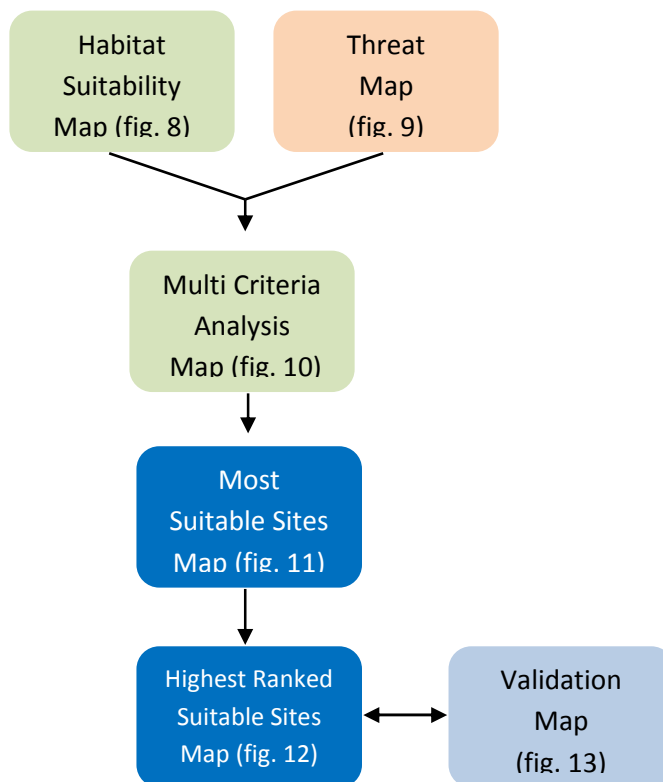


Figure 7: Visualisation of the connection between the resulting maps of the study.

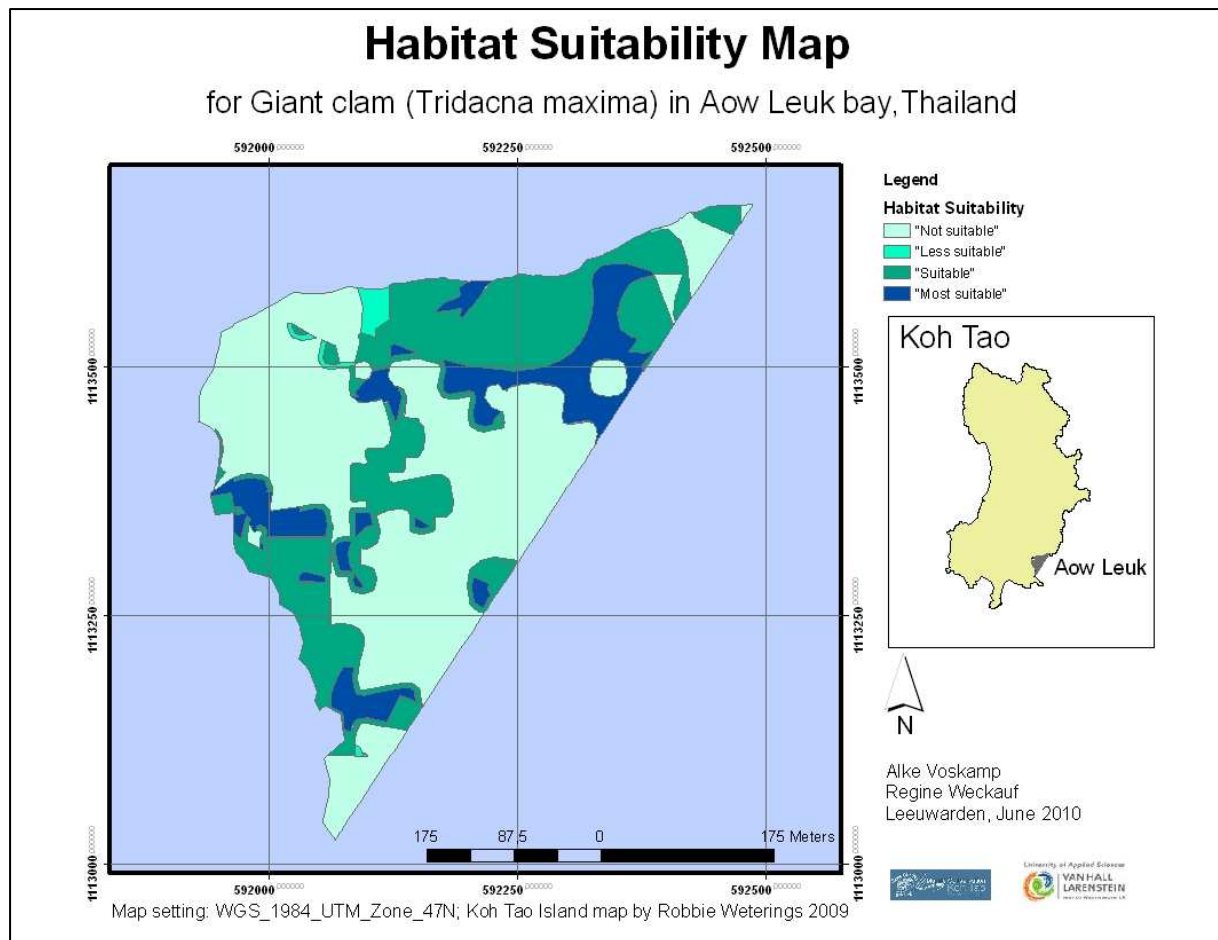


Figure 8: Map of the Habitat Suitability, for Giant clam (*Tridacna maxima*) Aow Leuk bay, Koh Tao, Thailand.

For the MCA the suitability of the Giant clam habitat has been divided into four classes "Not suitable", "Less suitable", "Suitable" and "Most suitable" (see MCA for ranking of points). All four suitability classes have been found within the bay of Aow Leuk. The "Most suitable" and "Suitable" habitat was found along in? the reef areas and the coastal shores on both sides of the bay. The "Not suitable" habitat was mainly found in the sandy areas towards the middle of the bay and along the sandy shores. The position of the different suitability classes of the Giant clam habitat within the bay and their sizes can be seen in figure 8.

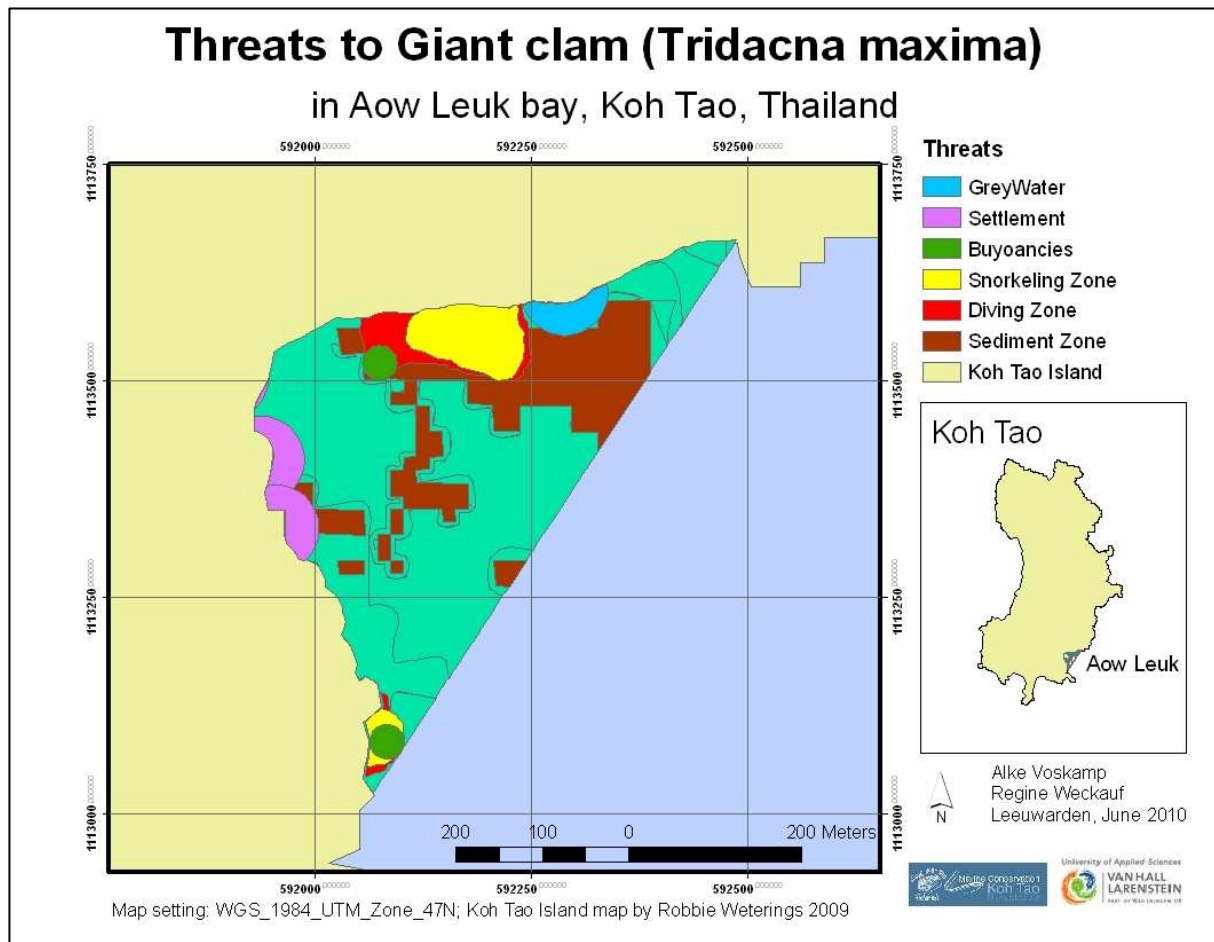


Figure 9: Map showing the threats for Giant clams (*Tridacna Maxima*), within Aow Leuk bay, Koh Tao, Thailand.

The different threats which occur in the bay are the settlement areas, buoyancy lines, sediment, diving and snorkeling zones, and a grey water outlet. The settlement areas and the grey water outlet are located along the coast of the bay, the diving and snorkeling zones are located in the coral reef areas along the coastal shores on both sides of the bay. The buoyancy lines are located within the coral reef areas close to the diving zones, and the sediment occurs mostly towards the middle of the bay within the sandy areas. The positions of the found threats are shown in the threat map which can be seen in figure 9.

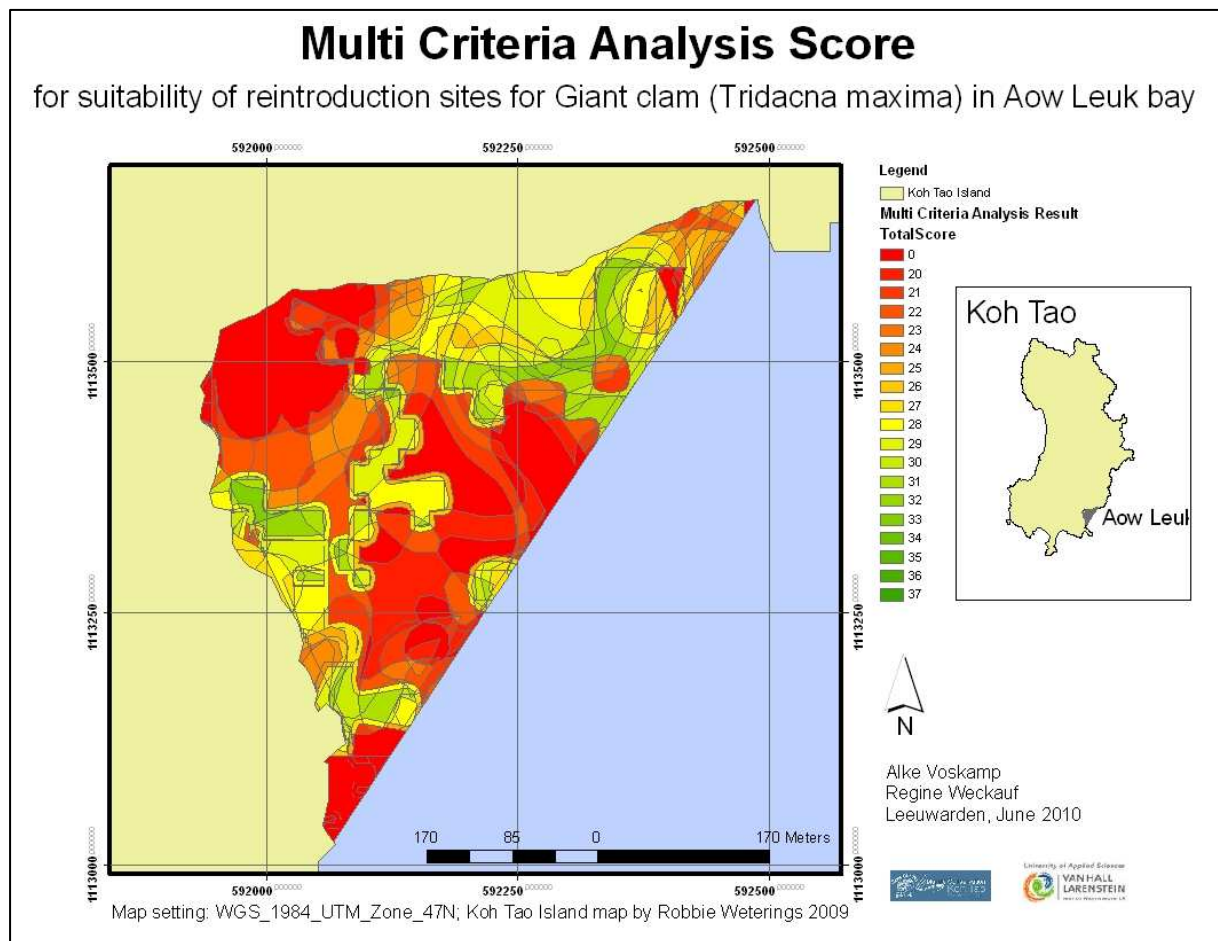


Figure 10: Map of the Multi Criteria Analysis Score, for the suitability of sites for reintroduction of Giant clam (*Tridacna maxima*) Aow Leuk bay, Koh Tao, Thailand.

