Modelling the Potential Impact of Sea-Level Rise

A Study on the Loggerhead Sea Turtle Nesting Habitat in Crete Island - Greece

Irawan Asaad

February, 2009

Modelling the Potential Impact of Sea-Level Rise

A Study on the Loggerhead Sea Turtle Nesting Habitat in Crete Island - Greece

by

IRAWAN ASAAD

Thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation - Natural Resources Management

Thesis Assessment Board

Chair	: Dr. Ir. C.A.J.M. de Bie (Department of Natural Resources, ITC)
External Examiner	: Dr. P. Lymberakis (Department of Zoology, University of Crete)
Supervisor	: Dr. A.G. Toxopeus (Department of Natural Resources, ITC)

Supervisors : Dr. A.G. Toxopeus (Department of Natural Resources, ITC)
Dr. T.A. Groen (Department of Natural Resources, ITC)

ITC

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS

Disclaimer

This document describes work undertaken as part of a programme of study at the International Institute for Geo-information Science and Earth Observation. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the institute.

Abstract

Sandy beaches, the exclusive nesting habitat of the Loggerhead sea turtle, could reduce both in quality and quantity due to sea-level rise. The aim of this study was to investigate the nesting habitat suitability of sea turtle and possible effects of the potential sea-level rise to these habitats.

A set of coastal physical parameters composed of sand characteristics and climatic data were used to identify the parameters that determine the suitability of certain beaches as nesting beaches and a set of beach profile data has been used to assess the impact of sea-level rise to those beaches.

Fourteen coastal physical parameters were categorized as different significantly for nesting and non-nesting beaches i.e. sand salinity, sand conductivity, NaCl content, sand grain shapes, minimum and maximum temperature in the months of May and July, precipitation and solar radiation in the months of May, July and September. Using a backward stepwise logistic regression, three parameters were categorized as the most important parameters and possibly influencing the nesting habitat suitability of the Loggerhead sea turtle i.e. precipitation in month of May, sand grain shape and sand salinity.

The impact of the sea-level rise within a beach has been analyzed using a coastal elevation model that has been developed from beach profiles data. Using a moderate scenario, with a 0.4 m rise of sea-level, up to 50 % of the total beaches area will be lost and the preferred nesting range will be reduced from 43.8 % to 17.1 % of the total beaches area. More than 69 % of the land-covers behind the beaches were categorized as "protected" that prevent the beaches to shift landward as an adaptation to sea-level rise. The threat of sea-level rise to the nesting habitat coupled with the uncontrolled coastal development will affect the viability of sea turtle to survive decades later.

Keywords : *Loggerhead sea turtle, Carreta carreta, sea-level rise, climate change, nesting habitat suitability, coastal physical parameters, coastal elevation model*

Acknowledgements

Alhamdulilahi Rabbil Alamin, Praise to Allah SWT, the most gracious and merciful, who gave His guidance, will and strength to successfully accomplish my study at ITC.

First of all I would like to express my gratitude to my first supervisor Dr. Bert Toxopeus. Thanks for inspiring discussion during research preparation, great and instructive field work and insightful comments during thesis writing; and my co-supervisor Dr. Ir. Thomas Groen, for valuable suggestions, scientific and critical comments to improve this thesis project. Indeed I owe both of you for shaping this work and for your encouraging words.

I would also like to extend my gratitude to Drs. Boudewijn de Smeth for his guidance and advice during laboratory work, Mr. Valentijn Venus for his companion during the fieldwork and assisting me on spatial data preparations, Mr. Nima Moin for his constructive and clear comments on sea turtle issues, Mr. Remco Van Merm and Mr. A. Muh Ibrahim for their invaluable remarks to make this thesis scientifically understandable.

I would like to acknowledge to the Netherlands Government through StuNED fellowship programme and NESO Indonesia for giving me a great opportunity to study in the Netherlands, to my employer Forestry Department of Indonesia for granting me to continue my study, to Pusbindikaltren-Bappenas for the scholarship preparations and EAP (English for academic purposes) course.

My sincere gratitude goes to Ir . Helmi, my superior, Head of Taka Bonerate National Park, who always encourage me to continue my study and for his invaluable support during scholarships preparations, Dr. Ir. Roland A. Barkey, my undergraduate supervisor and lecturer at Hasanuddin University, who open my eyes on GIS and RS issues, and Ikhsan Ahmad, ST. MT, former Head of Marine Conservation Foundation-Indonesia. Thanks to all of you for recommending me to pursue my study at ITC-Netherlands.

I would like also to give an appreciation to Dr. Michael Weir and Ms. Ceciel Wolters and all ITC-NRS staffs who gave me a good academic atmosphere to learn many new things and to widened my knowledge on GIS and RS subject.

I'm grateful to all my cluster-mates: Saleem, Amjad, Bharat, Claudia, Nelson, Marcela, Lucia, Ali, Cosmas for their true friendship and sharing their knowledge and experience for 18 months, my fieldwork-mate: Ruben Venegas, I hope we could fieldwork together in the next sea turtle project, my Indonesians fellow : Ade, Sigit, Edy, Barmawi, Lely, Oi, Naz, Kang Syarif, Mbak Wiwin, Bu Tyas, Pak Anaz, Pak Win, Pak Arif, Suhhat, Ketut, Wansety, Evy, Susan, Fuad and others whom I cannot mention one by one, thank you for being my new family in Enschede.

Finally, my deepest gratitude goes to my lovely wife Ivo Syayadi for her endless support, immense patience and enormous strength that she gave me during the completion of my study in Enschede. Thank you for being my wife and always motivated me to pursue my never ending dreams. To my father H Asaad and my late mother Hj. St. Napisah who had given me a best education and planting the spirit of courageous. And for all Asaad's family, with their indefinite and eternal support, thank you, I dedicate this work to all of you.

Irawan Asaad

Enschede-The Nethelands

February 2009

This thesis is an outcome of the BIOFRAG–ITC internal research project in collaboration among:

- International Institute for Geo-Information Science and Earth Observation ITC, Enschede, Netherlands
- Museum of Natural History / University of Crete, Iraklion, Crete, Greece

Special thanks to Prof . Mylonas PhD, Dr. Petros Lymberakis, Dr. Stavros Xirouchakis, Dr. Michalis Dretakis and Manolis Nikolakakis. Without their cooperation and willingness to share data, facilities and assistance during the fieldwork, this research would not have been possible.

Table of contents

List of figures

List of tables and appendices

List of abbreviations

AAS = Atomic absorption spectrometer
AOGCMs = The atmosphere-ocean general circulation models
AR = Assessment report
Biofrag = Biodiversity in fragmenting landscapes
CEM = Coastal elevation model
DEM = Digital elevation model
ESRA = European solar radiation atlas
FAR = Fourth assessment report
GIS = Geographic information system
GPS = Global positioning system
IPCC = Intergovernmental Panel on Climate Change
ITC = International institute for Geo-information science and Earth Observations
IUCN = International Union for the Conservation of Nature and natural resources
LiDar = Light detection and ranging
ppm = part per million
SRES = Special report on emissions scenarios
SRTM = Shuttle radar topographic mission
TAR = Third assessment report
TIN = Triangulated irregular network
UNEP = The United Nations Environment Programme
UTM = Universal transverse mercator
WGS = World geodetic system

“We can share beaches and ocean with sea turtles but it requires commitment and effort on our part. We can make certain that future generations will have the opportunity to know these unusual animals”

Archie Fairly Carr, Jr. (1909 – 1987)

1. Introduction

1.1. Background

Sea-level rise is one of the impacts associated with climate change that threatens coastal, low lying areas and small islands around the world. The IPCC (Intergovernmental Panel on Climate Change) predicts that during the next 100 years, the sea-level will increase 18 to 59 centimetres (IPCC, 2007a). Ecologically, such changes increase biodiversity loss, affecting both individual species and their ecosystems.

The Loggerhead sea turtle (*Carreta carreta*) is one of the endangered species that will be potentially threatened by such an event. Coastal areas that are used by the Loggerheads as nesting habitat will be affected by the sea-level change. Sea-level rise could reduce the suitable area for nesting habitat which in turn affects the viability of sea turtle populations.

The environmental conditions at nesting locations influence many characteristics of the hatching process, including hatching success, sex ratio, and fitness of the hatchling. However it is not clearly understood why some beaches are used as a nesting habitat and others are not. Environmental factors that potentially influence nesting suitability have been subject to many studies, but most results were inconclusive and even contradicting (Miller *et al.*, 2003).

For the reasons stated above, investigating the relevant coastal physical parameters that possibly drive nest site selection will be the first step in this research. The next stage will be to develop a model of the possible impact of predicted sea-level rise to beaches potentially suitable for the Loggerhead sea turtle nesting. The output will be valuable for stakeholders and decision makers to develop sound management strategies concerned with biodiversity, conservation and environmentally friendly beach development.

1.1.1. The Loggerhead sea turtle

Studies on sea turtles are an intricate issue, therefore it is important to have a basic knowledge about morphological and ecological aspects that will help us to understand the behaviour and lifestyle of this unique marine species.

The sea turtle is a reptile that exists since the early Cretaceous period, about 110 million years ago (Bowen, 2003). At the present day, seven distinct species of sea turtles still live in the world's oceans, split into two main subgroups: the family of *Dermochelyidae*, which consists of a single species i.e. *Dermochelys coriacea (*Leatherback turtle) and the six species of hard-shelled sea turtle : the family *Cheloniidae* i.e *Chelonia mydas (Green turtle), Eretmochelys imbricata* (Hawksbill turtle)*, Natator* *depressus* (Flatback turtle), *Caretta caretta* (Loggerhead turtle), *Lepidochelys kempii* (Kemp ridely turtle), *Lepidochelys olivacea* (Olive ridely turtle) (SWOT, 2006).

The Loggerhead turtle (*Carreta carreta*) is the largest sea turtle in the family Cheloniidae (Alderton, 1998). The genus name "*Caretta*" is a latinization of the French "caret" meaning turtle, tortoise or sea turtle. Loggerheads were named for their relatively large head compared to their body pit.

