Kasetsart J. (Nat. Sci.) 45 : 743 - 755 (2011)

A GIS-Based Assessment of Threats to the Natural Environment on Koh Tao, Thailand

Robbie Weterings[1,2]

ABSTRACT

The objective of this study was to provide an overview of the issues affecting the natural resources on Koh Tao, Thailand, so a management plan could be developed. Remote sensed data was combined with data from a questionnaire to create a model that assesses the condition of the reefs and threats to the reefs. Remote sensed data were acquired from 4 y (1975, 1994, 2001 and 2005) to assess changes in land usage and to determine the location of the reefs. With a geographical information system (GIS) different models were created based on the available data.

The results showed that areas on the northeast side of the island were in better condition than other areas. In recent decades, almost 50% of the rainforests have been lost, with soil erosion and subsequently sedimentation on the reefs as a consequence. The enormous reef recreation industry on the island has also caused stress to the reefs. While it was expected that the divers from the large number of diving schools would cause damage to the coral, commercially organized snorkel trips appeared to be more destructive. Most reef areas that were stressed suffered from sedimentation and physical damage caused by snorkeling and diving.

Keywords: coral reef, threats, reef recreation, erosion, remote sensing, geographic information system, Gulf of Thailand

INTRODUCTION

Koh Tao is a small island in the Gulf of Thailand; it is located in Surat Thani province in southern Thailand (Figure 1). It is approximately 21 km^2 in size and has over 300,000 visitors annually (Scott, 2009). Formerly, the island was covered with tropical rainforest of which approximately 51% remained as at 2005. Koh Tao has a high number of bays and is completely surrounded by coral reefs; the bays support a high abundance of corals (Hoek *et al.,* 1980).

The coral reefs support almost the complete economy of the island (SATLP, 2009). Koh Tao, Koh Phanang and Koh Samui are the three main islands in Surat Thani province and their economies depend mainly on tourism (IDRC, 1998). Koh Samui and Koh Phanang are party orientated; Koh Tao on the other hand still has some valuable coral reefs and therefore most of the tourism on Koh Tao is focused on reef recreation (SATLP, 2009). Even though Koh Tao is not the most pristine reef area in Thailand it is still one of the most popular places for diving in

[1] Zentrum fur Naturschutz, Georg-August Universität Göttingen, Germany. Von-Siebold-Strasse 2, 37075 Göttingen/Germany
[2] Marine Conservation New Heaven, Koh Tao, Surat Thani 84360, Thailand.
E-mail: robbie.weterings@gmail.com

Received date : 28/07/10 Accepted date : 12/04/11

Figure 1 Topology of study area including some dive sites at Koh Tao, Surat Thani province, Thailand.

the country. Approximately 40 diving schools are located on the island (SATLP, 2009). Besides these diving schools, divers from some of the schools on the other two islands also regularly dive around Koh Tao.

The reefs are under high pressure resulting from recreation, deforestation, over-fishing, global warming and pollution (Scott, 2008a; Wilkinson, 1999). To sustain and develop the social, economic and environmental welfare it is necessary to also sustain the coral reefs. Several local conservation initiatives have been undertaken during the last 4 y. Currently marine conservation is being carried out by a diving school and land conservation is being undertaken by a nongovernmental organization named Save Koh Tao. For example, the projects of both conservation-based organizations involve erosion control or reducing reef recreation damage. The present study is part of a more complementary study involving a long term ecological monitoring program. The aim of the present research was to obtain an overview of the problems affecting the natural resources so that a management plan can be developed. To do so, the following research questions have to be answered:

- How are the natural resources distributed on Koh Tao and how have they developed over time?
- What are the threats to the natural resources and how are they spatially distributed?
- What is the severity of these threats?

MATERIALS AND METHODS

The data were collected in the marine and terrestrial environment and were then analyzed with geographic information systems (ArcGIS Desktop 9.2© (ESRI, 2006), MultiSpec© (Purdue Research Foundation, 2010) and the GRASS plugin for QGIS (Quantum GIS Development Team, 2009)), to provide maps.

Remote sensing

Remote sensed land use and marine use classes were obtained using four different sets of satellite imagery. The images covered four different dates (4 July 1975, 23 September 1994, 22 February 2001 and 17 February 2005) and were provided by the US Geological Survey (USGS). The Multispec software package was used to classify the images based on eight different categories: rainforest, coconut farm, rock, settlement, sand, reef, rubble/submerged sand and deep sea. Training sites were collected in core areas (the center of an area in a certain category) and areas for which the history was known, so it was certain that these training sites represented the same classes in the different imagery years. Not all imagery was obtained from the same satellite and was thus composed of different bands. Therefore, the different images had to be enhanced and classified with differing methods.

2001 and 2005 imagery analysis

The 2001 and 2005 Landsat 7 imagery involved the red, green, blue, infrared and panchromatic bands (Mumby *et al.,* 2004; Bruno *et al.,* 2006). Using the panchromatic band, a pan-sharpened imagery set was calculated. This increased the spatial resolution from 30 m^2 per pixel to 15 m^2 per pixel. Using the red and infrared bands, a normalized differenced vegetation index (NDVI; Roettger, 2006) band was calculated. For the eventual classification, the green, blue and NDVI bands were used. The ECHO homogeneous cell likelihood classifier (Campbell, 1996) was applied for the eventual classification. Testing several classifiers showed the highest accuracies for this classifier (reference- and reliability-accuracy and kappa statistic). To calculate the accuracy, the re-substitution method was used (Landgrebe, 2003). The classes were given different weight factors because of high differences in abundance in order to increase the accuracy. The weights given to the different classes are displayed in Table 1. The imagery of the 2005 classification had gaps within the dataset caused by a malfunction of the Landsat 7 satellite. After the classification, these gaps were interpolated using the Thiessen method which can be used for categorical data (Carver, 1998).