The suitable sites for reintroduction for Giant clam in Aow Leuk bay have scored between 0 to 37 points, out of the possible 38 points set by the MCA. Most sites scored 16 points or less what means they are classified as “Not suitable” for Giant clams and are therefore regarded as lethal to the species. Very few sites scored between 17 to 24 points “Less suitable”, or more than 32 points “Most suitable”. The rest of the sites scored between 24 and 32 points “Suitable”. The maximum score which was reached during the MCA were 37 points. The results of the MCA and the distribution of the points can be seen in figure 10.

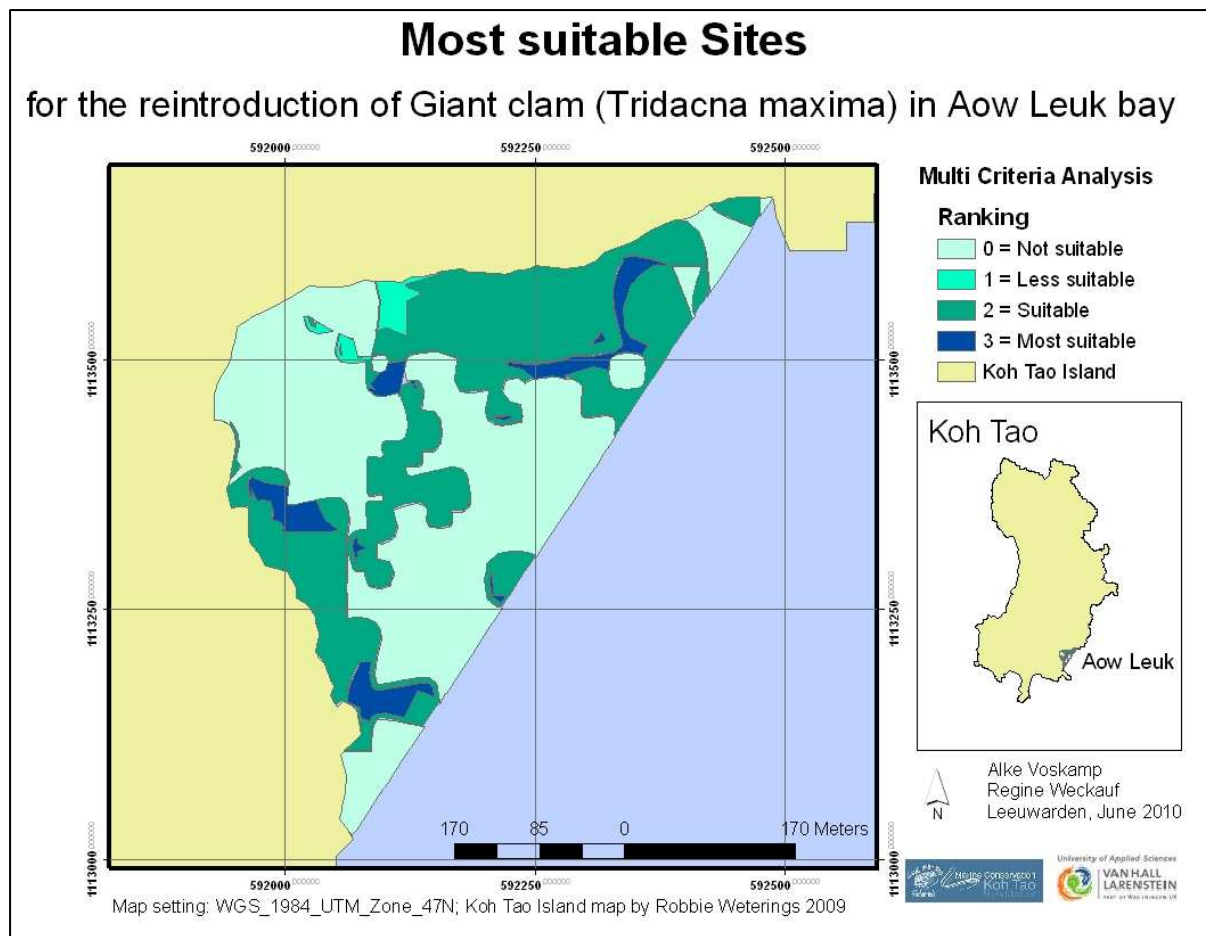


Figure 11: Map showing the most suitable sites for the reintroduction of Giant clams (*Tridacna maxima*) Aow Leuk, Koh Tao, Thailand.

To appoint the most suitable sites for the reintroduction, the habitat suitability map (figure 8) and the threat map (figure 9) were combined. The result can be seen in figure 11. Of the total investigated area (149 394 m²) 53.1 percent (79328.2 m²) of the bay have been found to be “Not suitable”, 1.7 percent (2539.7 m²) to be “Less suitable”, 39.7 percent (57155.7 m²) “Suitable” and 5.5 percent (8126.67m²) “Most suitable”. The most suitable sites for the reintroduction of the Giant clams are located along the coastal shores of Aow Leuk bay and around the reef areas on both sides of the bay.

Table 7: Score table for the five highest ranked sites for reintroduction of Giant clams.

Criteria	Temperature	Threat	Seabed	Substrate	Phosphate	Nitrate	Turbidity	Visibility	Depth	Total Score	Resulting Rank of the Site
Weighting	2	1	3	1	1	1	1	1	2		
	Points	Points	Points	Points	Points	Points	Points	Points	Points		
Area 1	6	3	9	3	3	2	2	3	6	37	1st
Area 2	6	3	9	2	3	2	2	3	6	36	2nd
Area 2	6	3	9	3	3	2	1	3	6	36	2nd
Area 2	6	2	9	3	3	2	2	3	6	36	2nd
Area 3	6	1	9	2	3	2	3	3	6	35	3rd

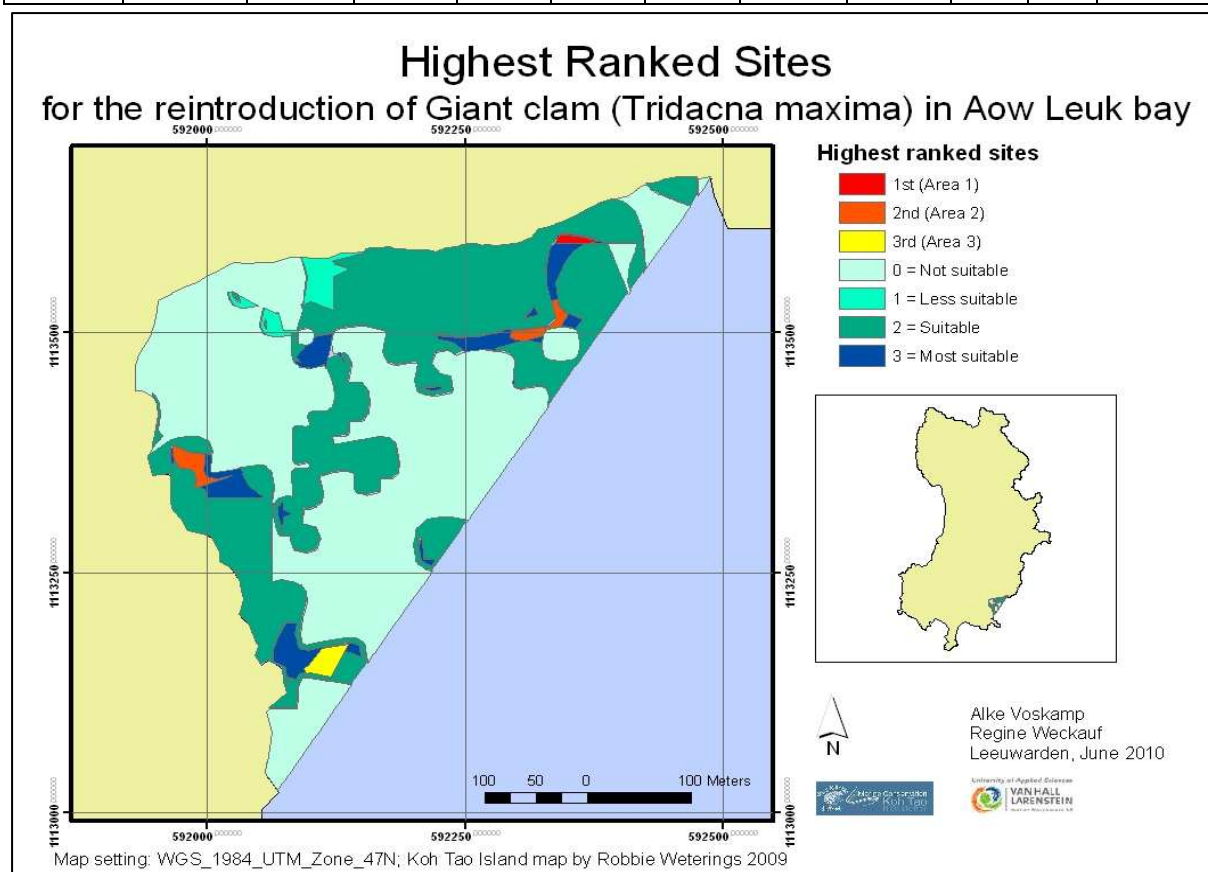


Figure 12: Map showing the location of the three highest scored sites, for the reintroduction of Giant clams (*Tridacna maxima*), in Aow Leuk bay, Thailand.

The positions of the three highest scored sites are shown on the map in figure 2. As it can be seen in the map, these sites lie in the “Most suitable” habitat areas around the reefs on both sides of the bay. The scores for the individual criteria of those areas are shown in table 7. All three areas reached the highest possible amount of points for the criteria temperature, seabed, phosphate, nitrate,

visibility and depth. They only differ little for the criteria of substrate, turbidity and the occurrence of threats.

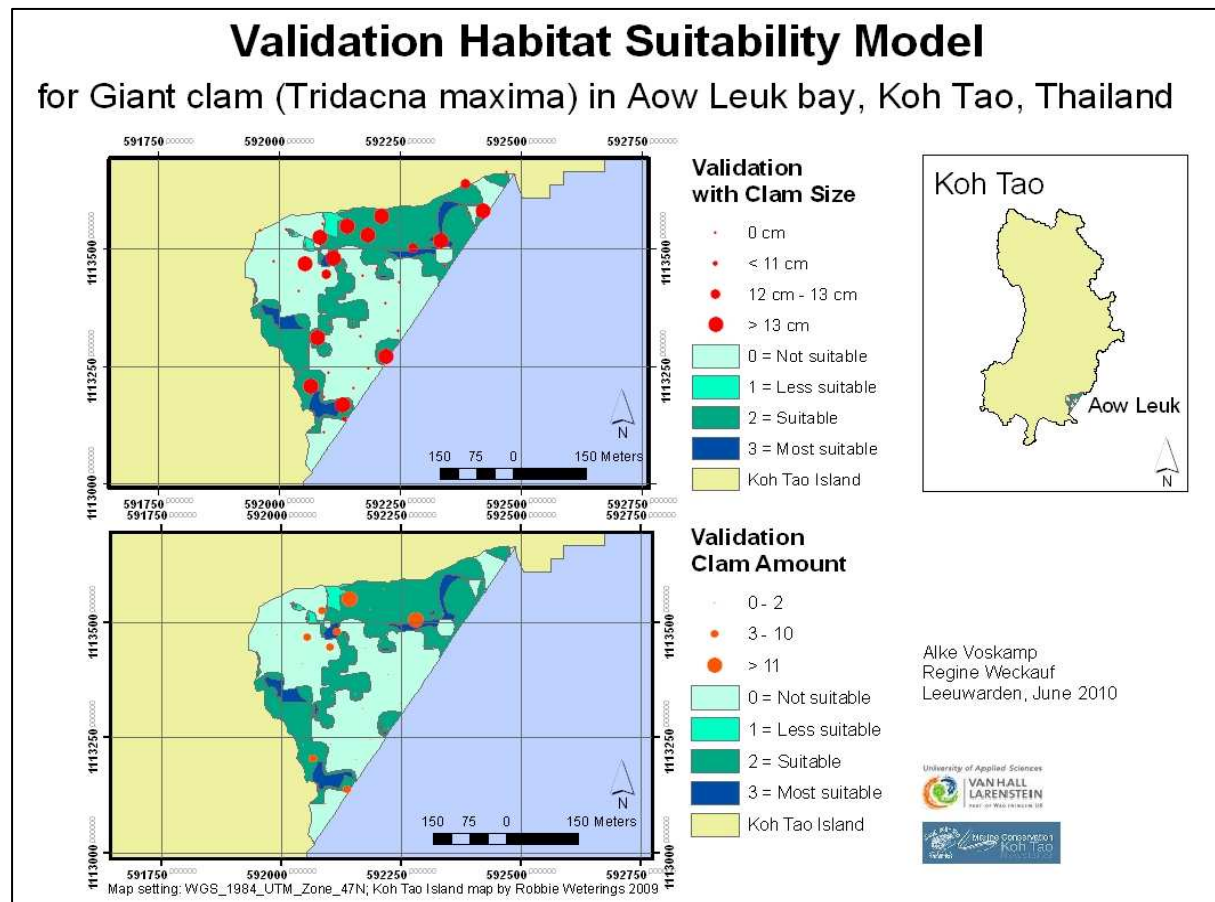


Figure 13: Map showing the validation of the Suitable Sites Model for Giant clams (*Tridacna Maxima*) Aow Leuk, Koh Tao, Thailand.