The Loggerhead turtle are globally distributed and have the greatest geographic range of nesting beaches and foraging areas, in both the temperate and tropical latitudes, and the diet is the least specialized of all sea turtle (Bolten, 2003). Loggerhead turtles are divided in five meta-populations: the Atlantic Ocean, Pacific Ocean, Indian Ocean, Caribbean and Mediterranean Sea.

The Loggerhead has a significant role in marine and coastal ecosystems, particularly in balancing food and energy cycles. The adult turtle are one of the top predators in the oceans, while the juvenile are food sources of marine and terrestrial predators. Its reproductive behaviour is a bridge in the transfer of energy and matter from the ocean to the nesting beaches that affect the ecology of terrestrial consumers (SWOT, 2007).

1.1.1.1. Morphology and life cycle

The loggerhead turtle can reach an average length of 95 cm and a weight of 120 kg. The carapace (top shell) is slightly heart-shaped and reddish brown in adults and sub adults with 5 vertebral and usually 5 pairs of costal scutes, while the plastron (bottom shell), is generally of a pale yellowish colour. The neck and flippers are usually dull brown to reddish brown on top and medium to pale yellow on the sides and bottom (Kamezaki, 2003). They are mainly carnivorous, feeding on molluscs, crustaceans, fish, jellyfish, and other small to medium-sized marine animals.

The life cycle of this species begins in the nesting chambers on the sandy beaches. The egg will hatch, under normal conditions, after 13 weeks of incubation. The hatchling spends more than 2 days in the nest before moving upwards to the beach surface. Hatchlings emerge from the nest from July until October, mostly at night, in mass or small groups to reduce exposure to predators (Cross *et al.*, 2005). Once they are on the beach surface they crawl towards the sea guided by its brightness, which is identified primarily by vision. It seems that hatchlings are more sensitive to cool lights (blue). They search for the highest brightness in the horizon, which should be the reflection of the moonlight in the sea water (Cross *et al.*, 2005). After entering the water, the hatchlings swim rapidly offshore taking advantage of the retreating tide. After this, most sea turtles are rarely seen. Some scientists call this period the "Lost Years". The loggerhead reaches sexual maturity at 20 - 30 years (Encalada *et al.*, 1998), at which point they start their developmental migration to their breeding habitat (where they were born) to prepare for a new life cycle (Cross *et al.*, 2005).

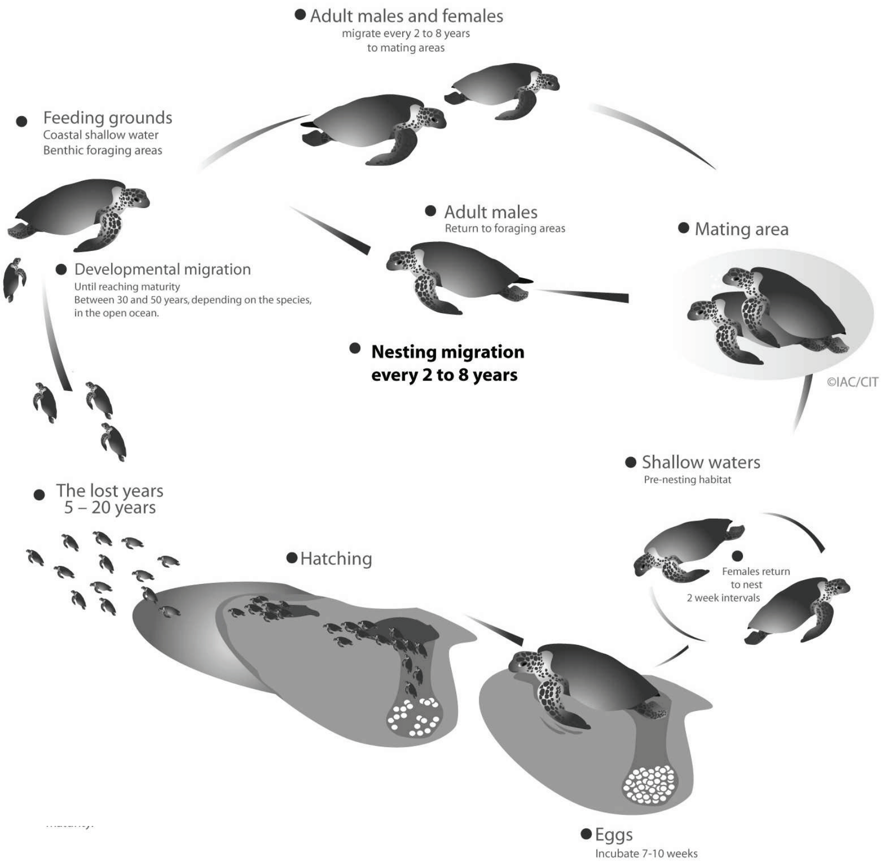


Figure 1. Generalized life cycle of a sea turtle (IAC-Seaturtle, 2008)

1.1.1.2. Nesting ecology

The environmental condition of the nesting site is a key component for hatchling success and related to the hatchling characteristics such as sex ratio, emergence success and fitness of the hatchling (Mazaris *et al.*, 2006). Although it is not clearly understood which are the specific parameters that governs a female sea turtle to select one beach to become a nesting beach, Miller *et al*. (2003) stated that the environmental conditions of the potential nesting beaches must meet several requirements that support embryonic development and survival.

Mortimer (1990) explained that the nesting site must be easy to access from the oceans, high enough to avoid inundation, the sand must have enough cohesion power to build a nesting chamber, the particle size of the sand should be fine enough to facilitate the gas aeration and the temperature should be warm enough to support the egg development. Therefore, sand characteristics such as temperature, salinity, moisture, conductivity, sand grain size, grain shape, sodium chloride and carbonate content are considered as a parameter that is correlated to the suitability of nesting beaches.

1.1.2. The current status of sea turtle in the Mediterranean Sea

The Mediterranean sea covers an area of about 2.5 million km^2 (965,000 sq mi), almost completely enclosed by continental land (Asia, Africa, Europe) but connected to the Atlantic Ocean by the Strait of Gibraltar to the west and roughly divided by two different basins i.e. the eastern and the western basin (Miller *et al*., 2003).

The marine biotas of the Mediterranean are primarily from the Atlantic Ocean. There are three species of sea turtles that live in the Mediterranean Sea, i.e. the Loggerhead turtle, the Green turtle and the Leatherback turtle. However, only two of those species nest on the Mediterranean beaches (Caminas, 2004) and the Loggerhead sea turtle is the most abundant in the Mediterranean Sea (Margaritoulis *et al.*, 2003).

The eastern basin of the Mediterranean Sea is habitat to the Loggerhead sea turtle. Greece, Cyprus, Turkey, Israel, and Tunisia are considered as the main host for breeding, in contrast to countries as Egypt, Italy, Libya, and Syria, where low breeding activity is recorded. The total nesting activity ranges from 3,375 to 7,085 nests per season (Margaritoulis *et al.*, 2003). Figure 2 shows the potential nesting area of the Loggerhead's along the Mediterranean cost.

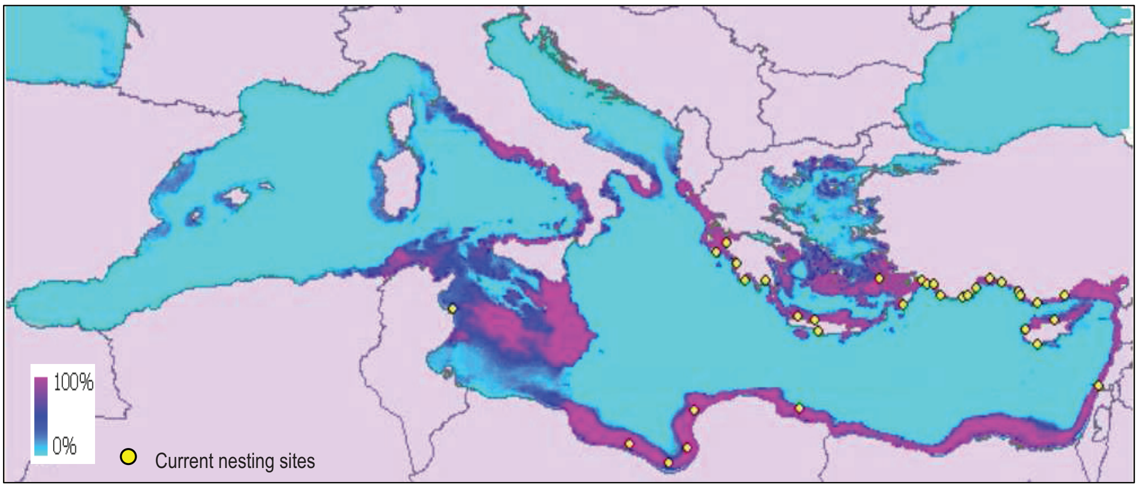


*Figure 2***.** Map of suitability assessment of the potential nesting beaches in the Mediterranean area (Moin, 2007)

The Loggerhead sea turtle is categorized as an endangered species on IUCN's red list (IUCN, 2007). Other international organizations and conventions such as CITES (The Convention on International Trade in Endangered Species of Wild Fauna and Flora), Bonn Convention (The Convention on the Conservation of Migratory Species of Wild Animals), Bern Convention (The Convention on the Conservation of European Wildlife and Natural Habitats), and Barcelona Convention (The Convention on the Protection of the Mediterranean Sea against Pollution) also consider this species as an endangered and threatened species and take actions to protect and conserve it.

The international community is highly concerned about the Loggerhead status due to the declining population trend. This critical status is mainly caused by human-induced pressures (SWOT, 2006).

The Marine Turtle Specialist Group of the World Conservation Union (IUCN) identified that there are at least five major threats from human behaviour to the survival of sea turtles i.e. fisheries, coastal development, direct harvesting, pollution and pathogens, and global warming (SWOT, 2007).