1994 imagery analysis

Landsat 5 imagery was used for the 1994 classification. Landsat 5 lacks a panchromatic band and therefore the spatial resolution (30 m per pixel) could not be enhanced. With a 3 × 3 edge detect kernel, the contrast was enhanced which made the different classes more distinct and reduced the distortion caused by clouds (Kechu and Wentao 1984). An NDVI band was calculated using the red and infrared bands. The green, blue and NDVI bands were used for the actual classification with the maximum likelihood classifier (Campbell, 1996). The classes were weighted according to Table 1.

1975 imagery analysis

Landsat 2 imagery was used for the 1975 classification. Landsat 2 is missing the blue and panchromatic bands and has a less accurate spatial resolution (75 m^2 per pixel) than the later Landsat satellites. Marine classification depends mainly on the blue band (Bello-Pineda *et al.,* 2005). Therefore the four marine classes in this classification were not as accurate as for the other years. An NDVI band was calculated from the red and infrared band. The green, red and NDVI bands were then classified with the ECHO homogeneous

Table 1 Weighting factors for classification.

Class	1975	1994	2001 and 2005
Deep sea	25	30	30
Rainforest	25	30	30
Coconut farm	15	15	10
Sand	15	15	15
Reef	10	5	5
Rock	5	15	15
Rubble	5	5	5
Settlement	5	5	5

cell likelihood classifier. The classes were weighted according Table 1.

Prediction of rainforest

The maps derived from remote sensing were analyzed to supply information about the decline of natural areas on Koh Tao. To highlight the rapid decline of the natural habitat on Koh Tao, the time at which the rainforest class would reach 0% cover was calculated. The total surface of this land use class was calculated and correlated with time in a scatter plot. The best fitting trend line was then calculated using the Microsoft Office 2007 Excel software package (Microsoft Corporation, 2007) and the equation of this trend line was then extrapolated.

Modeling

The threats to the marine environment were combined in a realistic spatial model to provide a better understanding of these threats. Different threats were mapped in ArcGIS and combined into a map displaying the severity of stress to the coral reefs. The threats that were included within the model were: erosion-related sedimentation, diving, snorkeling, boat traffic and waste water.

Sedimentation

A map was created that showed the relative stress of sedimentation on the shores, taking into account the values attributed to watershed area and land use as proposed by the Coral Reef Alliance (2005). The amounts of human-induced runoff sediment were modeled using the 2005 classification and a digital elevation model (DEM). From the DEM, a map showing different watersheds was calculated, based on the aspect of the slopes (using the Aspect module in GRASS). An overlay was made with the land use classes which displayed how much of each different land use class was covering the watersheds using three classes—namely, ‘natural’ area, coconut farm and settlement/road.

The classes were weighted neglecting the natural background of sedimentation; therefore the ‘natural’ areas were weighted with a value of 0. The class covering most of the altered areas was coconut farm. This class was weighted with a value of 1. Settlements and very poorly constructed roads have lost most of their vegetation and function as highways for runoff water and sediment; therefore these areas were weighted with a value of 3, rather than a value of 2, as a value of 3 better represents the relatively high impact of these relatively small areas. The area covered by each of the three classes in a single watershed was multiplied by its respective weight factor; these were then summed and divided by the length of the watershed shoreline (Equation 1).

$$\frac{(d\cdot 0)+(e\cdot 1)+(f\cdot 3)}{C} = Y \qquad (1)$$

where

0 = Weighting factor for the natural area (=0)

1 = Weighting factor for coconut farm (=1)

3 = Weighting factor for settlement or road (=3)

C = Length of shoreline for a certain watershed

d = Surface of a watershed covered with natural area

e = Surface of a watershed covered with coconut farm

f = Surface of a watershed covered with settlement or road

Y = Sediment pressure relative to the length of the shoreline and the land use per watershed

Hydrological maps were not available and were therefore not taken into consideration. This process was repeated for all watersheds to estimate the relative human-induced sedimentation impact along the complete shoreline of Koh Tao. Figure 2 shows a schematic overview of this process. The final shapefile showed the sedimentation impact in a 250 m wide zone, parallel to the coast.