After accomplishing the Multi Criteria Analysis the model has been validated by using the data on the amounts and sizes of the found Giant clams within the area of Aow Leuk bay. The highest amounts of Giant clams have been found within the areas which have been classified as “Suitable” and “Most suitable” sites during the MCA. Also most of the largest giant clams have been found within those two classes. This shows that the developed model does function as expected when used under the given circumstances. The found amounts and sizes of the Giant clams and the position of those findings can be seen on the map within figure 13.



4. Discussion

Biological

The results show that only 5.5 percent of the study site can be regarded as “Most suitable” sites, and 39.7 percent as “Suitable sites” for the reintroduction of Giant clams. The distribution of the seabed in the bay however gives a percentage of almost 80 percent of habitat that was considered to be suitable habitat in literature, namely reef, coral rubble and sand (Ellis, 2000). This shows that other criteria as environmental factors and relevant threats have a considerable effect on the habitat of a species which conforms to the definition of habitat by Corsi et al. 2000: “Habitat has been defined either as a place or area where a species lives and/or as the type of environment where a species lives, either actually or potentially.” In addition, when sand forms an entirely seabed type it may not be regarded as suitable habitat after all, but it should rather be regarded as suitable habitat that occurs only locally as a substrate where the clam can attach to. This may be confirmed by the findings that “No suitable” habitat was found in the sandy areas towards the middle of the bay and along the sandier parts adjacent to the coast, but however, it was discovered that clams lived on the sand close to the reef. Also rock, which was not particularly stated as suitable habitat by literature was found to be suitable habitat for clams when located close to reefs (Ellis, 2002, Gilbert, 2006, Hart, 1998, 1999, Munro, 1993, Teitelbaum, 2008, Wells, 1997, Weterings, 2009). This could be explained by the fact that these areas still consist of small reef fragments and rocks which provide sufficient shelter for the clams. It may also be that some sample points where clams are recorded for, are indicated in a “No suitable” habitat as the GPS coordinates fall into this area, but the transect of 45 m runs to a great extent into habitat classified as suitable.

When combining the suitable habitat classes of the bay with the relevant threats, it can be seen that the threat sedimentation has a major influence on the suitability of a site. “Most suitable” sites increase with a decrease of the sedimentation zones. Areas where sedimentation is present are mostly classified as “Suitable” sites, when sedimentation would not apply these sites would turn into “Most suitable” sites. The sedimentation derives from erosion caused by deforestation in elevated areas above the bay (Scott, pers. comm.) and this should be kept in mind when identifying suitability classes and threats in other bays around the island.

Although that most of the “Most suitable” sites are located in regions where no threats apply, most clams were found in areas where the threats of dive and snorkel pressure do occur. A reason for this might be that reef habitats, where clams occur naturally, are the same areas which attract snorkel and diving activities. The location of threats collide with the distribution of clams as it was expected, both have been found along the coastlines of Aow Leuk bay and close to the buoyancies within the bay. Therefore it can be discussed if t “Most suitable” sites however may also be found in combination with a comparably low threat pressure instead of a consistent no threat. Nothing has

been documented for this and it has to be kept in mind that the mentioned threats are only the ones which are induced by tourists.

The results show that most clams have been found in areas which have been classified as “Suitable” or/and “Most suitable”. This conforms to the expected outcome that “Most suitable” sites consist of areas where most criteria meet the requirements of the Giant clam as it was stated by Chad Scott.

The criteria of Seabed, Substrate, Depth, Temperature, Turbidity, Visibility, Phosphate, Nitrate, Threats, Amount of clams, and Size of clams were regarded as the presentation of the ultimate criteria forming the suitability of sites in the bay of Aow Leuk. It was found that the criteria nitrate and phosphate do not show a large variation of values as they do not change to a great extent on a small scale such as in a bay. It was however decided to include them as they can act as indicators for changes in time, sudden changes due to natural processes, and can have a different level of importance in other areas.

It should be kept in mind that the measurements of the criteria and hence the outcome of the study may also underlie seasonal changes (Tan et al., 2002).

Technical

The quality of the data collection and the data itself during this study was dependent on several factors. Working in an underwater environment required certain adjustments or alterations of wildlife research methods. Navigation was done by calculating bearings and distances from individual GPS coordinates which were reached by using the compass and counting kick cycles. It can be discussed that the accuracy of this method rises and falls with the diving and navigation ability of the individual diver, underwater conditions as strong currents and visibility, and the discrepancy resulting from a bias between researchers. However this method is still the most widely used in marine research and facilitates an easy and quick way of collecting data (Scott, 2009). To minimise the possibility of inconsistency due to different researchers the methods of data collection were explained in detail to every participant and further instructions given on and in the water. (Other factors which can present inconsistency in data were time restriction by air supply, changing weather conditions and equipment failure. Those factors were tried to be minimized by sufficient preparation.

The Marine- use classes given by the USGS image from 2001 had to be altered over the course of the study as certain areas in reality did not represent the classes given by the image. A larger area of rock was indicated by the image in the north-eastern corner and a larger area of sand in the middle part of the bay than it was the case in reality. As a result less area was classified as reef. Hence certain seabed-classifications of transects had to be altered along the way. To assure a better picture of the seabed classes, the substrate was noted on the end and start point of each transect line. The differences in the seabed classes may be due to the 9 years difference from when the image derives to when the study was conducted. It was still chosen for this image as the available images from more recent years showed more clouds and a higher level of distortion. A research on Marine Zoning around Koh Tao (Weterings, 2009) calculated the reference accuracy, the reliability accuracy, the overall accuracy and the Kappa-statistic for 4 USGS images between 1975 and 2005, and showed an overall better result for the image derived from the year 2001.

Geographical information systems have become of increased importance in habitat suitability modelling as they can provide information about the distribution of independent environmental attributes. (Skidmore, 2003) One has to keep in mind that they however do not represent a perfect picture of the real world but rather a simplification of complex environmental structures and

processes. One assumption is that mapped areas accurately reflect the availability and level of relevant criteria determining suitability. While GIS is useful in providing information about independent criteria by combining separate layers, it has to be kept in mind that this information needs to be regarded carefully when assigned to other situations. Where GIS is useful in providing information of independent criteria by combining separate layers it has to be kept in mind that this information needs to be regarded carefully when assigned to other situations. To maximise the generalisation of the model it was chosen to base it on literature, expert knowledge and field data which guarantees a broad picture.

The conducted Multi Criteria Analysis makes it possible to link this information into a flexible analysing tool. The major limitation in a MCA is that the weights are determined independently from the outside and thus already influence the result of the analysis. It has been tried to obtain the most accurate information by including diverse and reliable sources. It still has to be kept in mind that different MCA techniques and weighting motivations can lead to dissimilar results and some criteria may not show a considerable effect on such a small scale.

It also should be considered that the weighting may have to be adjusted when the model is used in other areas. To demonstrate that the model shows the desired effectiveness it has been validated with some of the criteria where data has been collected for. The criteria Amount of clams showed that most clams have been found in areas which were classified as suitable area by the MCA.



5. Conclusion

1. What are the most suitable sites for the reintroduction of Giant clams (*Tridacna maxima*) in the bay of Aow Leuk?

The most suitable sites for the reintroduction of Giant clams are sites where most suitable habitat occurs in combination with a low threat pressure. This applies to 5.5 percent of the total area of Aow Leuk bay.

a) What is the most suitable habitat for Giant clams in the bay of Aow Leuk according to the environmental factors?

The “Most suitable” habitat within Aow Leuk bay is structured as follows: the temperature lies between 29°C and 30°C, the seabed consists of reef, the visibility is higher than 7 meters, the nitrogen concentration is less than 20mg/l, the phosphate concentration is less than 0,5 mg/l, the depth lies between 5 to 10 meters, the substrate consists of hard coral or rock, and the turbidity lies between 5-10 FTU.

b) What threats for Giant clams occur in the bay of Aow Leuk?

The threats to Giant clams which have been found within Aow Leuk bay are the buoyancy lines, the snorkeling and diving areas, the grey water outlet, the settlement areas and also the areas in which high sedimentation has been recorded.

2. Where are the most suitable sites for the reintroduction of Giant clams (*Tridacna maxima*) located in the bay of Aow Leuk?

The most suitable sites within Aow Leuk bay are located along the edges of the reef areas as well as along both sides of the bay, outside of the snorkeling and diving zones and away from the buoyancy lines and the grey water outlet. There are no suitable sites found in the sandy areas towards the middle of the bay and along the sandier coast parts.

a) Where are the areas with the most suitable habitat in the bay of Aow Leuk located?

The most suitable habitat is located within the coral reef areas and along the coastal shores on both sides of the bay.

b) Where are the threats which occur in the area of Aow Leuk bay located?

The settlement areas are located in the north west of Aow Leuk bay. The diving and snorkeling zones and the buoyancy lines are located in the reef areas on both sides along the shore of the bay, and the grey water outlet lies in the north east of the bay. Threatening amounts of sediment have been recorded mostly towards the middle of the bay within the sandy areas.



6. Recommendation

The produced Suitable Sites Map for Giant clams (*Tridacna Maxima*) shows the most suitable sites for the clams within Aow Leuk bay under consideration of their environmental requirements and relevant threats. Therefore, it is advised to introduce the Giant clams from the coral nursery of the *Giant clam Nursery and Restoration Project* of the *Save Koh Tao Group* into those areas, as they provide the best conditions for the further growth of the Giant clams. The “Most suitable” sites which were found in the north east of the bay are outside the regular diving and snorkeling area but still lie within a reachable distance of the coral nursery of the *Save Koh Tao Group*. This makes them logistically the easiest accessible place to introduce the Giant clams to. The severity of the threat sedimentation should be kept in mind when identifying suitability classes and threats in other bays around the island.

Furthermore it is advised to conduct more research on this topic. The developed GIS model can be used to examine other bays around Koh Tao Island and to identify more potential areas for the introduction of Giant clams. None of the areas within Aow Leuk bay scored the highest possible amount of points in the MCA. It is however possible that other areas located around the island show an even higher suitability for Giant clams than the “Most suitable” sites which were found in Aow Leuk.

When using the model in other bays around Koh Tao it is recommended to check if, and to what extent, the criteria and their applying weightings have to be adjusted as the criteria and therefore the function of the model could be influenced by species adaptation.

In general, it should be taken into account that data availability is the limiting factor for GIS habitat suitability models within many areas. The model can only be adapted to other areas with presence of sufficient data for those areas.

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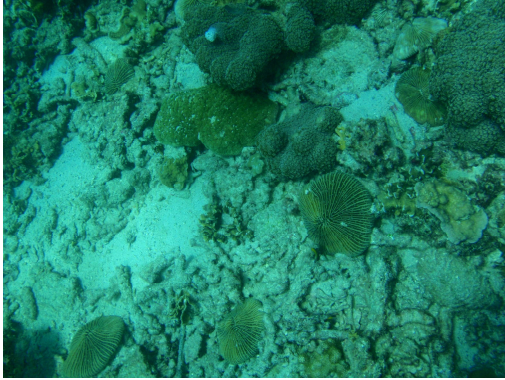
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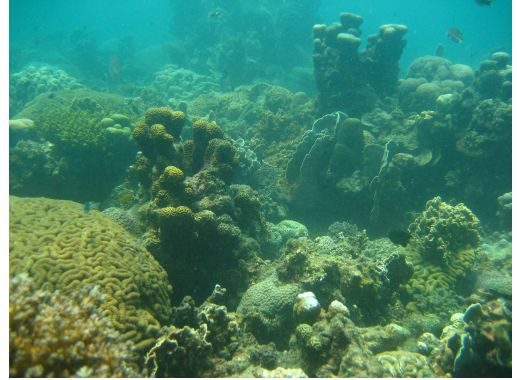
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8. Appendices

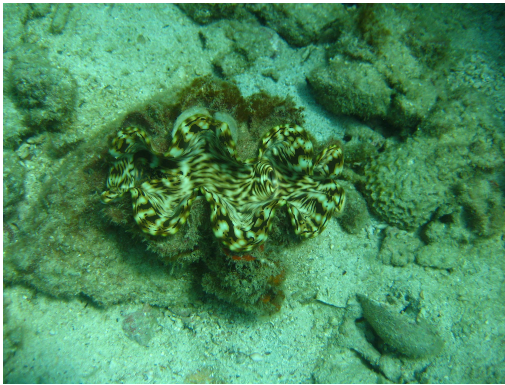
Appendix I: Seabed types



Coral Rubble



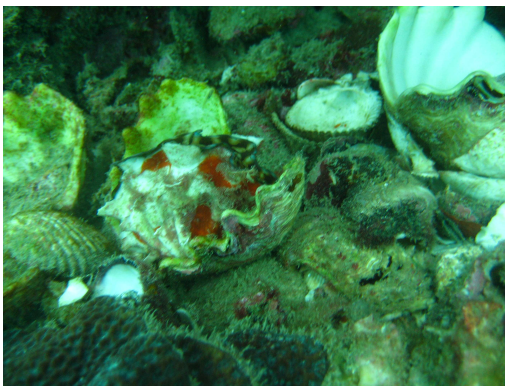
Reef



Sand



Deep Sea



Rock

Appendix II: Steps of data collection and belt transect

Steps of data collection

1. *Go to start point*

The coordinates from the start point will be found with a GPS from the boat and following directions to the data points given before entering the water.