In the Mediterranean area, Greece is the most important nesting site. The nesting sites are dispersed along Greece's western and southern coast line and on the island of Crete (Margaritoulis *et al.*, 2003). In Greece, Zakynthos in Laganas bay is the highest density nesting beach with an average of 236.6 nests/km followed by Peloponnesus and Rethymno on Crete Island. Table 1 shows the details of annual nesting activity on the major nesting areas in Greece.

Table 1. Data of annual nesting activity in Greece (Margaritoulis *et al*., 2003; Margaritoulis and Rees, 2003)

Nesting Area	Beach length (km)	Number of season	Number of nest/season			Average nesting density (nest/km)
			Average	*Min*	*Max*	
Zakynthos, Laganas Bay	5.5	16	1,301.3	857	2,018	236.6
Peloponnesus, Kyparissia Bay	9.5	15	580.7	286	927	61.13
Rethymno, Crete	10.8	8	387.3	315	516	35.86
Lakonikos Bay	23.5	7	191.9	107	239	8.17
Chania Bay, Crete	13.1	6	114.9	77	192	8.77
Messara Bay, Crete	8.1	8	53.5	15	80	6.61
Koroni	2.7	5	55	35	66	20.37

The Loggerhead sea turtles in Greece are threatened by human-induced pressures. The most important threats for the Loggerhead are coastal development and extensive urban expansion for tourism and recreations (Arianoutsou, 1988; Margaritoulis *et al.*, 2003). Demetropoulus (2000) stated that influence from beach development such as beach erosion, sand compaction, and marine pollution affect nesting success. Lima (2008) explained that due to the increases of the tourism industry since early 1960's, the highly suitable nesting beach of the Loggerhead's in Rethymno-Crete has decreased by 50 percent. Nonetheless, the effects from global warming, one of the sea turtle burning issues, has not been really explored yet particularly the threats related to loss of nesting habitat.

1.1.3. Climate change, sea-level rise and biodiversity

1.1.3.1. The predicted impact of sea-level rise

The IPCC (Intergovernmental panel on climate change) defines that: "Climate change refers to a statistically significant variation in either the mean state of the climate or in its variability, persisting for an extended period (typically decades or longer). Climate change may be due to natural internal processes or external forcing or to persistent anthropogenic changes in the composition of the atmosphere or in land use" (IPCC, 2007a).

The major impact of changes in the climate system are unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea-level (IPCC, 2007a). The global average temperature increased about 0.15 °C and 0.3 °C in 1990 – 2005, or about 0.2 °C per decade. Global average sea-level rose an average rate of 1.8 (1.3 to 2.3) mm per year over 1962 – 2003.

This global sea-level change is driven by two major processes: the increase of water volume in the global ocean because of thermal expansion and the loss of land-based ice due to increased melting (Bindoff *et al.*, 2007).

The impact of global sea-level rise to coastal areas has been of major concern since the last century. International focus is given to human population living in coastal areas and small island, as those are directly affected by the impacts of climate change through sea-level rise. While coastal areas only cover 4 % of the total earth landmass it nonetheless supports almost 23 % of earth's human population (UNEP, 2006) and the utilization is steadily increasing since the 20th century, where at least 634 million people live within 10 meters of sea-level and two third of the world cities with a population over five million are in coastal area (McGranahan *et al.*, 2007). An increase in the global average temperature and sea-level are among the impacts that threaten coastal area physically, socially and ecologically.

In order to provide a policy-relevant advice on the consequences of human induced climate change in the 21st century, IPCC developed emission scenarios known as Special Report on Emission Scenarios (SRES). Based on SRES, the IPCC Fourth Assessment Report (FAR)-2007 predicted that global warming will lead to a sea-level rise of 18 to 59 cm by the years 2090-2099 (Solomon *et al.*, 2007). The predicted global temperature and sea-level rise on different scenarios are presented in Figure 3 and Table 2.

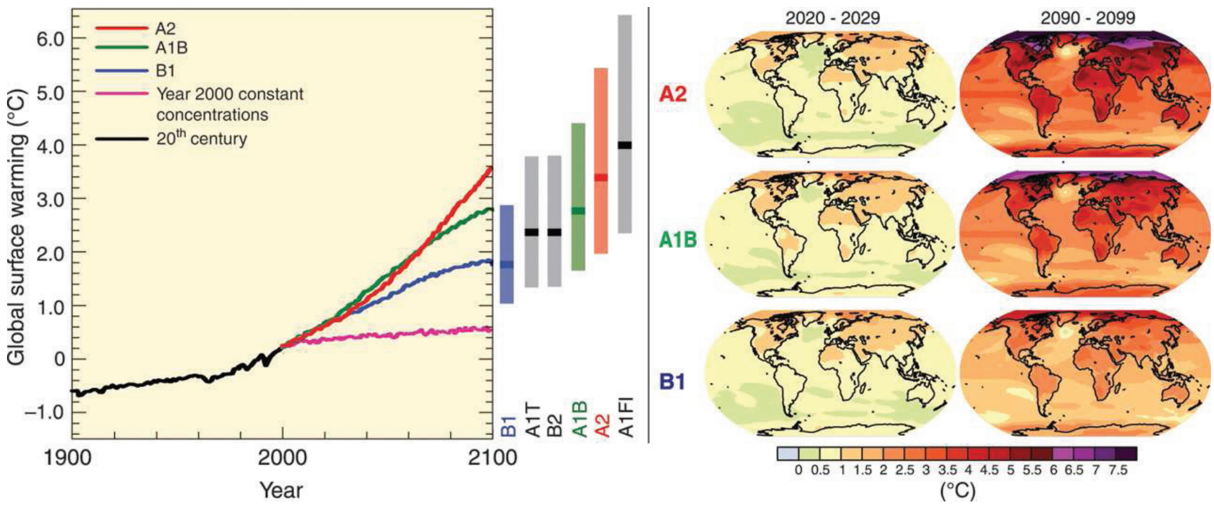


*Figure 3***.** General circulation model projections of surface warming (IPCC, 2007c)

Note : *Left panel* : The global surface temperature projections based on IPCC predictions

Right panels : Projected surface temperature changes for the early and late 21st century relative to the period 1980-1999.

Table 2. Projected global average surface warming and sea-level rise at the end of the 21st century (IPCC, 2007a)

Case	Temperature Change (^{0}C at 2090-2099 relative to 1980-1999)[a]		Sea-Level Rise (m at 2090-2099 relative to 1980-1999)
	Best estimate	***Likely Range***	***Model-based range including future rapid dynamical change in ice flow***
Constant Year 2000 concentrations [b]	0.6	0.3 – 0.9	NA
B1 scenario	1.8	1.1 – 2.9	0.18 – 0.38
A1T scenario	2.4	1.4 – 3.8	0.20 – 0.45
B2 scenario	2.4	1.4 – 3.8	0.20 – 0.43
A1B scenario	2.8	1.7 – 4.4	0.21 – 0.48
A2 scenario	3.4	2.0 – 5.4	0.23 – 0.51
A1F1 scenario	4.0	2.4 – 6.4	0.26 – 0.59

Note [a].These estimated are assessed from hierarchy of models that encompass a simple climate model, several Earth System Models of Intermediate Complexity and a large number of Atmosphere-Ocean General Circulation Model (AOGCMs)
[b] Year 2000 constant composition is derived from AOGCMs only
For scenario abbreviations, refers to IPCC, 2007a

The impacts of sea-level rise will affect the physical systems as well as biological systems in coastal areas. Such impacts may include increased coastal erosion, extensive coastal inundation (Snoussi *et al.*, 2008), increased flood risk, potential loss of life and property (Thumerer *et al.*, 2000; Dasgupta *et al.*, 2007), loss of non-monetary cultural resources and values, impacts on agriculture and aquaculture through decline in soil and water quality, loss of tourism, recreation, and transportation functions (IPCC, 2007b), impact on biodiversity and species habitat loss (Brander, 2003; Fish *et al.*, 2005; Roessig *et al.*, 2004). Moreover, due to the complexity of coastal environment, the impact will be varying on local and regional level as well as in time and space.

1.1.3.2. Sea-level rise and biodiversity

One of the impacts due to sea-level is on ecological system. An ecological system in coastal area provides valuable ecological services to a large number of species in terms of feeding, nesting and nursery grounds (UNEP, 2006). A coastal area also forms a natural barrier from adjacent habitats (such as lagoons and wetlands) and important nesting sites for several endangered species such as sea turtles (Fish *et al.*, 2005). Such services will be hampered by sea-level rise. On the species level, climate change and sea-level rise can cause species extinction, change in distribution and abundance of species and probably threaten some sensitive systems, such as coral reefs, mangroves, sandy beaches and other coastal systems (Brander, 2003).

The effect of sea-level rise to endangered species has been observed by several researchers. Daniels *et al*. (1993) stated that by increases in sea-level of 31 to 150 cm, endangered species in South Carolina USA will be threatened by saltwater intrusion, temporary flooding, inundation or erosion. These impacts will result in the destruction of nesting and feeding areas. Baker *et al*. (2006) found that by an increase of sea-level between 9 – 88 cm, at least 65% under a median scenario (48 cm rise) and

75% under the maximum scenario (88 cm rise) terrestrial habitats of endangered and endemic mega-fauna in the North-western Hawaiian Islands will be lost. Robinson *et al.(*2008) highlighted several impacts of climate change and sea-level rise to the migratory species such as loss of breeding habitat of sea turtle, marine mammals and fish as well as loss of non-breeding habitat of birds and marine mammals. A summary of the impact of climate change to the migratory species is shown in Table 3.

Table 3. Summary of likely climate change impacts on population dynamics of migratory species (Robinson *et al*., 2008)

	Sea turtle	Birds	Marine mammals	Fish
Number of migratory species	7 (100 %)	1530 (16 %)	43 (36 %)	874 (3 %)
Knowledge	**	***	**	*
Increased temperatures	Yes	Yes	Yes	Important
Changed precipitation	Yes	Yes	No	No
Loss of breeding habitat	Important	Yes	Important	Yes ?
Loss of non-breeding habitat	No ?	Yes (important for some)	Yes	-
Loss of migration	No ?	Yes (important for some)	No ?	Yes ?
Longer migratory pathways	No ?	Yes	Yes	?
Changes in food availability	-	Yes	Important	Yes
Miss match in timing	-	Important ?	?	Yes
Interspecies competition	No	?	No ?	No ?