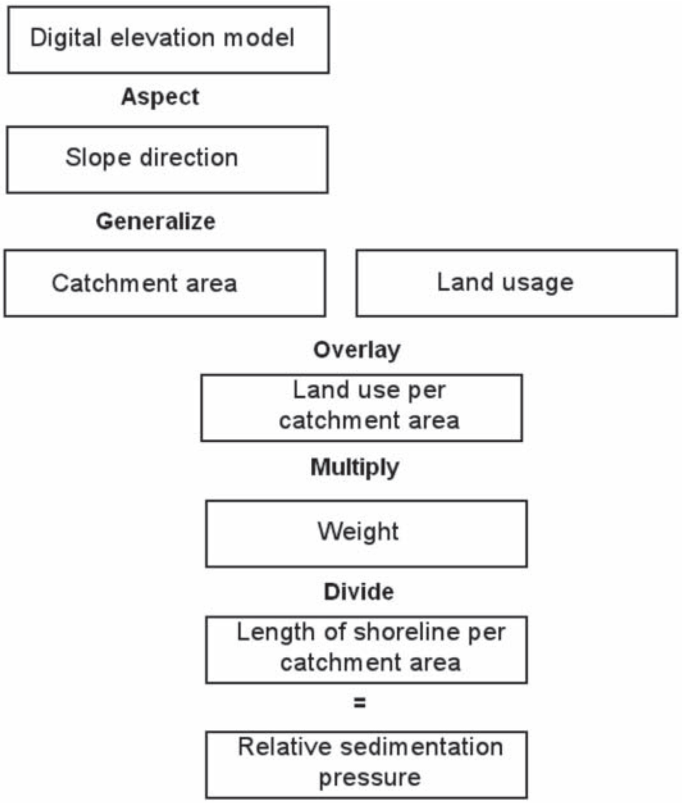

Figure 2 Schematic GIS model of sedimentation pressure.

Diving

On Koh Tao, the impact of diving was assessed using a questionnaire distributed among 23 of the 43 dive shops. Figure 3 shows the distribution of all the dive shops and the ones included in the questionnaire. The core part of the questionnaire surveyed information on the top 10 dive sites around Koh Tao and the number of customers during the high and low season. These data were analyzed and modeled; the dive pressure for a dive site caused by a single dive shop was calculated using Equations 2 and 3 for dive sites with a northeastern and western swell, respectively.

$$\frac{1}{a}\cdot(Dh\cdot Ch+Dl\cdot Cl)\cdot Se=E \quad (2)$$

$$\frac{1}{b}\cdot(Dh\cdot Ch+Dl\cdot Cl)\cdot Sw=W \quad (3)$$

where:

a = Rank of dive site in top10 per dive shop, with northeastern swell
b = Rank of dive site in top10 per dive shop, with western swell
E = Rank of dive site relative to the size of dive shop with northeastern swell
W = Rank of dive site relative to the size of dive shop with western swell
Dh = Average number of dives trips per week in high season
Ch = Average number of customers per dive trip in high season
Dl = Average number of dives per week in low season
Cl = Average number of customers per dive in low season
Se = Weeks of northeastern swell per year
Sw = Weeks of western swell per year

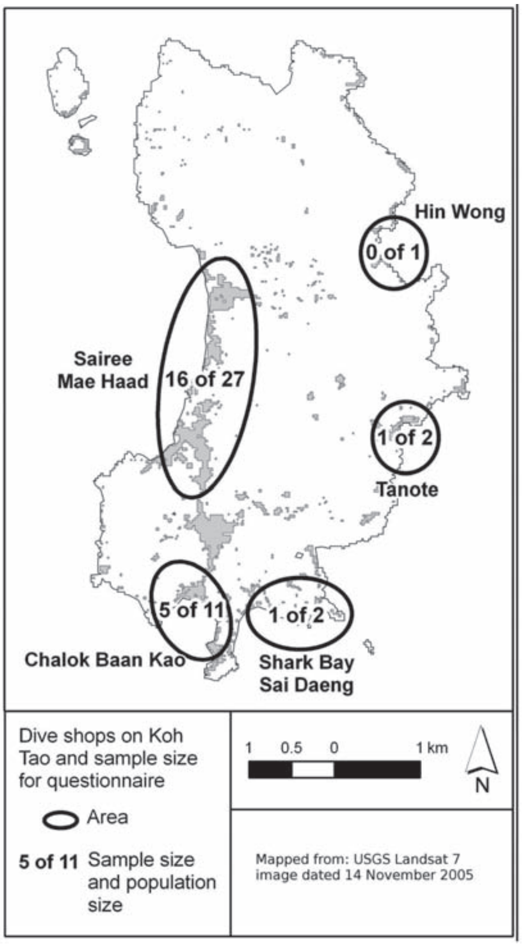

Figure 3 Sample and population size of dive shops on Koh Tao. (Dive shops in Sairee and Mae Haad are generally larger than others on the rest of the island.)

This process was carried out for all dive shops and all dive sites. All values for a single dive site were added, resulting in the eventual relative pressure values. The outcomes for every dive site were then re-indexed relative to the most visited dive site, setting this dive site at a standard pressure value of 20.

The dive sites were digitized in ArcGIS. A 300 m radius was drawn around the center of every dive site to define the complete dive site area in most cases. The calculated pressure values were assigned to these polygons, resulting in a map showing the differences in dive pressure among the various dive sites.

This model considered the period of time during a year that a dive site can be visited as well as the number of dives during the high and low season. In the first instance, the number of dives during the high and low season were related with the accessibility of the dive sites, but these differences were minimal and therefore were not considered.

Other threats

Snorkel sites, sewage outlets and heavy boat traffic areas were mapped based on information obtained from the Save Koh Tao meetings and supplied by Marine Conservation Koh Tao. These maps were digitized with ArcGIS.

In 2006, work commenced on a water reservoir in the Tanote watershed but this was aborted and never completed. The construction of this project caused and currently still is causing severe erosion resulting in sedimentation problems in Tanote Bay (Scott, 2008b). The 2005 classification did not include the construction of this reservoir and so the effects of this reservoir were not included in the sedimentation model. Figure 4 displays the results from the Save Koh Tao meetings and the Tanote Bay shoreline with a 250 m buffer.