The boat will be used as the reference point; it will be dived straight down to the bottom and this start point will function as the first data point from where the first transect will be laid.

2. *Lay down Belt transect (45mx5m)*

Attach the measuring line on a fixed point e.g. rock (or weight) and swim the given direction, laying down 45m of measuring line. Attach the line at the end point.

3. *Data collection Clams and Depth*

Note down the depth AND substrate at the end point and swim back along the transect carrying out the data collection for the Giant clam 2.5m to each side of the transect line,

i.e. Count, Measure, Note down substrate

Stop at the start point and note down the depth AND the substrate.

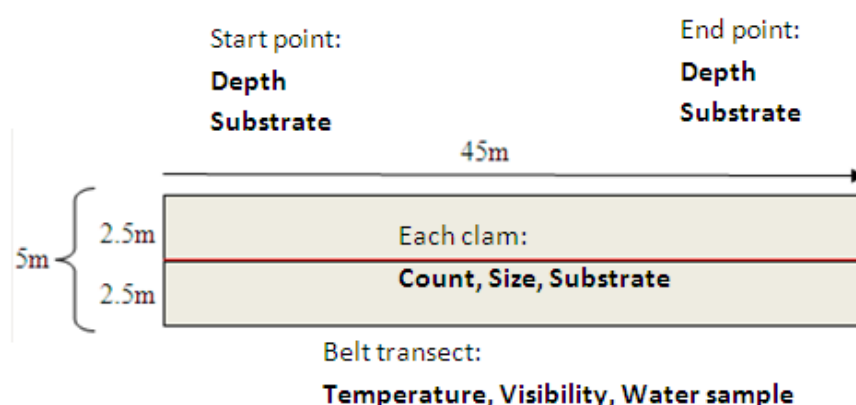
4. *Data collection Turbidity, Visibility and Temperature*

While one takes a water sample (to measure turbidity, nitrate and phosphate) close to the bottom (close to clams), and notes down the temperature the other one swims back along the line and checks the horizontal visibility by aid of a secci disk which will be held by the one left at the start. He/she will then swim on to reel in the measuring tape.

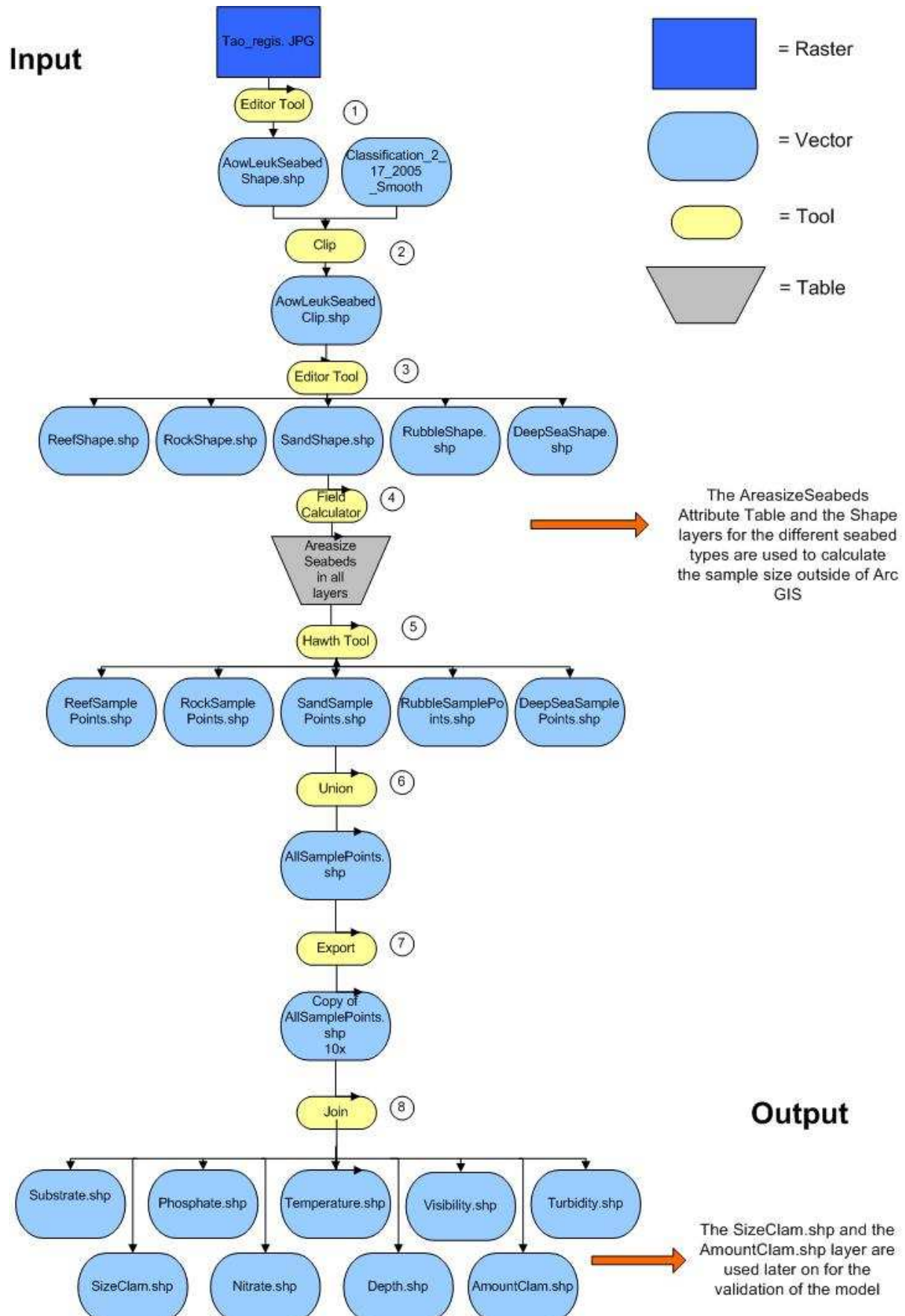
Needed Equipment:

- Slate, Pen, Ruler
- Reel (optional weights)
- Water sample bottle
- Secci disk
- Dive computer
- Compass

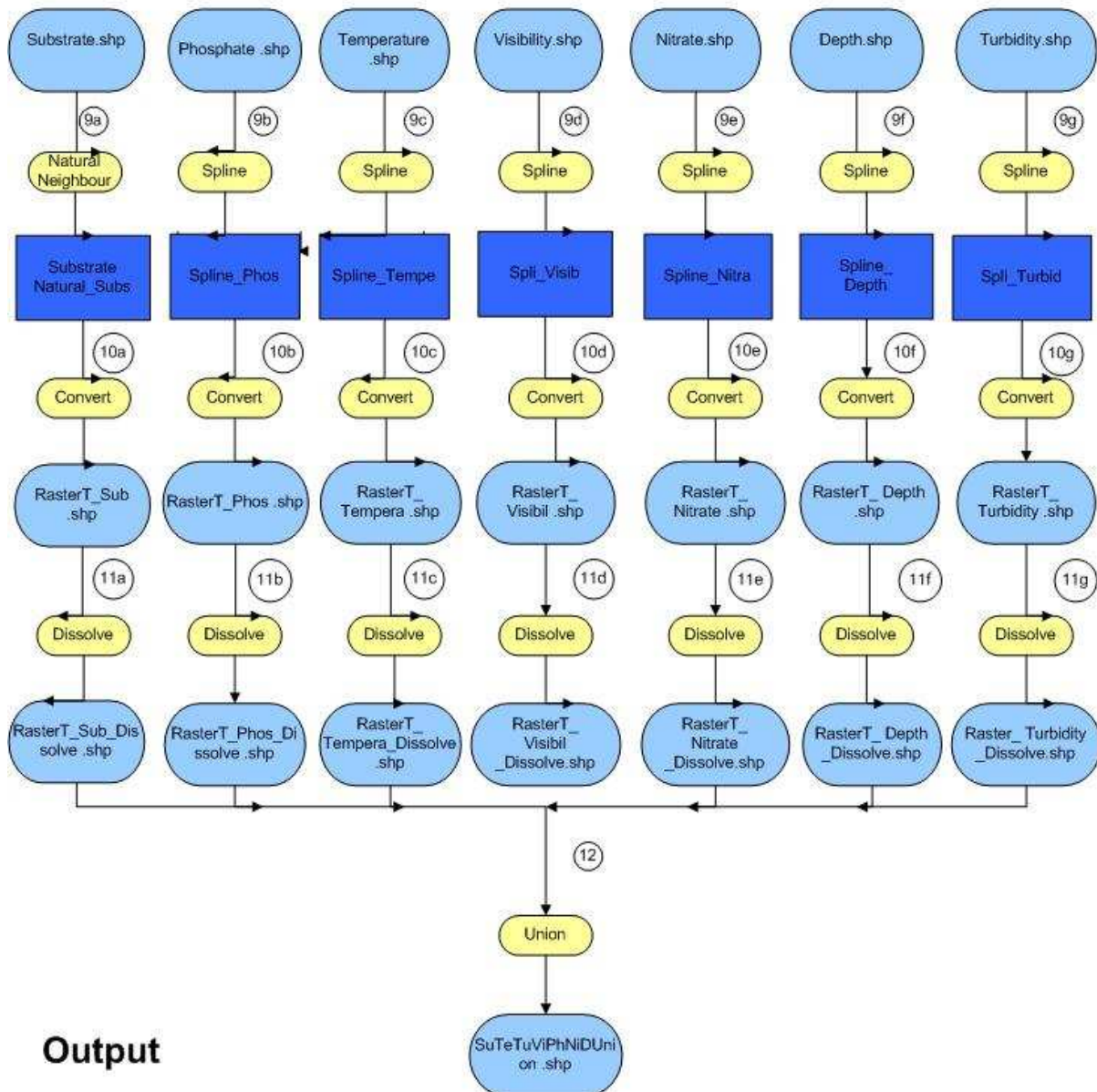
Visualisation of Belt transect and data to collect