Note : *** good for at least some species, ** moderate for at least some species , * little or no knowledge.
? : area of particular uncertainty. - : factors not generally relevant for a group

1.2. Research Problem

Anthropogenic factors exert major pressure on coastal areas that are providing the exclusive nesting habitat for sea turtle. However, the main factors that govern the sea turtle to choose a beach to be a nesting beach are not clearly understood yet and subject to several studies. Results from these studies have identified numerous environmental parameters associated with nesting ecology e.g. width, slope and vegetation cover of the beach, salinity, particle size of the sand, pH, organic content, conductivity, water content, sand temperature, clay layer, sand texture (Miller *et al*., 2003; Mazaris *et al*., 2006).

Wood and Bjorndall (2000) concluded that sea turtles are likely to use multiple environmental factors in nest site selection either by integrating environmental information or by using critical thresholds that must be reached for each one of these environmental factors. Despite this considerable attention, interestingly, many of the studies only focused on the nesting beaches, ignoring the non-nesting beaches that are relatively nearby. A comparative study of coastal physical parameters between nesting and non-nesting beaches will be an alternative approach and perhaps valuable to improve our understanding and knowledge about the possible cues driving nest site selection.

Several studies have been carried out in order to conserve and to ensure the survival of this endangered species. However, few studies have been done to investigate the impacts of anthropogenic factors on the survival of this species. And also from the branch of climate change research, only a few studies have been done to assess the impacts to this endangered species.

Climate change has various impacts to the sea turtle. Almost the entire life cycle of the sea turtle is affected by climate change. Possibly, the most vulnerable area is the nesting habitat (SWOT, 2007). The development of the egg during the incubation period is determined by the nest environment i.e. the temperature, moisture and gas exchange (Carthy *et al.*, 2003). When global temperatures increase, nesting temperature is also likely to increase. As for most reptiles, nest temperature regime determines the sex ratio of the sea turtle hatchlings, where warmer temperatures produce more female hatchling (Mrosovsky, 1994; Yntema and Mrosovsky, 1980). A nesting beach needs stability over time to ensure the continuity of the nesting activity. The increase of storm intensity will affect the stability of the beach topography, and the sea-level rise might result in habitat loss. So far, little attention has been paid to the impact of sea-level rise to sea turtle nesting habitat, except by Fish *et al.* (2005), who predicted that up to 32% of Caribbean sea turtle nesting habitat will be lost with 0.5 m sea-level rise and 26 % of Barbados turtle nesting habitat will be lost with 0.5 m sea-level rise (Fish *et al.*, 2008). Because of the limited amount of research in this field, the study on the impact of sea-level rise to the Loggerhead sea turtles will be a good contribution to conservation strategies. This kind of research will be valuable to stakeholders to understand the impacts from this event and prepare alternatives for mitigating adverse effects.

For this reason, it is important to analyze to which extent sea-level rise can affect the nesting beaches. The identification and knowledge of this kind of impact will be advantageous to develop sound management decisions, to manage beach development and to decide for the right conservation programmes.

1.3. Research Objectives

1.3.1. General objective

This research aims to investigate the nesting habitat suitability of sea turtle and possible effects on these habitats from a potential sea-level rise.

1.3.2. Specific objectives

1 a). To analyze the differences between coastal physical parameters of nesting and non-nesting beaches

b). To find out the coastal physical parameters than can explain the selection of certain beaches as nesting beaches.

2 a). To assess the potential habitat loss of the Loggerhead sea turtle nesting site due to inundation by the predicted sea-level rise.

b). To assess the potential shift landward of the Loggerhead sea turtle nesting site due to inundation by the predicted sea-level rise.

1.4. Research Questions

1 a). What are the differences between coastal physical parameters in nesting beaches and non-nesting beaches?

b). Which are the important coastal physical parameters that are highly correlated with the nesting habitat of the Loggerhead sea turtle?

2 a). How much area of the nesting beaches will be lost due to predicted sea-level rise?

b). How much area of the nesting site will be shifted landward due to predicted sea-level rise?

1.5. Research Hypotheses

There are two hypotheses for this research:

- $H1_0$: The investigated coastal physical parameters do not have a significant difference in non-nesting beaches and nesting beaches.

  $H1_1$: The investigated coastal physical parameters do have a significant difference in non-nesting beaches and nesting beaches.
- $H2_0$: There are no coastal physical parameters that are significantly important to nesting habitat of the Loggerhead sea turtle.

  $H2_1$: There are coastal physical parameters that are significantly important to nesting habitat of the Loggerhead sea turtle.

2. Material and Methods

2.1. Study Area

Crete is the biggest island in Greece, situated in the Mediterranean Sea, in the southern part of Greece. Geographically, Crete lies from 23°31' to 26°18' E and from 34°55' to 35°41'N. Crete has an elongated shape that covers an area of 8,336 km^2, with a length of 260 km, and a width that spans from 12 to 60 km. The total length of the Cretan coastline is 1046 km and consists of both sandy beaches and rocky shores (West-Crete, 2008). Administratively Crete is divided in four nomoi or prefectures i.e. Chania, Heraklion, Lassithi and Rethymno, and it has approximately 630.000 inhabitants (Explore-Crete, 2008)

Crete is a mountainous island with three different groups of high mountains i.e Lefka Ori, Psiloritis and Dikti mountains that stretch from east to west. Crete Island is divided in two different climatic zones i.e. Mediterranean in the northern part and North-African in the southern part. In general, the climate is temperate and quite humid. The temperature in winter is mild and ranges from 20 – 30^0C in the summer (West-Crete, 2008).

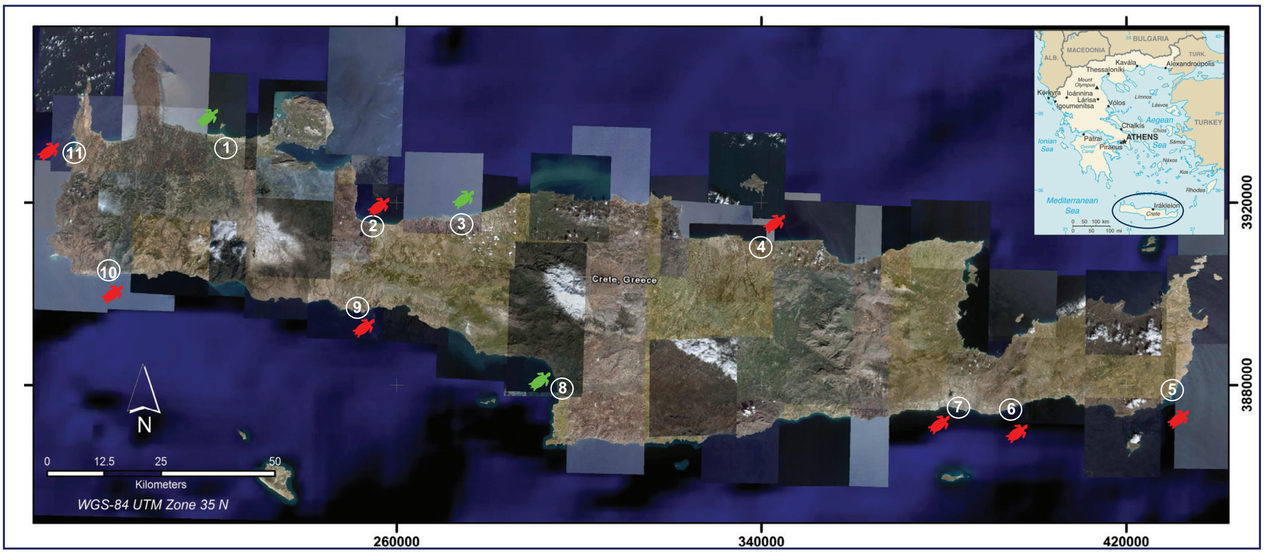
Most of the rivers in Crete are short and they dry up during the summer months. There are two Rivers that flow year-round i.e. Preveli river in Rethymno and the river at Vrisses in Chania. (Explore-Crete, 2008).

The main reason to choose Crete Island as a study area in this research is that the island of Crete has been categorized as one the most important nesting sites for Loggerhead turtle in the Mediterranean, where at least three major nesting sites are found, i.e. at Rethymno, Chania and Messara bay (Margaritoulis and Rees, 2003).

These three nesting beaches together with eight non nesting beaches are the subject of this research. For representative purposes, the chosen non-nesting beaches are spread out over the Cretan coastline i.e in the northern side of the island (Georgeopolis beach and Iraklion beach), southern side (Irapetra beach, Koutsunary beach, Frangocastelo beach and Palaechora beach), western side (Phalasarna beach) and eastern side of the island (Xerocampos beach).

The main criteria to choose non-nesting beaches as a subject of study are based on the basic nesting beaches requirements for Loggerhead sea turtle, e.g. sandy substratum, wide and fronted by a sandy flat beach (Miller *et al.*, 2003).

Figure 4. Map of Crete Island- Greece, with the investigated nesting and non nesting beaches.



Note : *1. Chania ; 2. Georgeopolis ; 3. Rethymno ; 4. Iraklion ; 5. Xerocampos ; 6. Koutsunary ; 7. Irapetra ; 8. Messara ; 9. Frangocastello ; 10. Palaechora ; 11. Phalasarna.*

= nesting beaches = non-nesting beaches

2.2. Research Scheme

Figure 5 summarizes the steps followed for the investigation of nesting habitat suitability for Loggerhead sea turtle and possible effects on these habitats from a potential sea-level rise in the island of Crete.