The model

All threats that have been mentioned were combined in a single map displaying the relative severity of stress on the coral reefs. The most severe cases of island-wide stress factors (sedimentation, diving and snorkeling) were set at a pressure value of 20, so that these factors were treated as equally important. Boat traffic, waste water and the Tanote reservoir were weighted with a pressure value of 6.67, so when all of these threats were present red at the same location, a total value of 20 would be assigned to that area.

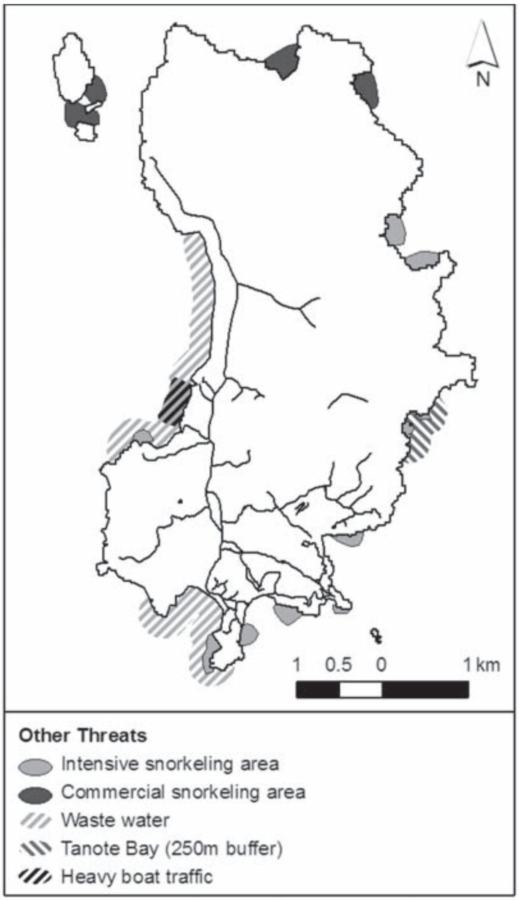

Figure 4 Location of mixed threats: snorkel areas, waste water outlet, Tanote Bay and heavy boat traffic on Koh Tao. This information was gathered during Save Koh Tao meetings for the Marine Zoning Program (2009). The buffer zones for both waste water and Tanote Bay are displayed as parallel zones 300 and 250 m, respectively, from the shoreline.

Using the Union module in ArcGIS, all these maps were combined into a single output, so that every polygon had all the pressure values for every threat; these values were summed in a new field of the attribute table. The final shapefile showed the total of the weighted pressure values on the reef areas.

RESULTS

Remote sensing

The habitat types/land use and marine use classes that were mapped with the four remote sensed imagery sets are displayed in Figure 5. Table 2 shows the area classified by habitat type. Table 3 shows the accuracy of the different classifications and indicates a decrease in rainforest and a substantial increase in coconut farms, with a loss of 300 ha of rainforest within 4 y from 2001 to 2005, while the other classes remained mostly unchanged. The deep sea class shows an outlier in 1975 because the satellite imagery used covered a slightly smaller area.

In 1975, a total area of 62 ha was altered by humans. By 2005, this area had increased to 814 ha. The total surface of the island is approximately 1,900 ha. Using the modeled extrapolation, by 2009 approximately half of the island's surface could be expected to have been altered.

From the period 2001 to 2005, Table 2 shows that the rainforest area on Koh Tao decreased from 1,266 to 967 ha which is a 23% reduction; most of this loss was situated near Aow Leuk, Chalok Baan Kao and Tanote. The remote sensed data showed a decreasing trend in rainforest area on Koh Tao (Figure 5). If this trend continues ($y = 15.56x + 32278$; $R^2 = 0.8179$; where x = year and y = area), there will be no forest left by 2075. Every year, around 15 ha of rainforest are transformed into coconut farms, roads and settlements (mainly resorts).

Modeling

Figure 6 shows the output of the erosion-related sedimentation model showing clearly that the west side of the island was stressed relative to the rest of Koh Tao. The major deforestation in the Tanote watershed was not considered in the sedimentation model because the imagery used for the model was taken one year before the start of the deforestation (Scott, 2008b). The combined stress model however does take this problem into account.

The stress caused by diving is displayed in Figure 7. This model shows that Twin Peaks was the most frequented dive site, followed by White Rock, Chumporn Pinnacle, Shark Island, Green Rock and Japanese Garden. Moreover, it visualizes very clearly how diving is concentrated at just a few sites and how other sites shown in Figure 8 are rarely visited.