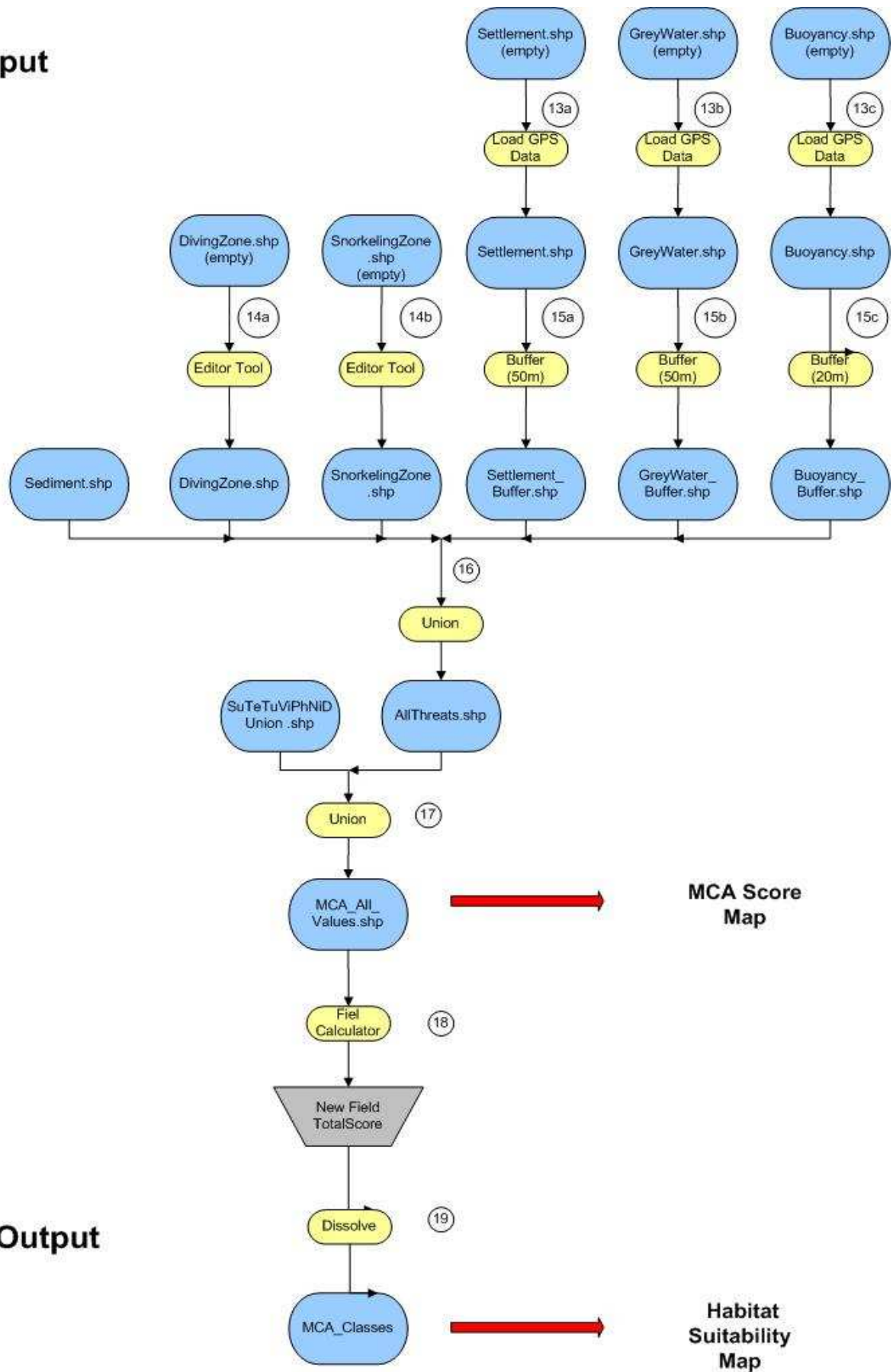
Appendix III: Flowchart



Input



Input



Output

Appendix IV: Flowchart Steps

1	<p>Use the Editor Tool to draw the shape of Aow Leuk bay into a new shape file</p> <ul style="list-style-type: none"> - IP: Tao_regis.JPG - OP: AowLeukSeabed typeshape.shp
2	<p>Use the Clip Tool to cut the shape of Aow Leuk bay out of the Classification layer</p> <ul style="list-style-type: none"> - IP: AowLeukSeabed typeshape.shp / Classification_2_17_2005_Smooth - OP: AowLeukSeabedClip.shp
3	<p>Use Editor Tool to draw the shapes of the different seabed types</p> <ul style="list-style-type: none"> - IP: AowLeukSeabedClip.shp -OP: ReefShape.shp, RockShape.shp, SandShape.shp, RubbleShape.shp, DeepSea.shp
4	<p>Use the Field Calculator Tool to determine the area size of the different seabed types</p> <ul style="list-style-type: none"> - IP: AowLeukSeabedClip.shp - OP: Area Size Row in Attribute Table of AowLeukSeabedClip.shp
5	<p>Use the Hawth Tool (Create Random Points) to determine the sample points</p> <ul style="list-style-type: none"> - IP: AowLeukSeabedClip.shp - OP: ReefSamplePoints.shp, RockSamplePoints.shp, SandSamplePoints.shp, RubbleSamplePoints.shp, DeepSeaSamplePoints.shp
6	<p>Use the Union Tool to combine the different sample point layers into one sample point layer</p> <ul style="list-style-type: none"> - IP: ReefSamplePoints.shp, RockSamplePoints.shp, SandSamplePoints.shp, RubbleSamplePoints.shp, DeepSeaSamplePoints.shp - OP: AllSamplePoints.shp
7	<p>Use the Export Tool to make copies of the all sample points layer</p> <ul style="list-style-type: none"> - IP: AllSamplePoints.shp - OP: 10x AllSamplePointsCopy.shp
8	<p>Use the Join Tool to connect the information about the different criteria to the newly created shapefiles</p> <ul style="list-style-type: none"> - IP: 10x AllSamplePointsCopy.shp - OP: Substrate.shp, Phosphate.shp, Temperature.shp, Visibility.shp, Turbidity.shp, Nitrate.shp, Depth.shp, SizeClam.shp, AmountClam.shp
9 a	<p>Use the Natural Neighbour Tool to interpolate the substrate layer</p> <ul style="list-style-type: none"> - IP: Substrate.shp - OP: Substrate_Natural_Subs
9 b	<p>Use the Spline Tool to interpolate the phosphate layer</p> <ul style="list-style-type: none"> - Setting: settings were chosen as default, i.e. Output cell size: Input cell size divided by 250, Spline type: Regularized, Weight: 0,1, Number of Points: 40. - IP: Phosphate.shp

	<ul style="list-style-type: none"> - OP: Spline_Phos
9 c	<p>Use the Spline Tool to interpolate the temperature layer</p> <ul style="list-style-type: none"> - Setting: settings were chosen as default, i.e. Output cell size: Input cell size divided by 250, Spline type: Regularized, Weight: 0,1, Number of Points: 40. - IP: Temperature.shp - OP: Spline_Tempe
9 d	<p>Use the Spline Tool to interpolate the visibility layer</p> <ul style="list-style-type: none"> - Setting: settings were chosen as default, i.e. Output cell size: Input cell size divided by 250, Spline type: Regularized, Weight: 0,1, Number of Points: 40. - IP: Visibility.shp - OP: Spli_Visib
9 e	<p>Use the Spline Tool to interpolate the nitrate layer</p> <ul style="list-style-type: none"> - Setting: settings were chosen as default, i.e. Output cell size: Input cell size divided by 250, Spline type: Regularized, Weight: 0,1, Number of Points: 40. - IP: Nitrate.shp - OP: Spline_Nitra
9 f	<p>Use the Spline Tool to interpolate the depth layer</p> <ul style="list-style-type: none"> - Setting: settings were chosen as default, i.e. Output cell size: Input cell size divided by 250, Spline type: Regularized, Weight: 0,1, Number of Points: 40. - IP: Depth.shp - OP: Spline_Depth
9 g	<p>Use the Spline Tool to interpolate the turbidity layer</p> <ul style="list-style-type: none"> - Setting: settings were chosen as default, i.e. Output cell size: Input cell size divided by 250, Spline type: Regularized, Weight: 0,1, Number of Points: 40. - IP: Turbidity.shp - OP: Spli_Turbid
10a	<p>Use the Convert Tool to change the Substrate_Natural_Subst layer from raster into vector data</p> <ul style="list-style-type: none"> - IP: Substrate_Natural_Subst - OP: RasterT_Sub.shp
10b	<p>Use the Convert Tool to change the Spline_Phos layer from raster into vector data</p> <ul style="list-style-type: none"> - IP: Spline_Phos - OP: RasterT_Phos.shp

10c	<p>Use the Convert Tool to change the Spline_Tempe layer from raster into vector data</p> <ul style="list-style-type: none"> - IP: Spline_Tempe - OP: RasterT_Tempera.shp
10d	<p>Use the Convert Tool to change the Spli_Visib layer from raster into vector data</p> <ul style="list-style-type: none"> - IP: Spli_Visib - OP: RasterT_Visibil.shp
10e	<p>Use the Convert Tool to change the Spli_Nitra layer from raster into vector data</p> <ul style="list-style-type: none"> - IP: Spli_Nitra - OP: RasterT_Nitrate.shp
10f	<p>Use the Convert Tool to change the Spline_Depth layer from raster into vector data</p> <ul style="list-style-type: none"> - IP: Spline_Depth - OP: RasterT_Depth.shp
10g	<p>Use the Convert Tool to change the Spli_Turbid layer from raster into vector data</p> <ul style="list-style-type: none"> - IP: Spli_Turbid - OP: RasterT_Turbidity.shp
11a	<p>Use the Dissolve Tool to aggregate the features of the RasterT_Sub.shp layer based on the attribute substrate (Attribute table row: Substrate)</p> <ul style="list-style-type: none"> - IP: RasterT_Sub.shp - OP: RasterT_Sub_dissolve.shp
11b	<p>Use the Dissolve Tool to aggregate the features of the RasterT_Phos.shp layer based on the attribute phosphate (Attribute table row: Phosphate)</p> <ul style="list-style-type: none"> - IP: RasterT_Phos.shp - OP: RasterT_Phos_dissolve.shp
11c	<p>Use the Dissolve Tool to aggregate the features of the RasterT_Tempe.shp layer based on the attribute temperature (Attribute table row: Temperature)</p> <ul style="list-style-type: none"> - IP: RasterT_Tempe.shp - OP: RasterT_Tempe_dissolve.shp
11d	<p>Use the Dissolve Tool to aggregate the features of the RasterT_Visibil.shp layer based on the attribute visibility (Attribute table row: Visibility)</p> <ul style="list-style-type: none"> - IP: RasterT_Visibil.shp - OP: RasterT_Visibil_dissolve.shp
11e	<p>Use the Dissolve Tool to aggregate the features of the RasterT_Nitrate.shp layer based on the attribute nitrate (Attribute table row: Nitrate)</p> <ul style="list-style-type: none"> - IP: RasterT_Nitrate.shp - OP: RasterT_Nitrate_dissolve.shp
11f	<p>Use the Dissolve Tool to aggregate the features of the RasterT_Depth.shp layer based on the attribute depth (Attribute table row: Depth)</p> <ul style="list-style-type: none"> - IP: RasterT_Depth.shp - OP: RasterT_Depth_dissolve.shp
11g	<p>Use the Dissolve Tool to aggregate the features of the RasterT_Turbidity.shp layer based on the attribute turbidity (Attribute table row: Turbidity)</p> <ul style="list-style-type: none"> - IP: RasterT_Turbidity.shp

	<ul style="list-style-type: none"> - OP: RasterT_Turbidity_dissolve.shp
12	<p>Use the Union Tool to combine the 7 dissolved layers into one layer</p> <ul style="list-style-type: none"> - IP: RasterT_Sub_dissolve.shp, RasterT_Phos_dissolve.shp, RasterT_Tempe_dissolve.shp, RasterT_Visibil_dissolve.shp, RasterT_Nitrate_dissolve.shp, RasterT_Depth_dissolve.shp, RasterT_Turbidity_dissolve.shp - OP: SeTeTuViPhNiDUnion.shp
13a	<p>Load the coordinates of the settlement areas from the GPS into the new created shapefile Settlement.shp via the program DNA Garmin</p> <ul style="list-style-type: none"> - IP: Settlement.shp (empty) - OP: Settlement.shp
13b	<p>Load the coordinates of the Greywater outlet from the GPS into the new created shapefile Greywater.shp via the program DNA Garmin</p> <ul style="list-style-type: none"> - IP: Greywater.shp (empty) - OP: Greywater.shp
13c	<p>Load the coordinates of the Buoyancies into from the GPS into the new created shapefile Buoyancy.shp via the program DNA Garmin</p> <ul style="list-style-type: none"> - IP: Buoyancy.shp (empty) - OP: Buoyancy.shp
14a	<p>Use the Editor Tool to digitize the diving zone from the Save_Koh_Tao_Meeting_Map.jpg into the new shapefile Divingzone.shp</p> <ul style="list-style-type: none"> - IP: Divingzone.shp (empty) - OP: Divingzone.shp
14b	<p>Use the Editor Tool to digitize the snorkeling zone from the Save_Koh_Tao_Meeting_Map.jpg into the new shapefile Snorkelingzone.shp</p> <ul style="list-style-type: none"> - IP: Snorkelingzone.shp (empty) - OP: Snorkelingzone.shp
15a	<p>Use the Buffer Tool to create a 50 m buffer around the settlement</p> <ul style="list-style-type: none"> - IP: Settlement.shp - OP: Settlement_Buffer.shp
15b	<p>Use the Buffer Tool to create a 50 m buffer around the greywater outlet</p> <ul style="list-style-type: none"> - IP: GreyWater.shp - OP: GreyWater_Buffer.shp
15c	<p>Use the Buffer Tool to create a 20 m buffer around the buoyancy line</p> <ul style="list-style-type: none"> - IP: Buoyancy.shp - OP: Buoyancy_Buffer.shp
16	<p>Use the Union Tool to combine the different threat layers into one layer</p> <ul style="list-style-type: none"> - IP: Sediment.shp, Divingzone.shp, Snorkelingzone.shp, Settlement_Buffer.shp, GreyWater_Buffer.shp, Buoyancy_Buffer.shp - Op: AllThreats.shp