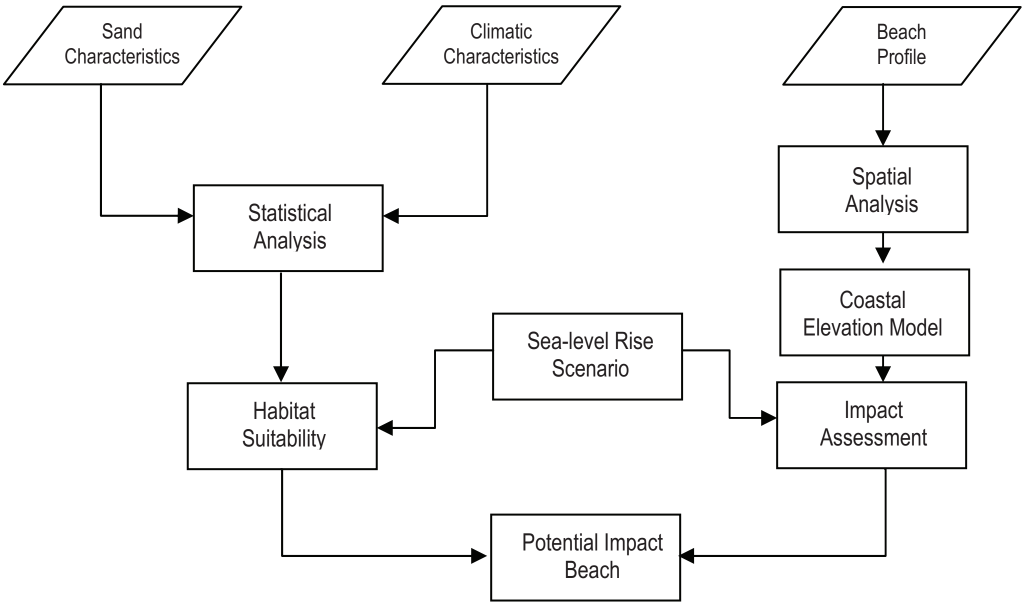


Figure 5. Research scheme
(Details are explained in the next section)

2.3. Data Collection

2.3.1. Field work preparations

Fieldwork preparation was done by preparing a set of Google Earth images of the study area. The Google earth images were downloaded using Google Earth Pro 4.2 which allows downloading high resolution images and the geo-referencing process was done using Erdas Imagine 9.2. All the images were geo-referenced to WGS-84 as geographic coordinate system and UTM-Zone 35 N as a projection system. The images were saved to img format for further spatial analysis and also converted to ecw format using ECW compressor 2.6 to make them compatible with i-Paq GPS devices. All the ecw images were transferred to a SD card for i-Paq GPS devices. A Sampling sheet was prepared to collect all the relevant data at location (See Appendix B).

2.3.2. Field work / In-situ data collection

Fieldwork was carried out from September 7th to October 4th 2008, where the fieldwork was divided in two different parts i.e. beach profile data collection and sand characteristics data collection.

The beach profiles were measured using an updated method from a standard surveying technique that was developed by Cambers (1988) and Fish *et al*. (2005). The beach profiles were measured relative to the high water mark, on every change in beach profile, using a levelling tool. The levelling tool was used to measure the height of a particular point relative to another point with an accuracy of a centimetre. The geographic coordinates were captured using the i-paq GPS device. The distance from an initial point to the next point was measured using a roll meter. The beach aspects were measured using a compass. The land use behind the beach and the activities around the beach were also recorded. The picture of every profile was taken in four directions as well as a sketch drawing of the profiles of the beach.

The sand characteristics were measured and collected in a range of 100 to 500 meters, depending on the beach profile, at a depth of 30 - 40 cm, the average depth of nesting chambers (Miller *et al.,* 2003), and the elevation range of 0.3 – 0.7 m above sea-level, the preferred nesting area for sea turtle (Maktav *et al.*, 2000).

The sand temperature, salinity, and moisture were measured in-situ using a Hydra-probe water reader. The sand temperature was measured in centigrade with a standard accuracy of ± 0.6°C, the moisture was measured in wfv (water fraction by volume) with a standard accuracy of ± 0.03 wfv. The salinity is presented in units of total Sodium Chloride (NaCl) burden (grams) per unit volume (litre), with a standard accuracy of ± 20%. Sand samples were also collected and preserved in a sealed sample bag for further laboratory analysis.

The Google Earth images were used as supporting and complementary data to get a general understanding and a wide-ranging view of the beaches.

Figure 6. The profile of a surveyed beach

Note : *Left panel : Nesting beach : Eastern part of Rethymno*
Right panel ; Non nesting beach : Eastern part of Georgeopolis

2.3.3. Laboratory analysis for sand samples

There are seven parameters of the sand samples that have been analyzed in the laboratory i.e grain size, pH, Sodium Chloride (NaCl) content, conductivity, Calcium carbonate ($CaCO_3$) content, grain shape and cleanliness.

A big portion of the sand samples were removed from the sealed bag, weighed using Digital Mettler PC 440 and air dried using Jouan oven at 105°C for one day. The 105°C was chosen as an oven dried temperature based on the assumption that all the water in the sand samples will evaporate at such temperature.

The grain size was classified by particle size analyses using a net of sieves. The sieves were ordered sequentially in 6 classes/fractions:

- Fraction 1: more or equal to 2 mm (≥ 2 mm)
- Fraction 2: more or equal to 1 mm and less than 2.0 mm (1.0 ≥ < 2.0 mm)
- Fraction 3: more or equal to 0.5 mm and less than 1.0 mm (0.5≥ <1.0 mm)
- Fraction 4: more or equal to 0.25 mm and less than 0.5mm (0.25 ≥ < 0.5 mm)
- Fraction 5: more or equal to 0.10 and less than 0.25 mm (0.10 ≥ < 0.25 mm)
- Fraction 6: less than 0.10 mm (< 0.10 mm)

For each sample, the sieving was processed using a Fritch sieving machine for 7 minutes sieving with amplitude 1.5. The sand particles of each sieving stage were weighted using Digital Mattler PC 440 and the final value of each sample was presented in percentage of total sand quantity.

The NaCl content, pH and conductivity were conducted by taking 10 grams of fresh sand samples and mixing it with 20 ml de-ionized water. These diluted samples were stirred for 2 hours in a stirring machine. After that, 5 ml of the diluted samples were preserved in a laboratory glass tube for the NaCl content measurement and the rest was preserved for pH and conductivity measurements.

The pH and conductivity analysis were measured by inserting the probe of the Hatch-multimeter HQ 40d into the diluted sample. The pH was measured with an accuracy of 0.01 and the conductivity was measured in units of micro Siemens/cm (μS/cm) with an accuracy of 0.1.

The NaCl content was measured by mixing the preserved 5 ml diluted sample with 9.5 ml de-ionized water. These extra diluted water samples were examined using AAS (atomic absorption spectrometer) to measure the NaCl content in units of part per million (ppm).

The $CaCO_3$ content was also measured using AAS (atomic absorption spectrometer) but with a different procedure. The sample was prepared by taking 10 grams of dried sand samples and mixing it with 20 ml HCl 10%. These diluted samples were stirred for 30 minutes in the stirring machine with hot water incubation. After that, 5 ml of these diluted samples were mixed with 9.5 ml of de-ionized water. These extra acid extraction samples were examined using AAS to measure the $CaCO_3$ concentration in the sand sample.

The grain shape and cleanliness of the samples were measured in the dried sand sample using a microscope with a magnification of 30 x. Through visual examinations, the grain shape, cleanliness and any significant feature were observed. The grain shape of each sample was classified as rounded, mixture (mixture of rounded and angular shape) and angular shape. The cleanliness was categorized as dust free, moderate and highly dusty.

2.3.4. Climatic data collection

A dataset has been collected for climatic parameters i.e. air temperature, precipitation and solar radiation. The data were gathered on three different months i.e. May, July and September as a representation of the initiation, intermediate and end of the sea turtle nesting season (Margaritoulis and Rees, 2003).

For air temperature and precipitation, data were derived from the Worldclim database at http://www.worldclim.org/. WorldClim is a set of global climate layers (climate grids) with a spatial resolution of 30 arc second (resolution ~ 1 km). These data are explained in Hijmans *et al*. (2005).

For solar radiation, data were derived from ESRA 2000 (European Solar Radiation Atlas) through the Biofrag-ITC gateway. This radiation dataset comprises ten-year (1981-1990) averages of monthly means of daily radiation in watt hour per square meter (Wh/m^2).

2.4. Data Analysis

2.4.1. Habitat suitability assessment

The Loggerhead sea turtle nesting habitat suitability was determined by investigating a set of coastal physical parameters i.e. sand characteristics (from field work and laboratory analysis) and climatic characteristics.

There were two types of analysis. The first analysis focused on determining the difference in value of each parameter in the nesting and non-nesting beaches. The second analysis focused on the identification of the relationship between the nesting beaches and the coastal parameters, and to determine the parameters that are correlated with the nesting activity. All of the analyses were done using SPSS 16.

In order to determine the difference in value of each parameter, independent t-tests and chi-square (X^2) significance tests were applied.

The Independent t-test is used to test the statistical significance of a possible difference between the means of a continuous variable of two groups on some independent variable where the two groups are independent of one another. The independent t-test is simple, straightforward and adaptable to a broad range of situations (Lowry, 1999). The two groups are non-nesting beaches and nesting beaches. The independent variables are sand temperature, sand moisture, sand salinity, pH, conductivity, NaCl content, $CaCO_3$ content, air temperature, precipitation and solar radiation.

A chi-square (X^2) statistic is used to investigate whether distributions of categorical variables differ from one another. The chi-square statistic is computed as the sum of the squared difference between the observed frequency and the theoretical frequency divided by the theoretical frequency (Field, 2005). The variables that are tested using a chi-square test are sand grain size, sand grain shape, and sand cleanliness.

In order to determine the parameter that highly correlated with the suitable beaches, a logistic regression technique with backward stepwise likelihood method was used.

Binomial (or binary) logistic regression is a form of regression which is used when the dependent variable is dichotomous and the independent variables are of any type. The logistic regression can be used to predict a dependent variable on the basis of continuous and/or categorical independent variable, to rank the relative importance of independents, to assess interaction effects and to understand the impact of covariate control variables (Field, 2005).