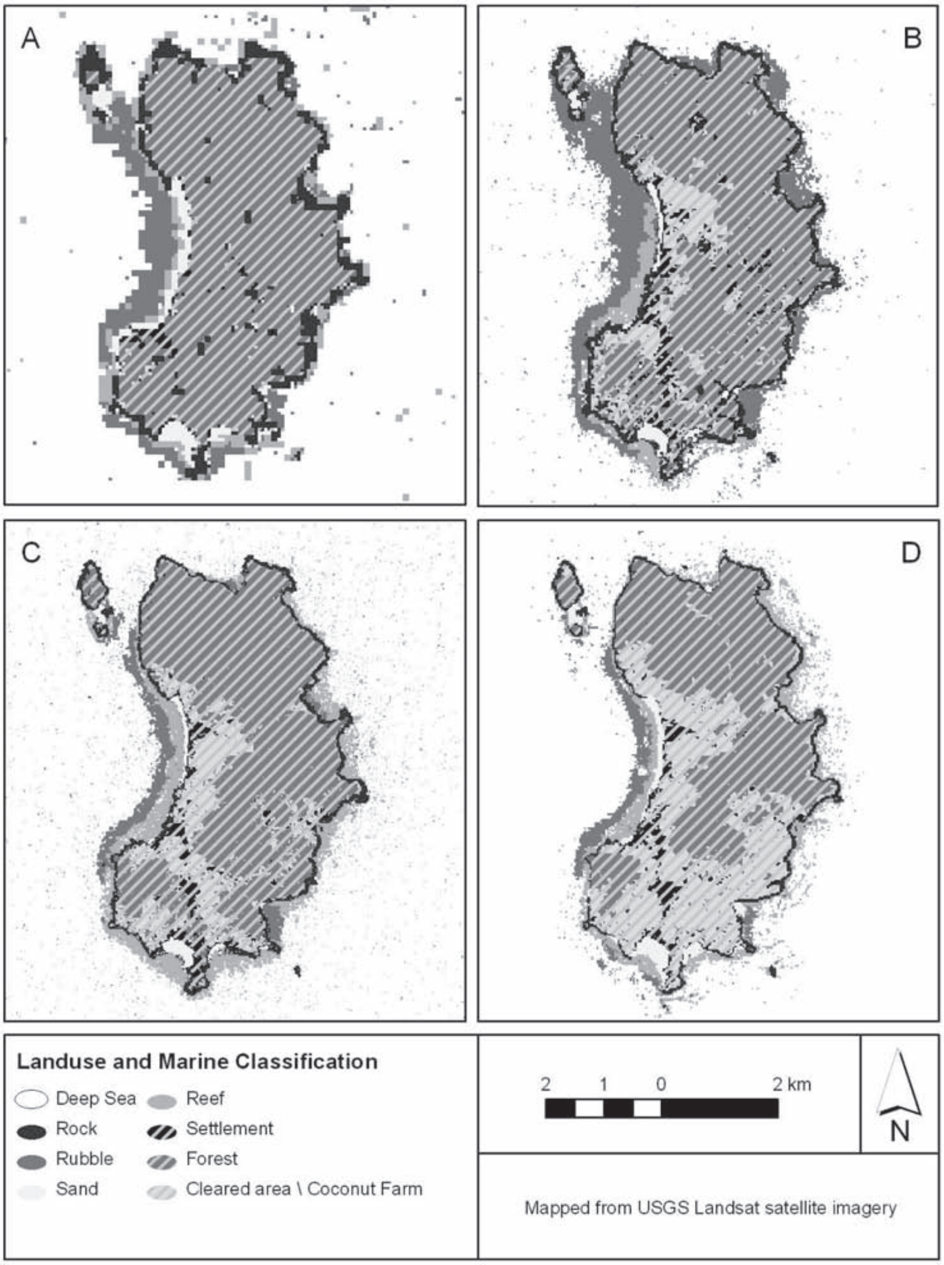

Figure 5 Maps of Koh Tao showing marine and land usage changes over time based on satellite imagery: (A) 1975; (B) 1994; (C) 2001; (D) 2005.

Figure 9 shows the combined stress model. Koh Nangyuan, Sairee and Mae Haad had relatively high stress levels. For Mae Haad and Sairee this was due to a large number of problems, that is, sedimentation, waste water and traffic. On Koh Nangyuan, stress was mainly caused by commercialized snorkeling (organized snorkel trips with over 200 customers at one time) and to a lesser degree by diving.

In the northeastern part of the island, the stress was generally much lower, Mango Bay and Lighthouse showed higher stress levels, mainly caused by commercialized snorkeling. The southeastern part showed a moderate stress level, with the main problem here being recent development causing erosion-related sedimentation, while snorkeling and diving were less serious in this area.

DISCUSSION

Remote sensing

No reference sites were collected due to the small size of the research area. Table 3 shows the reference accuracy, the reliability accuracy, the overall accuracy and the kappa statistic. The reference accuracy shows the number of pixels of a certain habitat type that were in a training site and also classified as this habitat type. The reliability accuracy shows the number of pixels within the training sites of a certain habitat type that were classified as a different habitat type. The overall accuracy is based on both the reliability and reference accuracy and gives an overall view

Table 2 Total surface per class for 1975, 1994, 2001 and 2005.

Class	1975 (ha)	1994 (ha)	2001 (ha)	2005 (ha)
Reef	251	286	398	287
Deep sea	6,602	8,335	8,356	8,555
Rubble	313	359	140	116
Sand	105	39	37	68
Rock	303	214	243	129
Settlement	41	135	108	114
Coconut farm	21	333	378	700
Rainforest	1,527	1,263	1,266	967

Table 3 Reference accuracy, reliability accuracy, overall accuracy and kappa statistic for different classifications.

Class name	1975		1994		2001		2005	
	Reference Accuracy (%)	Reliability Accuracy (%)	Reference Accuracy (%)	Reliability Accuracy (%)	Reference Accuracy (%)	Reliability Accuracy (%)	Reference Accuracy (%)	Reliability Accuracy (%)
Rainforest	95.60	98.70	97.80	99.00	99.30	99.90	91.50	87.90
Settlement	46.70	70.00	78.80	87.00	83.60	93.30	96.20	84.70
Deep sea	98.40	95.90	99.50	99.30	99.10	99.90	98.80	99.90
Sand	97.80	66.20	99.30	94.60	98.60	93.40	98.10	97.30
Coconut farm	100	78.60	92.80	86.70	98.10	84.20	77.10	84.30
Reef	36.30	83.30	81.00	88.60	90.30	58.60	84.00	64.20
Rock	90.40	75.90	91.30	70.00	95.80	84.50	96.00	97.00
Rubble	96.60	57.50	91.50	84.70	97.60	70.70	99.30	93.90
Overall accuracy	90.70		98.10		99.05		95.00	
Kappa statistic	86.00		95.50		96.10		92.00	

of the accuracy of the complete map (Ismail and Jusoff, 2008). The kappa statistic compares the classification with a randomized classification; if this number is 0, then the classification relies completely on chance, while if this number is 100 the classification does not rely on chance at all (Bruno *et al.,* 2006).