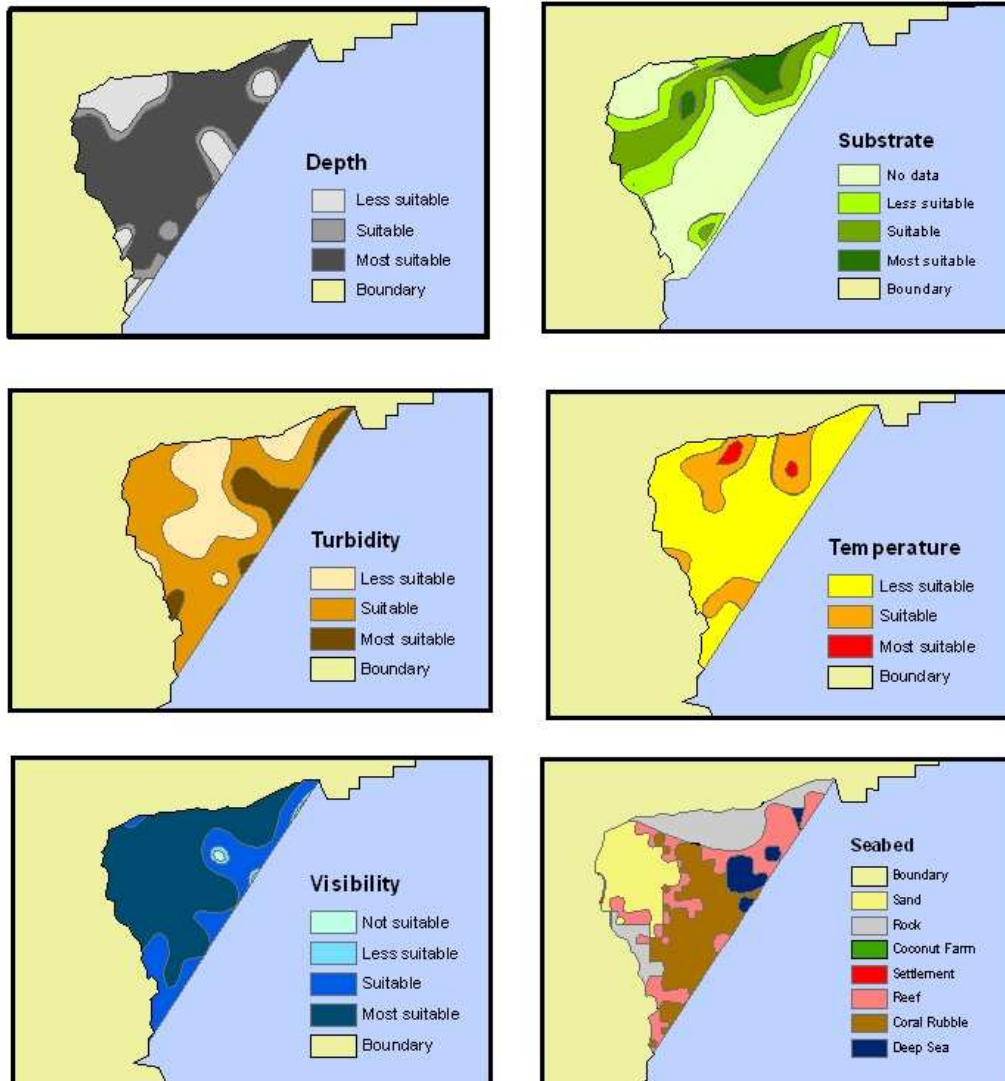
17	<p>Use the Union Tool to combine the all threats layer with the (unioned) all criteria layer</p> <ul style="list-style-type: none"> - IP: SuTeTuViPhNiDUnion.shp / AllThreats.shp - Op: MCA_All_Values.shp
18	<p>Use the Field Calculator to sum up the points each area scored for the individual criterias and to add the weighting for the criteria seabed, depth and temperature</p> <ul style="list-style-type: none"> - IP: MCA_All_Values - OP: MCA_All_Values with new row "TotalScore" in the attribute table
19	<p>Use the Dissolve Tool to aggregate the features of the MCA_All_Values.shp layer based on the attribute total score (Attribute table row: TotalScore)</p> <ul style="list-style-type: none"> - IP: MCA_All_Values.shp - OP: MCA_Classes.shp

Appendix V: Metadata table

Data Name	Content	Year / Date	Scale	Owner	Format
classification_2_22_2001_ Smooth	Landuse types	2001	WGS_1984_UTM_Zone_47N	Robbie Weterings	Vector data
boundary.shp	Shape of Koh Tao Island	2009	WGS_1984_UTM_Zone_47N	Robbie Weterings	Vector data
Tao_regis.JPG	Aerial photo of Koh Tao	2001	-	Chad Scott	Raster 3 band
All sample points Table	Coordinates of sample point locations	2010	WGS_1984_UTM_Zone_47N	Save Koh Tao Conservation	xls
Substrate Table	Substrate types for the 40 sample points	2010	-	Save Koh Tao Conservation	xls
Temperature Table	Temperature for the 40 sample points	2010	°C	Save Koh Tao Conservation	xls
Depth Table	Depth for the 40 sample points	2010	meter	Save Koh Tao Conservation	xls
Nitrate Table	Nitrate content for the 40 sample points	2010	mg/l	Save Koh Tao Conservation	xls
Phosphate Table	Phosphate content for the 40 sample points	2010	mg/l	Save Koh Tao Conservation	xls
Visibility Table	Visibility for the 40 sample points	2010	meter	Save Koh Tao Conservation	xls
Turbidity Table	Turbidity for the 40 sample points	2010	FTU	Save Koh Tao Conservation	xls
Clam Size Table	Size for all found clams + Location	2010	cm	Save Koh Tao Conservation	xls
Clam Amount Table	Amount found clams+ Location	2010	-	Save Koh Tao Conservation	xls
Location Settlement	Coordinates of settlement location	2010	WGS_1984_UTM_Zone_47N	Save Koh Tao Conservation	xls
Location Grey Water	Coordinates of grey water outlet location	2010	WGS_1984_UTM_Zone_47N	Save Koh Tao Conservation	xls
Location Buoyancy Lines	Coordinates of buoyancy lines location	2010	WGS_1984_UTM_Zone_47N	Save Koh Tao Conservation	xls
Koh_Tao_Threat_Map.jpg	Location of different threats occurring around Koh Tao	2009	-	Chad Scott	jpg
Sedimentation_Model.shp	Sedimentation areas in Aow Leuk	2009	WGS_1984_UTM_Zone_47N	Robbie Weterings	Vector data

Appendix VI: Maps of different criteria

Suitability for the Criteria Depth, Visibility, Temperature, Turbidity, Substrate and Seabed for Aow Leuk bay, Koh Tao Thailand



200 100 0 200 Meters



Alke Voskamp
Regine Weckauf
Leeuwarden, June 2010



Map setting: WGS_1984_UTM_Zone_47N; Koh Tao Island map by Robbie Weterings 2009

Appendix VII: EMP Manual

Koh Tao Ecological Monitoring Program

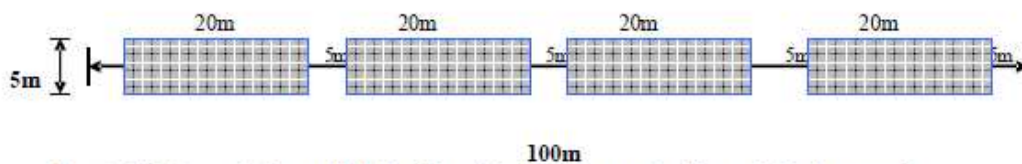


Procedure for Conducting the EMP

The Roving Diver Survey

The roving diver survey is a good way to practice fish and invertebrate identification and provides data which shows a simple picture of reef composition. For the Roving Diver survey, Save Koh Tao has chosen to use the standards and methods set forth by Green Fins International. The procedure for this survey can be found in the Green Fins manual. After completing the Green Fins Survey please send your data to both Green Fins international and Save Koh Tao.

Belt Transect Method



For the EMP, a technique called the Atlantic belt transect method is used. 'Belt transect' means that a reference line is laid out in an area and then data are taken in relation to that line. For our purposes, we use a 100 meter belt that is laid down using two 50 meter measuring tapes. Data are then taken in four, 20 meter long and 5 meter wide segments of that belt (see figure above.) The belt is laid down using known starting and ending points from concrete buoys that have been previously installed by the CPAD Foundation. Belts can also be laid down randomly, but special care should be taken to keep the depth relatively the same from start to finish. At each established site, there is both a shallow and a deep line, and the starting and ending points are labeled as A and B respectively (see the section on site descriptions.)

Koh Tao Ecological Monitoring Program



Substrate Types

One of the most important surveys conducted during the EMP is the substrate survey. Substrate is a term that refers to the bottom composition on the reef, whether that be organic or inorganic. For the substrate survey, participants will need to be able to identify living substrates such as corals, algae, and clams; as well inorganic bottoms such as sands, silts, rocks, and rubble. The category names below are followed by a code which will be used to record data during the substrate survey, and should be learned in addition to the species identification.

Coral types

Hard Coral (HC) - Any coral that secretes a calcium carbonate skeleton and adds to the structure of the reefs. You can usually identify hard corals because they will be in distinct growth forms and inflexible. In addition to identifying the coral as 'hard' you will need to record the growth type.

Coral Growth Forms

Since it is very difficult to identify coral species, you will need to know the following growth forms in order to take data on the substrate of the reef.



Branching (B)



Corymbose (C)



Digitate (D)



Encrusting (E)



Foliose/Turbinate (F)



Laminar (L)



Massive (M)



Submassive (S)



Tabulate (T)



Solitary (R)

Koh Tao Ecological Monitoring Program



- **Branching (B)** - These corals grow in a tree like shape with relatively long primary and secondary branches and small polyps. Often, damsel fish and hermit crabs can be found living within the branches of the branching coral.
- **Foliose/Turbinate (F)** - Grow in a vase-like formation, often resembling a flower, small polyps.
- **Corymbose (C)** - consists of small branching corals or tabulate corals in which the branches have many smaller offshoots.
- **Laminar (L)** - Grow in thin sheets of dense coral polyps
- **Digitate (D)** - Thick pillar or finger-like growths with no secondary branches.
- **Massive (M)** - Spherical or hemispherical boulder like growth, with larger polyps.
- **Submassive (S)** - Similar to the massive but with smaller polyps and a more pillar-like growth form.
- **Encrusting (E)** - Corals which grow on rocks or hard substrate and expand in diameter, not height.
- **Tabulate (T)** - A table-like structure made up of small, tightly packed branches.
- **Solitary (R)** - Singular corals that are made up of one large polyp, often mushroom shaped.



Soft Coral (SC) - Corals that do not secrete a calcium carbonate skeleton that adds to reef, but instead may have internal protein or calcium spicules for support. This includes whip and harp corals, Gorgonians, Leather Corals, and sea pens. Many soft corals will shrink during the day, and then absorb water at night to extend out for feeding. Because most soft corals do not harbor symbiotic algae, they can survive in much deeper water where there is not enough light for photosynthesis. The EMP does not divide soft corals into growth forms, but it might be helpful to learn some in order to assist in conducting the survey.

Sponges (SP) - Sponges are not actually organisms, but a colony of specialized cells with each having a specific function. Collar cells within the sponge pump water through small openings in the sponge tissue, while other cells remove food and nutrients from the flowing water. Sponges can filter vast amounts of water each day and help to maintain water quality in reefs. Many different species of sponges exist, so it is not important for species type to be identified for the EMP.

Nutrient Indicator Algae (NIA) - All Macro algae is an indicator of high nutrient levels, as algae extracts nutrients directly from the water. In areas where nutrients levels are high, algae will have a competitive advantage over corals and grow over them.

Rock (RC) - Any solid, inorganic substrate that is not covered in living coral tissue. Most rocks encountered in reefs will be coated with encrusting algae, barnacles, oysters, etc. Large corals that have been dead for a long time are also counted in this category.

Rubble (RB) - Pieces of dead coral or rocks that measure between 0.5 cm and 15 cm in diameter (often found in areas that have experienced mass coral die-offs). Will usually be covered in a thin layer of algae.

Recently Killed Coral (RKC) - Coral that has died within the past year. Will not usually be encrusted with sponges or algae, and the structure of the coral will still be recognizable.

Silt/Clay (SI) - Sediment with very small grain sizes that remains in suspension after being disturbed.

Sand (SD) - Sediment with slightly larger grain size and will fall quickly back to the bottom if disturbed.

Trash/Garbage (TR) - Any manmade item which is not serving an intended function within the reef.

Other (OTH) - Any bottom composition that does not fit into the above categories including: tunicates, sea anemones, sea cucumbers, and wrecks.

Appendix VIII: Multi Criteria Analysis

A Multi Criteria Analysis (hereafter referred to as MCA) was conducted in order to facilitate the ranking of the different habitat suitability classes. This approach allows several criteria to be considered at one time and hence assigns the possible habitat suitability classes based on how closely each of them meets those criteria. Within GIS the MCA presents a visualisation of the classes by providing a picture of the suitability across the study site Aow Leuk.

The criteria have been selected by literature review and personal communication with the Project Coordinator and other experienced individuals.

Further individual weights have been assigned by this method to each criterion to calculate weighted summations distributed over the study site and guarantee a more objective way of assessing the suitability by breaking the levels in smaller portions (Saaty, 2008).

The nine criteria which were chosen for the MCA are:

1. Seabed (Sand, Rock, Reef, Rubble, Deep Sea)
2. Depth (m)
3. Temperature(C°)
4. Visibility (m)
5. Nitrate (mg/l)
6. Phosphate (mg/l)
7. Turbidity (FTU)
8. Substrate Clam (Sand, Hard Coral, Coral rubble, Rock, Silt)
9. Threat (Dive Pressure, Grey Water, Snorkeling, Sedimentation, Settlement, Buoyancies)

After conducting the MCA the developed GIS model was validated to proof that it is working properly. The factors which have been chosen to validate the model were:

1. Amount of Giant clams (*Tridacna maxima*)
2. Size of Giant clams

To conduct the MCA the different criteria need to be ranked individually the ranking will be explained per chosen criteria.

Ranking of the criteria

The ranking for the different criteria is done by using their limiting values, in relation to the positive or negative effect on the Giant clam. For each criterion the points are awarded according to the suitability of the value. The ranking is subdivided in "Most suitable" (3), "Suitable" (2), "Less suitable" (1) and "Not suitable" (0). For each criterion the recorded values which are lethal for the Giant clams are ranked with 0 ("Not suitable").

For the MCA all areas which score 0 points in one (or more) of the criteria are not taken into accc

anymore and are therefore ranked with 0 points in total.

For the other areas, which achieved a “Less suitable” to “Most suitable” (1 to 3 points) per criterion, the reached points will be summed up to a final score. This means that the more points an area scores during the MCA the higher is the suitability of this area as habitat for the introduction of Giant clams. The maximum score which is possible to reach is 38 points. The minimum amount is 16 points. The final ranking of the total score reached by the different areas is as follows:

33 - 38 points = “Most suitable”

25 - 32 points = “Suitable”

17 – 24 points = “Less suitable”

≤ 16 points = “Not suitable”

The MCA model is generated to make it applicable to any bay around Koh Tao. Therefore it generally measures the suitability of an area for the reintroduction of Giant clams. That makes it possible that no area in the bay of Aow Leuk will be awarded with the maximum number of 38 points (100%). The possible minimum and maximum amount of points which can be reached for each criterion can be seen in table 1.