The backward stepwise likelihoods method was chosen because this method includes all the predictor parameters in the first model. At each step, the predictor that contributes the least is removed from the model, until all of the predictors in the model are significant (Field, 2005). Therefore, it allows exploring the importance and significance of each of the (possible) explaining parameters.

The parameters that are included in the logistic regression analysis were the parameters that based on the previous statistical test (i.e. independent t-test and chi-square test) have a significant difference in their mean value ($p<0.05$).

The multicollinearity problem among the parameters was also assessed as the logistic regression is potentially affected by multicollinearity. Multicollinearity refers to excessive correlation of the predictor variables (Garson, 2008).

Data reduction using the factor analysis technique with principal component analysis extraction was used for the climatic parameters, in order to reduce the complexity and to avoid the data redundancy as well as the multicollinearity.

The logistic regression was applied and come up with the importance of parameters that determine the habitat suitability of sea turtle nesting beaches.

2.4.2. Impact assessment of sea-level rise

The impact assessment was assessed by simulating the increases of sea-level and quantifying the impact of the projected sea-level change to the beaches. The impact analysis was done by measuring the area that possibly inundated by sea-level rise and the potential nesting area of the Loggerheads to shift landward as an adaptation to the predicted sea-level rise.

The scenario of sea-level rise, based on IPCC projection, predicts that by 2090 – 2099 the sea-level will have risen between 0.18 m and 0.59 m (see Table 2) (IPCC, 2007a). Based on these projections, three different sea-level rise scenarios were chosen i.e. a low (0.2. m), moderate (0.4 m) and high level scenario (0.6 m) and used in the analysis.

The analysis is based on the current nesting habitat and the beach morphology model, known as Bruun model (Bruun, 1962). The Bruun model works with the assumption that the beaches could maintain their long-term profiles and the system is essentially closed with no loss of sediment landward, offshore or alongshore.

The impact assessment was done firstly by constructing a model of the topography of each beach. To model the topography of the beaches, the coastal elevation models were derived from TIN (triangulated irregular networks) data. TIN data was generated from the beach profile - fieldwork data (a horizontal distance, height measurement and geographic coordinates) and for each profile using 3D-analysis tools in ArcGIS software. The TIN data were rasterized to produce a coastal elevation model (CEM), a floating elevation grid, with 1 m^2 horizontal resolution and 0.1 m vertical resolution (elevation recorded in centimetres). A topographic map, DEM SRTM and Google Earth images were utilized for validating purposes.

Three different scenarios were applied to assess the potential impact from sea-level rise. These three scenarios were plotted to the coastal elevation model and beach profile analysis technique was used to determine the nesting beach area that falls below the sea-level in each scenario. Using grid cell counts, the proportion of the beach that would be affected by the sea-level rise was assessed and calculated.

The potential nesting shift landward was the assumption that the female sea turtle will likely to adapt to the sea-level rise and tend to shift their nesting sites to the higher elevation area. To assess this impact, the beach profile analysis technique was applied. The preferred ranges of the nesting area (0.3 – 0.7 m above sea-level) was taken as a basis for analysis and assuming landward shift to this nesting range area in accordance with the increase of sea-level rise. For example, under a low scenario (0.2. m), the preferred nesting range will shift to the elevation range of 0.5 – 0.9 m above sea-level (see Figure 7)

The analysis was repeated for each scenario and by using grid cell counts the optimal nesting area remaining after each scenario was assessed and recorded.

The land-cover analysis was done to explore the possibility of the adaptation pattern of the beach due to sea-level rise. This analysis is based on the assumption that in the beach area, the potential shift will follow the elevation pattern, while at the edge of the beach area, the land-cover behind the beach could limit the adaptation pattern.

The land-cover was categorized either as "protected" or as "adaptable". The land-cover was categorized as "adaptable" if the land-cover is a natural or semi natural area that allows the beach to retreat or expand landward. The "protected" land-cover if the land-cover behind the beach would not allow the beach to expand. There are two classes of protected land-cover i.e. urban area and un-expandable area. The area behind the beach was classified as natural or semi natural area if the land-cover is shrub, low-dune, agricultural area or other natural structure. The area was classified as urban area if the land-cover is road, town, tourism infrastructure (hotel, restaurant, tavernas), concrete wall or other man made structure. The area was classified as un-expandable area if the land-cover is beach rock, high-dune, limestone cliff or other natural structure that would prevent the beach to expand landward. Finally the proportions of the land-cover behind the beach was assessed and recorded.

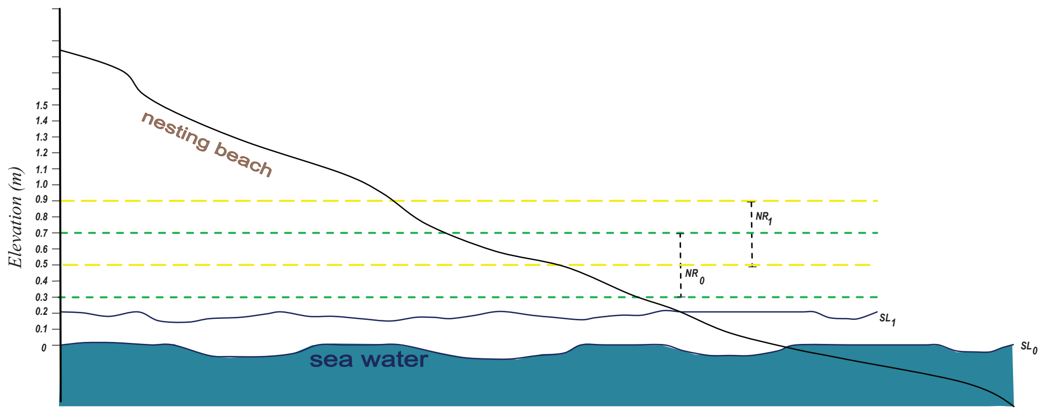


Figure 7 . The simplified design of the impact assessment

Note : *SL_0 = Initial sea level (Sea level = 0)*
SL_1 = Sea level rise = 0.2 m
NR_0 = Initial nesting range
NR_1 = Nesting range after sea level rise

3. Results

3.1. Habitat Suitability at Beach Level

3.1.1. Sand characteristics

3.1.1.1. Analysis of in-situ data

The detailed result of in-situ data for sand temperature, salinity and moisture are presented in Appendix C-1 and Appendix C-2. The basic idea is to compare the mean values of each parameter in nesting beaches and in non-nesting site to find out if there is any significant difference. In this analysis, the maximum, minimum and mean value of each parameter will be presented in order to understand the distribution of the data, and finally the results from a statistical analysis will be shown to infer the difference between mean values of nesting and non-nesting beaches.

a). Sand temperature

The temperatures both in non-nesting and nesting beaches showed a slight difference. The range of temperatures in the nesting beaches is wider than in non-nesting beaches. The minimum temperature in non-nesting beaches is 24.5 °C and the maximum is 35.7 °C. In nesting beaches, the minimum is 21.7 °C and the maximum is 34.4 °C. The mean average temperature in nesting beaches was cooler than in non-nesting beaches, with temperature of 27.9 °C and 28.7 °C, respectively. However, the statistical analysis showed that there is no significant difference between non-nesting and nesting beaches (t-test, $t = 1.140$, $df = 91.92$, $p = 0.257$).

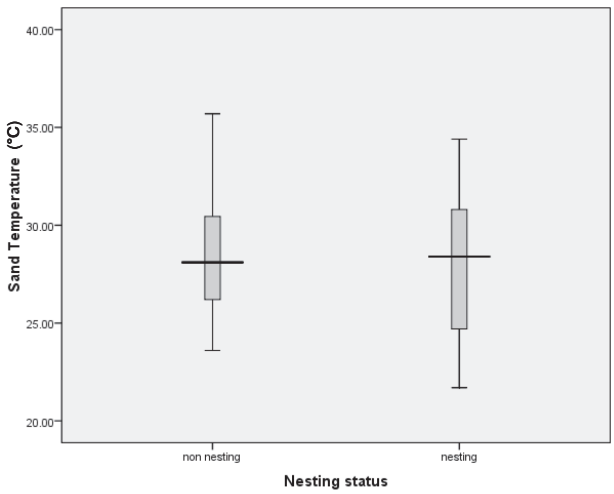


Figure 8. Comparison of temperature variations (° C) of the sand in non-nesting and nesting beaches

b). Sand moisture

The sand moisture content was measured in wfv (water fraction per volume). The data showed that both sites, i.e. non-nesting beaches and nesting beaches, have the same minimum value (0.01 wfv), but differ slightly in the mean value and maximum value. The non-nesting beaches have a maximum value of 0.21 wfv, lower than nesting beaches with value of 0.23 wfv. But, the mean value is higher in non-nesting beaches (0.0598), than in nesting beaches (0.0488). The data also shows an un-regular pattern of the sand moisture in nesting beaches, these data were taken at Messara Bay, a nesting beach in the eastern part of the Crete Island.

Statistically, there is no significant difference between moisture content both in non-nesting beaches and nesting beaches (t-test, $t = 1.228$, $df = 91.89$, $p = 0.223$)

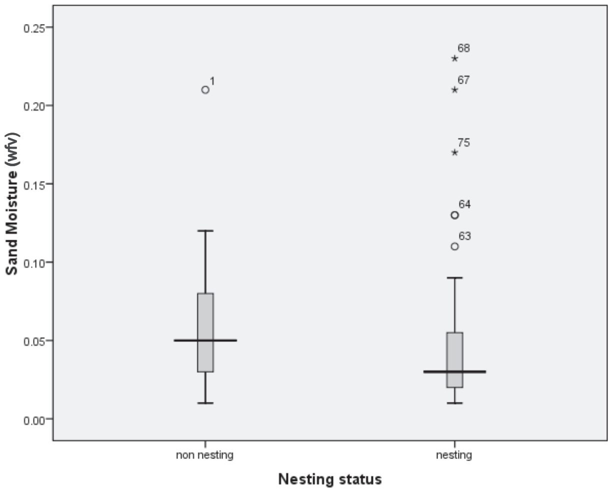


Figure 9. Comparison of moisture variations (wfv) of the sand in non-nesting and nesting beaches

c). Sand salinity

The salinity was measured using Stevens hydra-probe in units of total Sodium Chloride (NaCl, gram/litre). The minimum salinity in non-nesting beaches is 0.04 gr/ltr and the maximum value is 0.56 gr/ltr. Furthermore, the minimum salinity in nesting beaches is 0.03 gr/ltr and the maximum value is 0.46 gr/ltr. The mean value is higher in non-nesting beaches (0.221 gr/ltr) than in nesting beaches (0.164 gr/ltr).