In general, the accuracy was lower for the marine classes. For the 1975 classification, the blue spectrum was not available and therefore the marine classes from this classification are unreliable. The spatial resolution of this imagery was much lower causing a higher chance of mixed pixels and a higher chance that small coconut farms and small settlements (smaller than 75 m^2) were incorrectly classified (Xia and Guo, 2009).

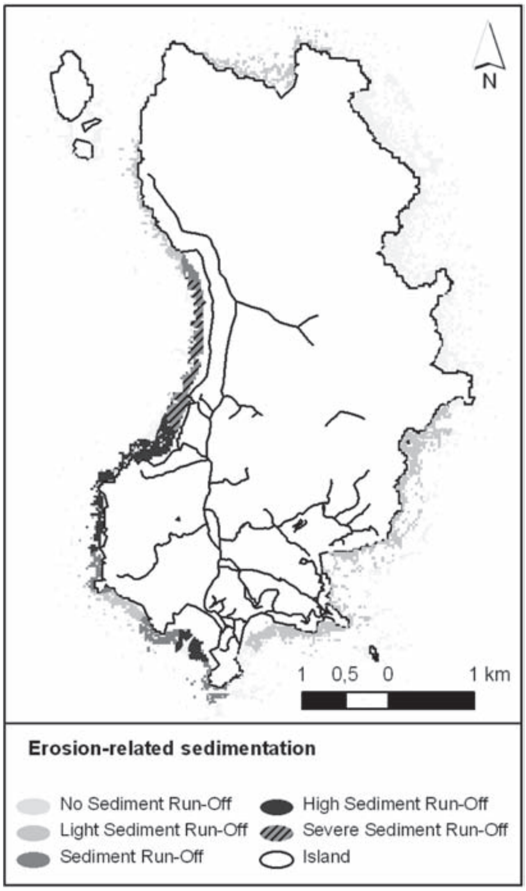

Figure 6 Erosion-related sedimentation impact on the coral reefs.

The 1994 imagery contained much distortion as a result of clouds, which caused incorrect classification (Kechu and Wentao, 1984) of the classes for reef and rubble in the northern part of the study area (around Sairee and farther north). The 2001 imagery showed a small amount of distortion on the southwest side of the island due to the swell and wave movement, which caused incorrect imaging of the reef (Ouchi, 1984). The 2005 image had fewer problems with swell but showed more boat traffic on the southwest side of the island. The best impression of the reef was gained from the 2005 classification. The location of the marine classes could differ slightly in reality

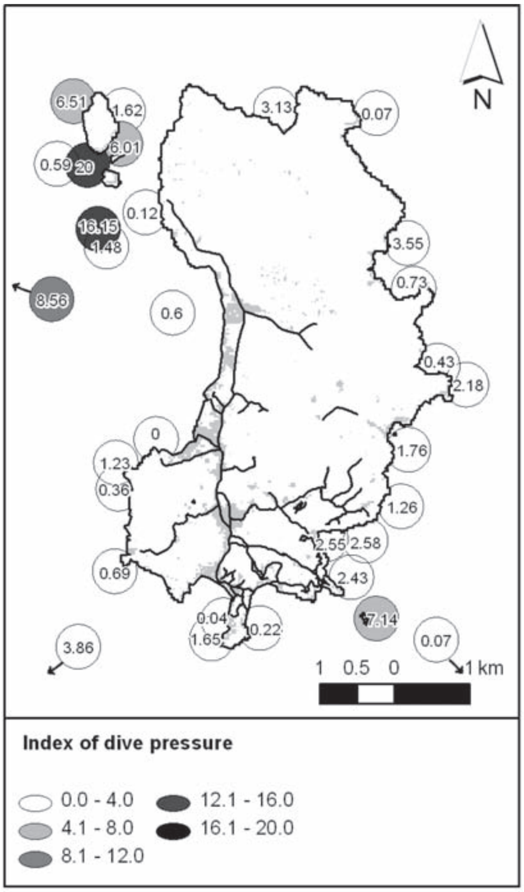

Figure 7 Stress caused by diving relative to the most visited dive site, with dive pressure based on questionnaire responses from 23 dive shops.

due to optical disturbance caused by the sea water column (Mumby *et al.,* 1998), keeping in mind that the gaps have been interpolated. A high level of accuracy was achieved for all classifications due to the high number of training sites relative to the size of the study area. Moreover, the resubstitution method that was used for the accuracy assessment was rather optimistic (Landgrebe, 2003)

Following the trend from 1975 to 2005, it is likely that shore areas with lower elevation and the smaller scattered areas would be lost next. This would suggest that Tanote will lose more rainforest in the emerging years and Hin Wong will also start to be affected soon, if nothing is done.