Table 1: The table shows the maximum and minimum amount of points which can be reached for each criterion.

	Seabed	Depth	Temperature	Visibility	Nitrate	Phosphate	Turbidity	Substrate	Threats	Total possible Points
Max	9	6	6	3	2	3	3	3	3	38
Min	3	3	3	1	2	3	1	0	1	17

Description of ranking for every criterion:

Substrate

Giant clams occur on sand or coral rubble ground. Sea grass beds can be a suitable ground if the turbidity is not too high (Ellis, 2000). There have no observations been made of Giant clams growing on sea grass. Also sea grass does not occur in areas of significant size in the bays around Koh Tao and is therefore not counted as a land use type (Weterings, 2009). It is therefore not taken into account for the MCA. Sand and coral rubble are ranked as “Most suitable”. Rock and Hard Coral are ranked as “Suitable” and Silt as “Less suitable”. Hard coral and rock are ranked according to the following table which shows the findings within the bay of Aow Leuk. Sand and coral rubble are ranked higher than hard coral and rock as they are known as most suitable from literature. The findings made during the data collection support the importance of rock and hard coral as substrate for the growth of Giant clams in the bay of Aow Leuk. The table shows the found percentage of Giant clams for each substrate within the bay of Aow Leuk. Furthermore the percentage of the seabed in which this subs

occurs mostly, is given for the bay. The ranks are given subsequently to the correlation between the percentage of the seabed type the substrate is found in, and the actual found percentage of Giant clams within this substrate. Sand and coral rubble are ranked higher than hard coral and rock. Since the MCA is not fitted only on Aow Leuk but is supposed to be useable for all bays around Koh Tao the general found suitability is ranked higher than the specific suitability found in Aow Leuk.

Table 2: Percentage of Giant clams found per seabed

Substrate Type	Percentage of Giant clams found per substrate type	Percentage of seabed the substrate type is mostly found in	Resulting rank
Rock	56.5 %	2,5%	1
Hard Coral (Reef)	20 %	30%	2
Sand	16.5 %	40%	3
Rubble	3.5%	22,5%	4
Silt	3.5%	(40% counted together with sand)	5

Subsequently, based on the literature and the findings on Giant clams within Aow Leuk bay, the substrate is ranked and scored as in figure 1. As none of the substrates has been found to be lethal to Giant clams no 0 will be given for this criterion.

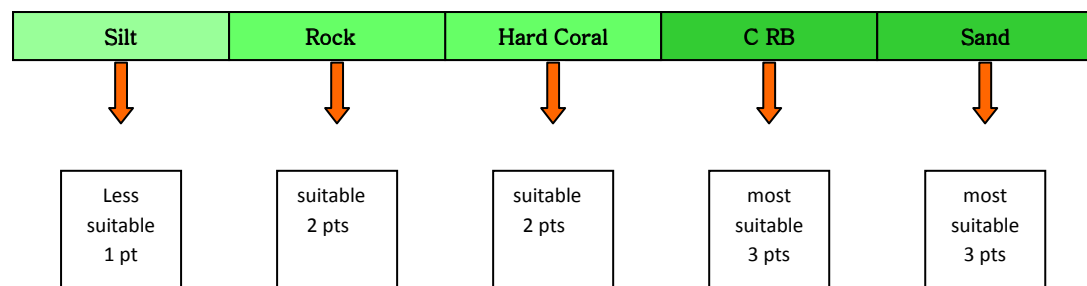


Figure 1: Ranking for the criterion substrate

None of the substrates has found to be lethal for Giant clams. Therefore substrate is not taken as a dominant criterion during the MCA. Even if the substrate in an area is not ideal (“Less suitable”) it is still possible that the Giant clams grow well in this area if the other criteria are within an adequate frame. Hence, the weighting for the criterion substrate is 1. That means that during the MCA the points scored for the criterion depth count once.

Seabed

Giant clams occur naturally in shallow coral reefs, reef flats and shallow lagoons. (www.arkive.org) Since they are able to attach to reefs, rocks or even sand by means of fibrous threads (www.sherrysknowledgequest.com), they are also able to live in sandy seabed, coral rubble and c rocks as long as there is shelter by isolated coral heads or rocks which prevent the Giant clam from physical disturbance but still allow enough water movement to prevent siltation and turbidity. (Ellis, 2000) The different seabed types used during the MCA are reef, rock, coral rubble, sand and deep sea. Coral reef will be ranked as “Most suitable” as it is found in the literature as the main habitat of the Giant clam and can contain all of the different substrates required by Giant clams. Rock, coral rubble and sand are ranked as “Suitable” as they all provide possible habitat for Giant clams and contain partly some of the required substrates. Coral Rubble and sand are divided in two classes. Only those areas with coral rubble or sand which lie 5 meters and closer to a reef or rocks are ranked as “Suitable”. Coral rubble and sand areas which lie further away than 5 meters from reef or rock do not provide enough shelter for the clams and are ranked as “Not suitable”. Also the deep sea areas are ranked as “Not suitable” as the depth presents a lethal factor. The ranking for the criterion seabed is shown in the figure 2.

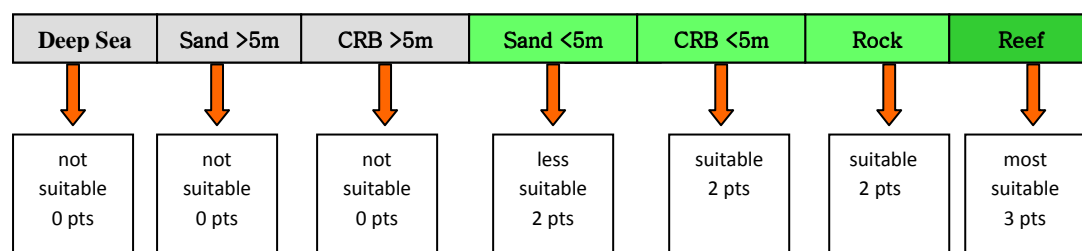


Figure 2: Ranking for the criterion seabed

Seabed is one of the most vital criteria. It contains the different substrates and influences turbidity, water movement and sedimentation. For the MCA this criterion will therefore be weighted 3 times, and thus the points scored for the criterion depth are multiplied by three.

Depth

Tridacna Maxima occur in depths of 1 to 20 meters. (www.arkive.org). A water depth of less than 1 meter or more than 20 meters is lethal for Giant clams. The ideal depth to introduce Giant clams from nursery cages into the open sea lies between 5 to 10 meters (Ellis, 2000). For the MCA the depth between 5 to 10 meters is ranked as “Most suitable”. Depths which differ less than one meter from the ideal depth are ranked as “Suitable”. This applies to 4 to 5 meters and 10 to 11 meters depth. Depths which differ more than 1 meter from the ideal level but are not lethal to the Giant clams are ranked as “Less suitable” for the introduction of the clams. This applies to 1 to 4 meters and 11 to 20 meters depth. Every recorded depth less than 1 meter or more than 20 meters is counted as lethal and will be ranked with 0. Figure 3 shows the ranking for the criterion depth and the points given for the different ranks.

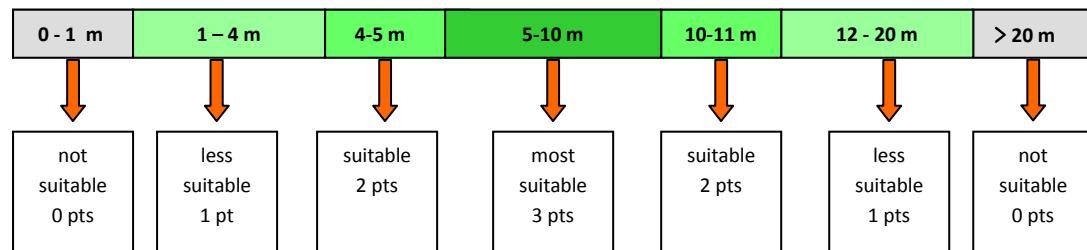


Figure 3: Ranking for the criterion depth

Depth is a very dominant criterion since every value below 1 and higher than 20 is supposed to be lethal to Giant clams. Therefore the weighting for this criterion is 2. That means that during the MCA the points scored for the criterion depth are counted twice.

Temperature

The optimal water temperature for Giant clams is not precisely stated but they appear to grow best in water temperatures of 25 to 30 degrees Celsius (Ellis, 2000, Isamu, 2008).

It is reported that clams are able to stand higher temperatures for a period of time but that prolonged exposure to higher temperatures will cause stress and lower the growth rate, and can even cause more serious effects as bleaching of the mantle and subsequently lead to death (Ellis 2000). The bleaching occurs as Giant clams live in close symbiosis with zooxanthellae which are highly dependent on sunlight and sensible to changes in water temperature (Pinet 2004). The El Nino incident of 1998 in the Gulf of Thailand showed that most of the corals, which live in the same symbiosis to zooxanthellae as clams, bleached and died following a rise in seawater temperature to 33 degrees (C. Scott, pers comm.).

Keeping in mind that the seawater temperature in tropical waters ranges from 25 to 28 degrees Celsius in colder months and from 28.8 to 32 degrees Celsius in warmer months (Mohsin et al, 1996), and that clams are sensitive to fluctuations in changes of temperature small margins are chosen within the MCA. A temperature of 29 to 30 degree Celsius is therefore regarded as “Most suitable” habitat. As a “Suitable” temperature only the next two successively following values are taken, being 28 and 31 degree Celsius. “Less suitable” temperatures are those exceeding or below the already assigned temperature until they reach the point where they get lethal to the species; “Less suitable” temperature is therefore 21 – 27 degree Celsius and 32 degree Celsius. The temperatures of 22 degree Celsius and beneath, and 33 degree Celsius and above are regarded as lethal and therefore assigned with 0 points. The ranking and assigned points can be seen in figure 4.

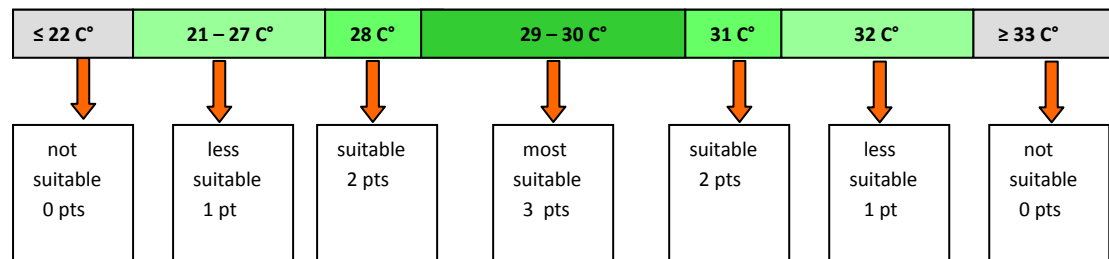


Figure 4: Ranking for the criterion temperature

Temperature is a dominant criterion for Giant clams as the value lower than and equal to 22 deg Celsius, and higher than and equal to 33 degree Celsius are regarded as lethal to the species. Therefore the weighting for this criterion is 2, meaning that during the MCA the points scored for the criterion temperature are counted twice.

Visibility

Giant clams require clear water and high levels of sunlight to satisfy the photosynthetic process of their zooxanthellae (Basker 1991). In the study, visibility values of 7 to 13 m were recorded. In the MCA the visibility is ranked with 0 points for a value of 0 visibility, everything greater than 0 receives points. A visibility of 0 to 1 is classified as “Less suitable”; values of 2 to 7 m are classified as “Suitable”. Every value equal or greater than 7 is regarded as “Most suitable” and no maximum is regarded as lethal margin as visibility is restricted by other criteria and affecting clams only in a positive way. The ranking and the assigned points can be seen in figure 5.

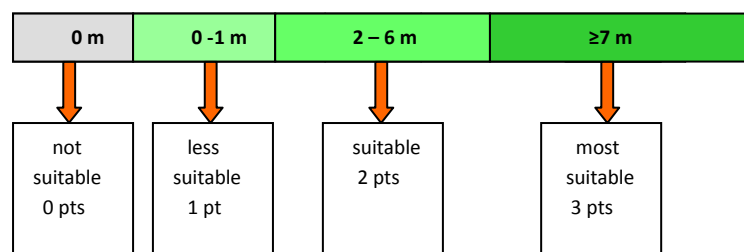


Figure 5: Ranking for the criterion visibility

Low visibility can act lethal to Giant clams. However, the criterion visibility depends strongly on other criteria as for example sedimentation. Therefore a weighting of 1 will be applied to the criterion visibility. That means that the points scored in the MCA for the criterion visibility count only once.

Turbidity

The cloudiness of the water is given as turbidity. Giant clams are dependent on photosynthesis for their nutrition and therefore they need clear water do get enough sun radiation (Ellis 2000). In the study, values of 0 FTU (Formazine Turbidity Unit) to 8 FTU were found. As turbidity depends on other criteria to a great extent and will change according to them only a turbidity of equal or greater than 25 FTU will be considered as lethal, as values beneath 25 FTU are considered as of a water quality as

“clear ponds” (www.h2ou.com). Hence, values of 25 FTU or greater are considered as “Not suitable”. “Less suitable” apply to values ranging from 10 to 25 and as “Suitable” values from 5 to 10 will be regarded. Values from 0 to 5 FTU will be considered as “Most suitable”. The ranking and assigned points can be seen in figure 6.