There is one sample of nesting beaches that has a very high value in comparison with other samples. This sample was taken at Kalamaki beach in The Messara Bay. The high value might be related to the closeness to sea water, but with a high elevation or steep slope and is considered as outlier. Correspondingly, non nesting beaches are more saline than nesting beaches. An independent t-test showed that there is a significant difference in salinity between non-nesting and nesting beaches (t-test, $t = 2.278$, $df = 78.6$, $p = 0.025$).

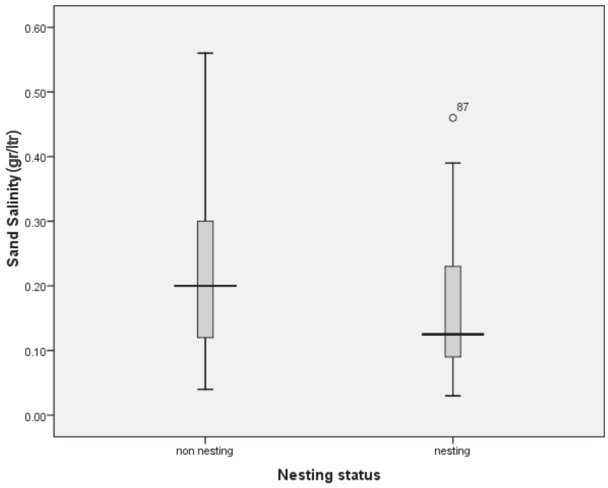


Figure 10. Comparison of salinity variations (gr/ltr) of the sand in non-nesting and nesting beaches

3.1.1.2. Laboratory analysis of sand samples

The results of laboratory analysis for pH, conductivity, NaCl content, $CaCO_3$ content, grain size, grain shape and cleanliness are presented in Appendix C-3 and Appendix C-4. The analyses focused on examine the difference between the parameters value both in nesting beaches and non-nesting beaches.

a). pH

The pH was measured in the diluted sand samples using Hach-multimeter HQ 40d . The minimum pH value in non-nesting beaches is 9.24 and the maximum value is 9.76. For nesting beaches, the minimum value is 9.36 and the maximum value is 10.01. The mean ph value is higher in nesting beaches than in non-nesting beaches, namely 9.60 and 9.52, respectively. There are two unusual samples that have a very high value in nesting sites in comparison to other samples and are considered as outlier. These samples were taken at Agia Triada Beach in the Messara Bay. This beach is located directly in front of the city, and might be polluted by city sewage.

A statistical analysis shows that there is not a significant difference in pH value between non-nesting and nesting beaches (t-test, $t = -1.879$, $df = 42.486$, $p = 0.067$).

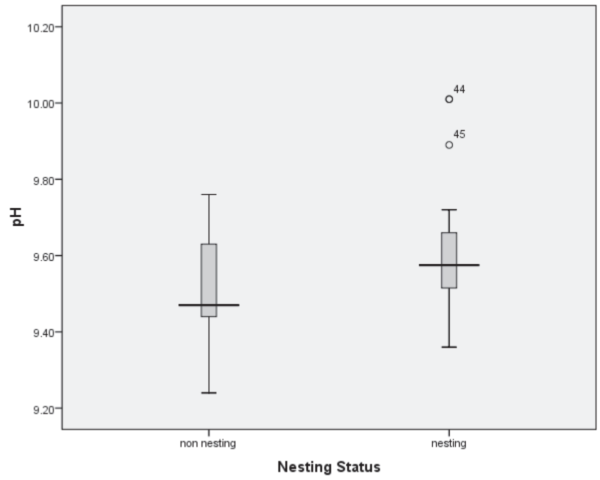


Figure 11. Comparison of pH variations of the sand in non-nesting and nesting beaches

b). Sand grain size

The grain size is divided in 6 fractions. The mean values of the three major sand grain sizes i.e. more than or equal than 0.5 mm and less than 1.0 mm (0.5≥ <1.0 mm), more than or equal than 0.25 mm and less than 0.5 mm (0.25 ≥ < 0.5 mm) and more than or equal than 0.10 and less than 0.25 mm (0.10 ≥ < 0.25 mm) were derived to describe the pattern of the sand grain size in nesting and non-nesting beaches. The data shows that the middle sand grain size (0.25 ≥ < 0.5 mm) contributed to the majority of the nesting beaches by 44 % and to non-nesting beaches by 33.6 %. The larger grain size (0.50 ≥ < 0.1 mm) contributed more in nesting beaches (23 %) then in non-nesting beaches (20.6 %), while the smaller sand grain size (0.10 ≥ < 0.25 mm) contributed more in non-nesting beaches (24.6 %) then in nesting beaches (13.5 %).

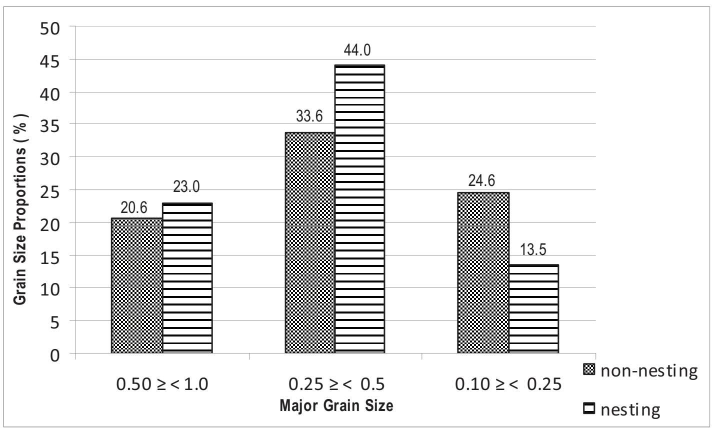


Figure 12. Comparison of three major grain size of the sand in non-nesting and nesting beaches

The most dominant grain fraction, the middle sand grain (0.25 ≥ < 0.5 mm), clearly shows the difference between nesting and non-nesting beaches, with a significance value of 0.026 (t-test, $t = -2.304$, $df = 42.910$, $p < 0.05$).

However, in order to examine the significant difference of all grain size fractions, the most dominant grain size of each sample was taken as a basis of analysis and was analyzed using chi-square test. The result showed that statistically there is no significant difference between the sand grading size in non-nesting and in nesting beaches (χ^2test, $p = 0.142$).

c). Conductivity

Conductivity was measured in the diluted samples using Hach-multimeter HQ 40d in units of micro Siemens/cm (μS/cm). The data shows that in non nesting beaches, the minimum value is 94.90 μS/cm and the maximum value is 1871 μS/cm. In the nesting beaches, the minimum value is 111.10 μS/cm and the maximum value is 1270 μS/cm. The mean value shows that the conductivity in the nesting beaches (332.32 μS/cm) is lower than in non nesting beaches (642.28 μS/cm).

There are samples with very high conductivity values in comparison to other samples. These samples were taken from non-nesting beaches in Frangocastelo and Irapetra, and from nesting beaches in Sfakaki beach at Rethymno and also from Kalamaki beach and Tympaky beach in Messara bay. These unusual values might be due to the geomorphology of the beaches that have a moderate slope but are relatively close to the sea water and is considered as outliers.

Based on the statistical analysis there is a significant difference between nesting and non-nesting beaches (t-test, $t = 2.432$, $df = 32.167$, $p = 0.021$).

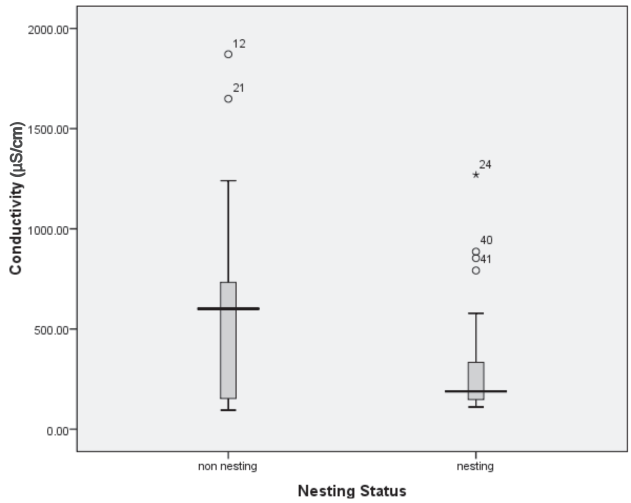


Figure 13. Comparison of conductivity variations (μS/cm) of the sand in non-nesting and nesting beaches

d). NaCl content

NaCl content was measured in the diluted samples using AAS (atomic absorption spectrometer) in units of parts per million (ppm). The results of the AAS revealed that the minimum value of non-nesting beaches is 9.06 ppm, the maximum value is 531.22 ppm and the mean value is 189.07 ppm. Furthermore, nesting beaches shows a moderate value, where the lowest value is 19.2 ppm and the highest value is 379.29 ppm. The range of NaCl value in non nesting is wider than in nesting beaches.

Statistically there is a significant difference of NaCl content between non-nesting and nesting beaches (t-test, t = 2.287, df = 43, p = 0.027).