Modeling

On the western side of the island, large areas of watersheds have been developed and the watersheds here are relatively large for Koh Tao thus increasing the effects of erosion-related sedimentation. The southeast showed a lower grade of erosion-related sedimentation, but this was in fact due to the more recent loss of the forested areas and the effects are much worse than the model displays.

The sedimentation model does not regard the influence of currents; therefore Sairee and Mae Haad show higher stress levels than Chalok Baan Kao while it is very likely that the closed character of Chalok Baan Kao Bay would increase the effects of sedimentation on the reef.

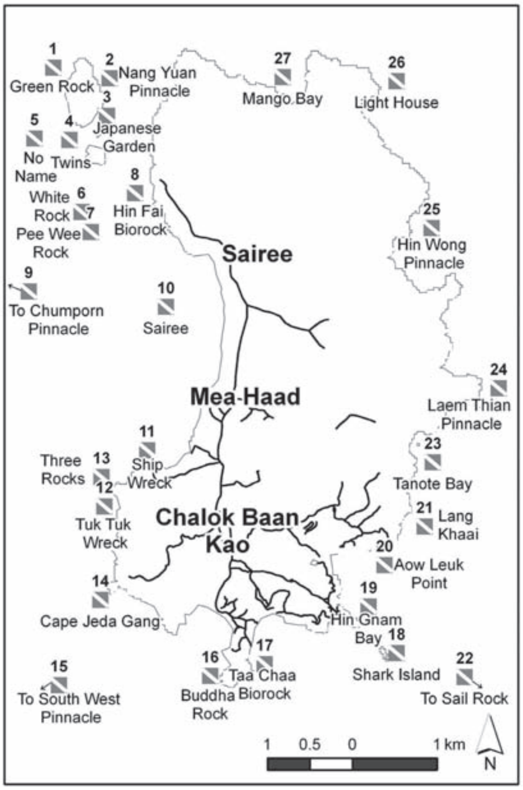

Figure 8 Map of dive sites around Koh Tao.

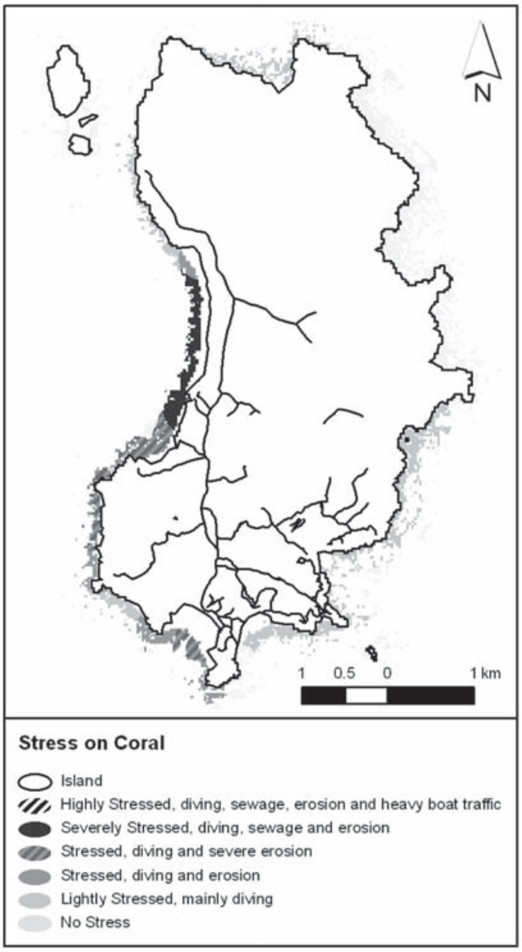

Figure 9 Model outcomes for all major threats to the coral reefs on Koh Tao.

The questionnaire showed that the two dive sites of Japanese Garden and Mango Bay suffered severely from physical damage, even though they were not the most visited dive sites. What these sites do have in common is commercialized snorkeling; therefore this stress factor was weighted with maximum pressure value for a single parameter (non commercialized snorkeling areas were given half of this value). In general, snorkeling causes more damage to corals than diving because snorkeling is shore based (the majority of dive operators do not practice shore dives but dive from boats); therefore most snorkelers have to walk on the reefs prior to swimming (Leujak and Ormond, 1999).

Dive sites around Koh Tao were not evenly used; some dive sites were visited by 10 dive shops a day whereas others were hardly visited. A high concentration of divers causes more damage to a reef than when they are more equally distributed (Zakai and Chadwick-Furman, 2002; Hasler and Ott, 2008). Mango Bay and Japanese Garden were dive sites often used by novice divers, who cause more damage than advanced divers (Zakai and Chadwick-Furman, 2002). To get a better understanding of these effects future research should include the skill level of the divers at the different sites and possibly measure the actual damage.

CONCLUSION

During the last few decades, Koh Tao has experienced rapid deforestation. Currently, only the northeast of the island has somewhat natural vegetation. The deforestation has caused soil erosion which has led to sedimentation on the coral reefs. Most of the island has been affected by this sequence of problems, but the southeast of the island is probably affected the most due to the more recent deforestation there. It is likely that reefs in Hin Wong and Mango Bay will be the next to suffer from sedimentation if the trend in deforestation continues.

Reef recreation is another stressor for the reefs; it appears that diving is highly concentrated at certain dive sites. However, while diving is expected to physically damage the reefs, commercially organized snorkeling trips seem to be more problematic. Other threats to the marine ecosystem are more local instead of island wide and are probably less serious. Nevertheless, waste water disposal could be a big problem with the rapid uncontrolled development of resorts.