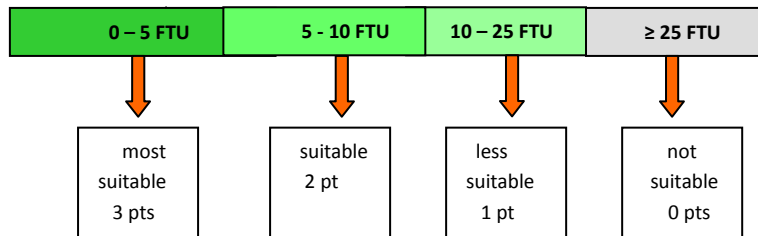


Figure 6: Ranking for the criterion turbidity

The criterion turbidity does restrict the growth of the Giant clams in a way that too high turbidity will be lethal to them. However the criterion is much dependent on other criteria as for examples on the threat sedimentation. Therefore a weighting of 1 will be applied to the criterion turbidity. That means that the points scored in the MCA for the criterion turbidity count only once.

Nitrate

Nitrate has an indirect influence on Giant clams since high levels of nitrate stimulate the growth of plankton and water weeds (www.h2ou.com). Visibility and turbidity are affected by nitrogen concentration as the excessive growth of algae will lead to an increase in turbidity and decrease in visibility. For marine animals, a maximum concentration of 20 mg NO₃-N/l may in general be acceptable (www.ncbi.nlm.nih.gov). From a certain level nitrate starts to be toxic for marine animals. As the zooxanthellae of the Giant clams need nitrate for their metabolism a rise in nitrate concentration leads to a significant increase in the population density of zooxanthelle (Marubini and Davies, 1996). But since nitrate is not a limiting criterion for metabolism, because phosphorus is generally a limiting criterion in water bodies there is no minimum value for the criterion nitrate. Every value beneath 20 mg NO₃-N/l may be taken as a suitable concentration (www.h2ou.com). Hence, areas which show a nitrate concentration of less than 20 mg/l are regarded as “Suitable” habitat and concentrations equal or higher than 20 mg/l are regarded as “Not suitable”. The ranking and assigned points can be seen in figure 7.

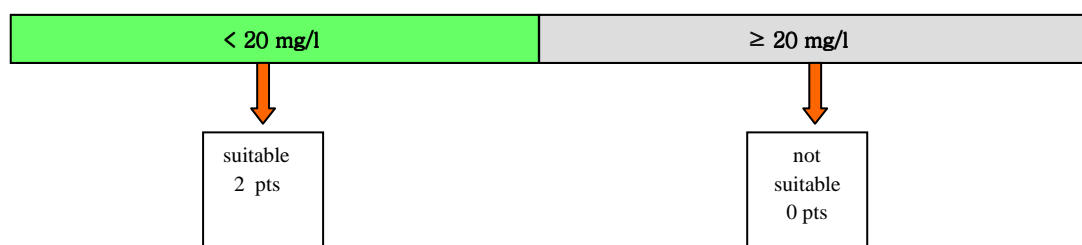


Figure 7: Ranking for the criterion nitrate

Since nitrate does only have an indirect influence on Giant clams, by influencing other criteria and stimulating the population density of the zooxanthellae, the weighting for this criterion is 1. That means that during the MCA the points scored for the criterion nitrate are only counted once.

Phosphate

Giant clams have a limited access to the inorganic phosphate in seawater (Belda et al., 1995). Most phosphate is bound within plankton. The plankton is caught by corals and clams to take in the phosphate and other substances like nitrogen, trace elements and energy (www.aquacare.de). Therefore phosphate dissolved in water does not have a direct influence on Giant clams. Like nitrate too much phosphate in seawater stimulates algae and water weeds to grow and use up large amounts of oxygen (www.h2ou.com). In addition, high phosphate can significantly inhibit calcification in calcareous organisms (kb.marinedepot.com). The maximum level of phosphate in water should not exceed 0.5 mg/l in order to not slow down the calcification of the Giant clam (Braley et al., 1992). The maximum level of phosphate in sea water should not exceed 0.5 mg/l in order to not slow down the calcification the Giant clam (www.h2ou.com). This value is taken as the maximum value in the MCA. Every recorded value of phosphate equal to or above 0.5 mg/l will be taken as “Not suitable”. Every recorded value beneath 0.5 mg/l is taken as “Most suitable” as dissolved phosphate in water is not the main source of phosphate for the Giant clam but can still have a positive effect onto the metabolism of the zooxanthellae (www.lenntech.com). The ranking for the criterion and the assigned points can be seen in the figure 8.

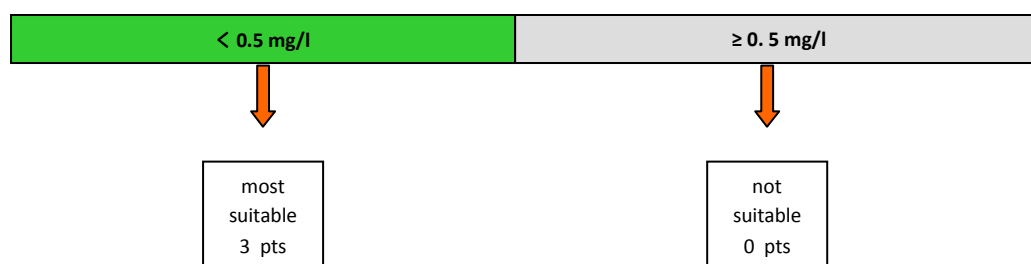


Figure 8: Ranking for the criterion phosphate

Since phosphate does only have an indirect influence on the Giant clams but is needed for the metabolism of the zooxanthellae the weighting for this criterion is 1. That means that the points scored in the MCA for the criterion nitrate are only counted once.

Threat

There are 6 threats identified as a risk to Giant clams in the bay of Aow Leuk and classified as zones for Sedimentation, Dive pressure, and Snorkeling and as points with an applying buffer zone for Grey water, Settlement, and Buyoncies. As the criterion threat forms a negative impact on Giant clams a reverse ranking is applied. By this the whole area will be covered in a way that points will be given to all areas, with areas outside threat zones receiving more points, and therefore still representing a reliable picture when comparing the areas. No lethal margin is applied as it is not apparent to what extent the threats are detrimental to the Giant clams, as well as a value of 0 points would not fit in

the method of ranking since not every area would get points and therefore not represent all possibilities.

Every area falling outside of any threat zones is ranked with 3 points as the value which is expected to be “Most suitable”. Areas within the buffer zones of Grey water, Settlement, and Buoyancies will receive 2 points as being “Less suitable”. Areas within the zones of Dive pressure, Snorkeling, and Sedimentation will be ranked with 1 point as being “Not suitable”. The ranking and assigned points can be seen in figure 9.

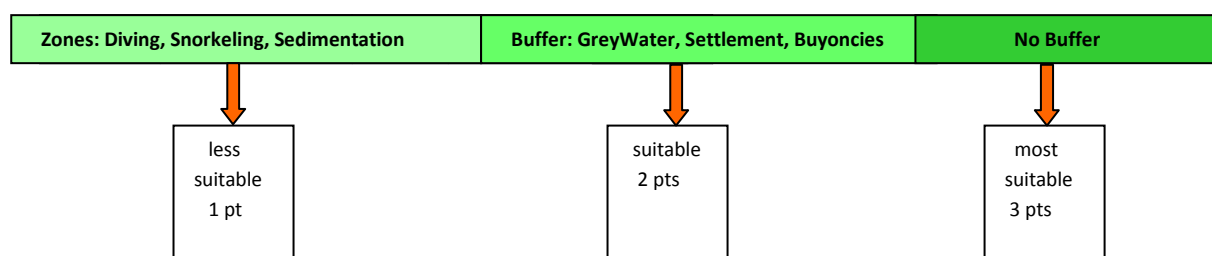


Figure 9: Ranking for the criterion threat.

Since it is not apparent to what extent the threats are detrimental to the Giant clams no lethal component could be applied to the criterion threat and it is not taken as a dominant criterion during the MCA. It is intended to assign areas without threats with more points after all to better represent the actual picture of the habitat suitability. Hence, the weighting for the criterion threat is 1 and the points scored for the criterion threat count only once in the MCA.

Table 10 shows the MCA, taking into account the individual weighting of the criteria and the points given for each value per criterion.

Table 10: MCA criteria for the habitat suitability mapping of Giant clams in the bay of Aow Leuk

Criteria	Seabed		Depth (m)		Temperature (C°)		Visibility (m)	
Weighting	3		2		2		1	
	Values		Values		Values		Values	
	Deep Sea	0	0 - 1	0	≤ 22	0	0	0
	Sand > 5	0	> 20	0	≥ 33	0	0 - 1	1
	CRB > 5	0	1 - 4	1	21 - 27	1	2 - 7	2
	Sand < 5	1	11 - 20	1	32	1	≥ 7	3
	CRB < 5	2	4 - 5	2	28	2		
	Rock	2	10 - 11	2	31	2		
	Reef	3	5 - 10	3	29 - 30	3		

Criteria	Nitrate		Phosphate		Turbidity (m)	
Weighting	1		1		1	
	Values		Values		Values	
	≥ 20	0	≥ 0.5	0	≥ 25	0
	< 20	2	< 0.5	3	10 - 25	1
					5 - 10	2
					0 - 5	3

Criteria	Substrate Clam		Threats	
Weighting	1		1	
	Values		Values	
	Silt	1	Zone: Diving, Snorkeling, Sedimentation	1
	Rock	2	Buffer: Grey water, Buoyancies, Settlement	2
	HC	2	No buffer	3
	CRB	3		
	Sand	3		

Validation of the model

After conducting the Multi Criteria Analysis by using the program ArcGIS 9.3 the resulting model needs to be validated to proof that the model is working properly. This is done by comparing the collected data about the abundance and the size of the Giant clams within the examined bay. The layers which contain the information about the amount of clams and the clam size are loaded into the final map. This makes it possible to compare the results of the MCA with the findings about the clams and will show if the highest amounts of clams and also the largest clams are found within the areas which have been found to be “Most suitable” and if there are no clams in the areas which have been found as “Not suitable” (Lethal). To produce those layers and to make the MCA results and the

two chosen factors for validation better comparable also these two factors “Average Amount Clams” and “Clam size” were ranked. The ranking was done as follows:

Average Amount Clam

To take into account not only every individual clam and its applying criteria but to regard every seabed with their actual amount of occurring clams, their average amount was used to rank them accordingly. The observations showed that for cases where clams were found the amounts of clams on each transect accumulated to around 1 to 2, around 5, or around 10 individuals. The maximum amount of Giant clams found was 13. As the study species is listed as globally threatened and the research was conducted on a small scale of a bay every clam is regarded as being positive and therefore awarded with points, with no maximum level of amount being set. None of the amounts can be seen as to be lethal to Giant clams and therefore no 0 is given for this criterion. As a result every average amount of clams from 0 to 2 is classified as “Less suitable”. An amount of 3 to 10 clams is classified as “Suitable” and every average amount equal to or above 10 clams is classified as “Most suitable”. The ranking and assigned points can be seen in figure 10.

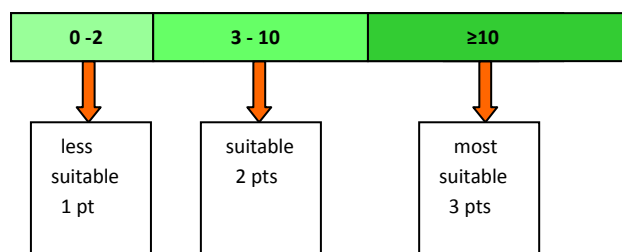


Figure 10: Ranking for the criterion average amount of clams

This criterion does not represent a lethal cause to clams but is however an important criterion as it takes into account the actual picture of clam distribution found in the area in straightforward way. It is aimed at assigning seabed types with a high average of clams more points to better represent this picture. The weighting for the criterion average amount of clams is 2 which means that the points scored for the criterion average amount of clam counted twice in the MCA.

Size Clam

Giant clams reach full maturity at a size of 11 to 13 cm and become sessile (Isamu, 2008). As they then represent a stronger habitat preference, sizes equal to or exceeding 13cm are ranked as “Most suitable”. Accordingly, points decline with the smaller sizes of 12cm and 11 and lesser than 11cm and get 2 points, 1 point respectively; ranked as suitable and less suitable in regard to their representation of habitat preference. A maximum, lethal margin is not applied as this is given by the biological limitations of the Giant clam itself.

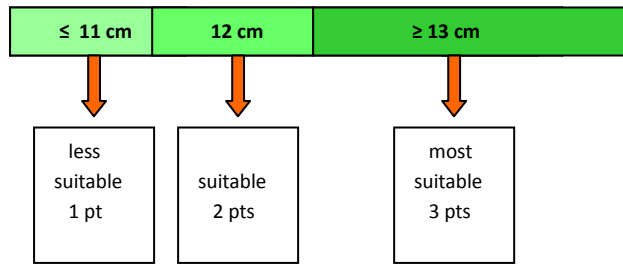


Figure 13: Ranking for the criterion size of clams

Since there is no lethal component in the criterion size of clams it is not taken as a dominant criterion during the MCA. It was aimed at assigning clams which are sessile with more points to better represent the actual picture of their habitat preference. Hence, the weighting for the criterion size of clams is 1, which means that the points scored for the criterion size of clam count once in the MCA.