ACKNOWLEDGEMENTS

This report was made possible by Mr. Chad Scot and Mr. Devrim Zahir (Save Koh Tao, New Heaven Dive School) and USGS who are all thanked for supplying data, equipment and the opportunity to carry out the work. The author is grateful to the dive schools that cooperated with the questionnaire and the volunteers that helped with conducting the surveys. Special thanks are extended to the Dutch governmental organization IB-group who granted the scholarship for conducting this study.

LITERATURE CITED

Bello-Pineda, J., M. A. Liceaga-Correa, H. Hernández-Núñez and R. Ponce-Hernández. 2005. Using aerial video to train the supervised classification of Landsat TM imagery for coral reef habitats mapping. **Environ. Monit. Assess.** 105: 145–164.

Bruno, R., M. Follador, M. Paegelow, F. Renno and N. Villa. 2006. Integrating remote sensing, GIS and prediction models to monitor the deforestation and erosion in Peten Reserve, Guatemala. **11th International Congress for Mathematical Geology.** 8: 13.

Campbell, J.B. 1996. **Introduction to Remote Sensing.** 2nd ed. The Guilford Press. New York. 622pp.

Carver, S. 1998. **Innovations in GIS 5.** Taylor & Francis Ltd. London, UK. 233pp.

Cuevas-Juménez, A., P.L. Ardisson and A.R. Condal. 2002. Mapping of shallow coral reefs by colour aerial photography. **Int. J. Remote Sens.** 23: 3697–3712.

ESRI, 2006. **ArcGIS 9.2 Desktop©.** Environmental Systems Research Institute. New York, USA.

Hasler, H. and J.A. Ott. 2008. Diving down the reefs? Intensive diving tourism threatens the reefs of the northern Red Sea. **Mar. Pollut. Bull.** 56: 1788–1794.

Hoek, K.A.V.D., B. Bouland, W. Neven, H. Mensing and T. Weisscher. 1980. **Reefs, Corals and Deep Sea.** Lekturama. Leiden. 128pp.

IDRC. 1998. **Economic Valuation of Mangroves and the Roles of Local Communities in the Conservation of Natural Resources: Case Study of Surat Thani, South of Thailand.** International Development Research Centre. EEPSEA. Singapore. 60pp.

Ismail, M.H. and K. Jusoff. 2008. Satellite data classification accuracy assessment based from reference dataset**. Int. J. Comput. Inf. Sci.** 2: 96–102.

Kechu, Y. and W. Wentao. 1984. On removing cloud interference in remote-sensing images. **J. Electron. (China)** 1: 18–27.

Landgrebe, D.A. 2003. **Signal Theory Methods in Multispectral Remote Sensing.** John Wiley & Sons. Hoboken, USA. 508pp.

Leujak, W. and R.F.G. Ormond. 1999. Reef walking on Red Sea reef flats: Quantifying impacts and identifying motives. **Ocean Coast. Manage.** 51: 755–762.

Microsoft Corporation. 2007. **Microsoft Office 2007©,** Microsoft Corporation, Redmond, USA.

Mumby, P.J., C.D. Clark, E.P. Green and A.J. Edwards. 1998. Benefits of water column correction and contextual editing for mapping coral reefs. **Int. J. Remote Sens.** 19: 203–210.

Mumby, P. J., W. Skirving, A.E. Strong, J.T. Hardy, E.F. LeDrew, E.J. Hochberg, R.P. Stumpf and L.T. David. 2004. Remote sensing of coral reefs and their physical environment. **Mar. Pollut. Bull.** 48: 210–228.

Ouchi, K. 1984. Two-dimensional imaging mechanisms of ocean waves by synthetic aperture radars. **J. Phys. D Appl. Phys.** 17: 25–42.

Purdue Research Foundation. 2010. **MultiSpec 3.2©.** Purdue Research Foundation Inc. West Lafayette, USA.

Quantum GIS Development Team, 2009. **Quantum GIS Metis 0.11.** Open Source Geospatial Foundation Project.

Roettger, S. 2006. **NDVI-Based Vegetation Rendering.** Computer Graphics Group, University of Erlangen, Erlangen, Germany. 5pp.

SATLP. 2009. **Koh Tao Info; All You Need to Know about Turtle Island.** 3rd Quarter 2009. Samui AdTack Limited Partnership (SATLP). Koh Samui. 103pp.

Scott, C. 2008a. **Koh Tao Future?** Save Koh Tao: Marine Conservation, Koh Tao. 11pp.

Scott, C. 2008b. **Loss of Tanote Bay: Analysis and Request for Assistance.** Save Koh Tao: Marine Conservation, Koh Tao. 6pp.

Scott, C. 2009. **Koh Tao Ecological Monitoring Program Project Manual.** Save Koh Tao: Marine Conservation, Koh Tao. 33pp.

The Coral Reef Alliance. 2005. **Watersheds and Healthy Reefs.** The Coral Reef Alliance. San Francisco. 2pp.

Wilkinson, C.R. 1999. Global and local threats to coral reef functioning and existence: review and predictions. **Mar. Freshwater Res.** 50: 867–878.

Xia, H. and P. Guo. 2009. Decomposition mixed pixels of remote sensing image based on 2-DWT and kernel ICA. **Neural Inf. Process.** 5863: 373–380.

Zakai, D. and N.E. Chadwick-Furman. 2002. Impacts of intensive recreational diving on reef corals at Eilat, northern Red Sea. **Biol. Conserv.** 105: 179–187.