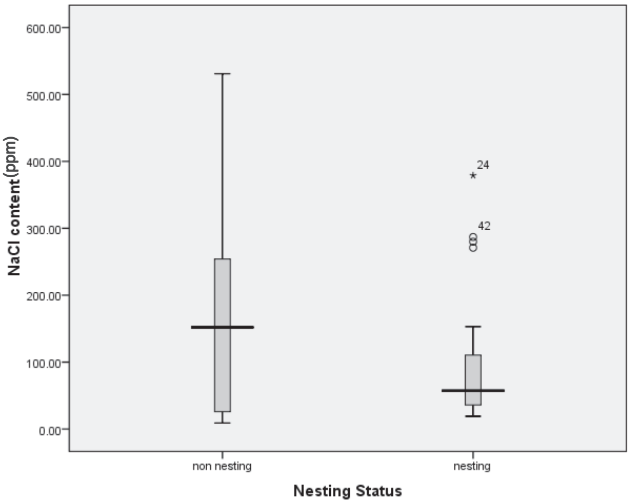


Figure 14. Comparison of NaCl content variations (ppm) of the sand in non-nesting and nesting beaches

e). $CaCO_3$ content

$CaCO_3$ content was measured in the diluted samples using AAS (atomic absorption spectrometer) and the value was transformed to percentage. The results show that in non-nesting beaches, the minimum value is 1.73 % and the maximum value is 1.98 %. And in nesting beaches, the minimum value is 1.02 % and the maximum value is 2.37 %. The mean is slightly different where in non-nesting (1.86 %) and in nesting (1.89 %).

There are three samples that have excessive values. These samples were taken from Georgeopolis, Koutsunary and Iraklion - Amnisos beach and are considered as outliers.

The acid solution method was applied to a part of these samples to examine the origin of the carbonate content and the test reveals that the carbonate content in the sand mainly comes from limestone rock fragments and seashell fragments.

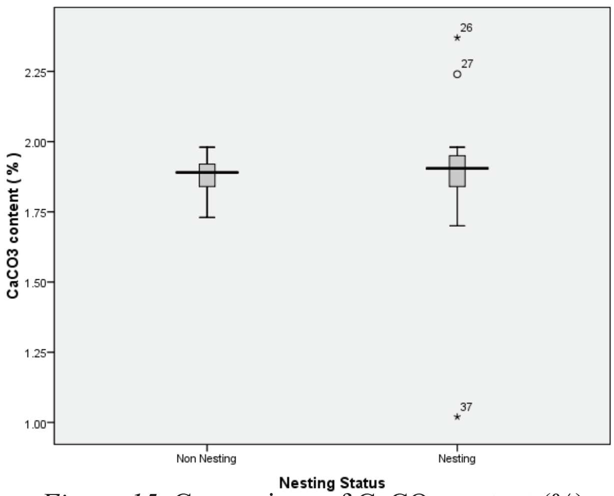


Figure 15. Comparison of $CaCO_3$ content (%) of the sand in non-nesting and nesting beaches

However, statistically there is no significant difference between $CaCO_3$ content in non-nesting beaches and nesting beaches (t-test, t = 1.902, df = 43, p = 0.064).

f). Visual microscopic analysis

The visual microscopic analysis was done on dried samples using a 30 x magnification microscope. These analyses were performed to examine the grain shape, cleanliness of the sample, foreign objects and other unusual features.

The grain shape was divided into 3 major classes i.e. rounded, mixture (mixture of rounded and angular shape) and angular shape. The data shows that more than 50 % of non-nesting beaches have a rounded grain shape while more than 75 % of nesting beaches have an angular grain shape.

The statistical analysis showed that there is a highly significant difference between grain shape in nesting and non-nesting beaches (χ^2test, p< 0.001).

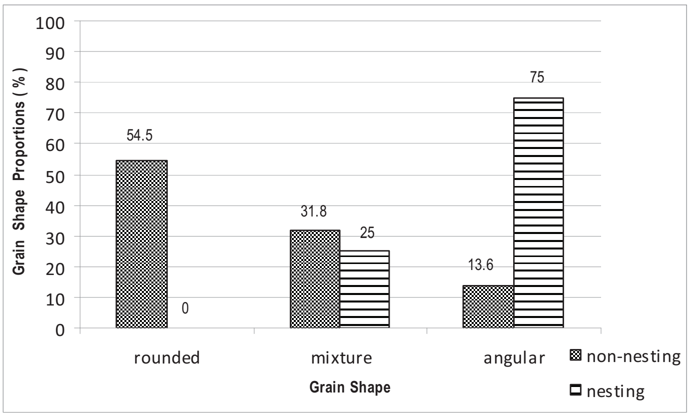


Figure 16. Comparison of grain shape variations of the sand in non-nesting and nesting beaches

The grain cleanliness was examined based on the amount of dust particles in the sample. The cleanliness has been divided into 3 different classes' i.e. low dust, moderate and high dust. The data shows that the sand of the beaches, both nesting beaches and non nesting are dominated by low dust sand. There are two samples containing large quantities of dust particles i.e. samples from a nesting sites on Adele beach in Rethymno, where these samples originated from a beach that is close to drainage of small dry river.

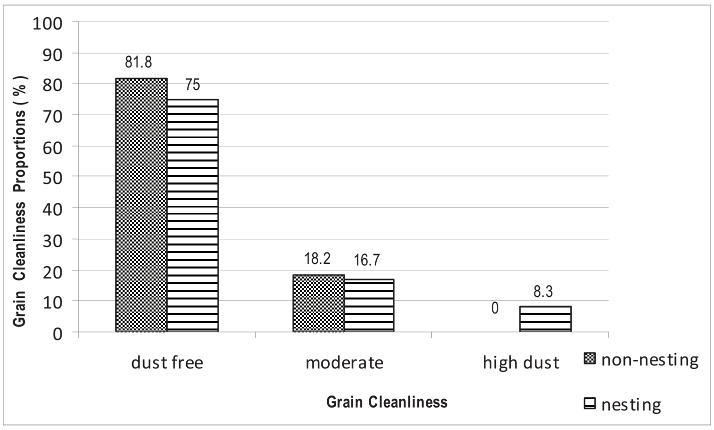


Figure 17. Comparison of grain cleanliness variations of the sand in non-nesting and nesting beaches

Statistically there is no significant differences regarding on grain cleanliness between nesting beaches and non nesting beaches (χ^2test, p = 0.399).

3.1.2. Climatic characteristics

Detailed data on the climatic parameters for temperature, precipitation and solar radiation are presented in Appendix C-5 and Appendix C-6. The temperature and precipitation data are derived from the World-Clim dataset (www.worldclim.org), and solar radiation data are derived from ESRA (European solar radiation atlas). To get a general overview of the climatic conditions during the nesting season, data was used of 3 different months i.e. May, July and September as being representative for the beginning, middle and end of sea turtle nesting season.

a). Air temperature

The total monthly mean of minimum and maximum air temperature is presented for non-nesting and nesting beaches. The lowest temperature is in the month of May and the highest temperature is in July. In September, as autumn begins, the temperature slightly decreased and shows an unstable pattern.

At the beginning of the nesting season, i.e. May, there are significant difference between the minimum and maximum temperature in non-nesting beaches and nesting beaches. [(t-test, $t = -3.902$, $df = 92$, $p < 0.001$), (t-test, $t = -4.212$, $df = 92$ $p < 0.001$), respectively]. The same condition was also recorded in July, the middle nesting season, where the temperature, both the minimum value and the maximum value, reveals also a significant difference between non-nesting and nesting beaches. [(t-test, $t = -4.265$, $df = 92$, $p < 0.001$), (t-test, $t = -3.928$, $df = 92$ $p < 0.001$), respectively]. The temperature in nesting beaches, in May and July, is higher than in non nesting beaches. But in the end of nesting season, September, there is no significant difference between the minimum and maximum values of nesting and non-nesting beaches.

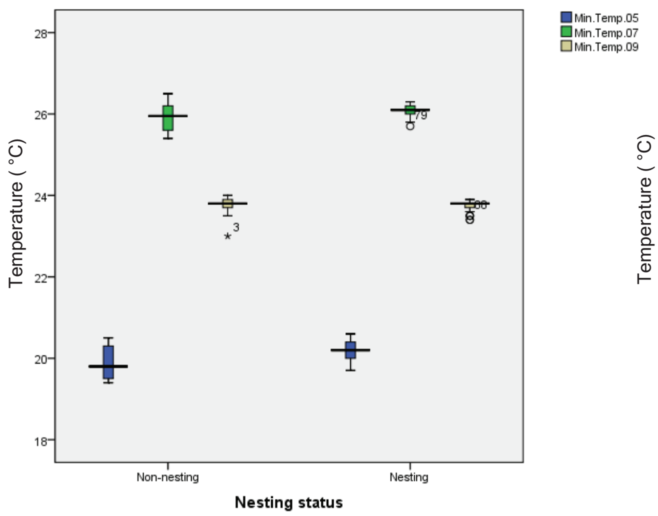


Figure 18. Comparison of minimum air temperature variations in non-nesting and nesting beaches during different month of the nesting season

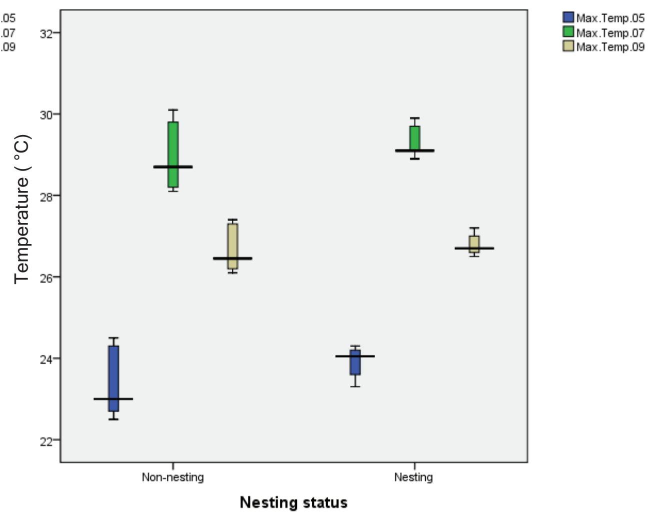


Figure 19. Comparison of maximum air temperature variations in non-nesting and nesting beaches during different month of the nesting season

b). Precipitation

The total monthly mean precipitation in millimetre (mm) is given for non nesting and nesting beaches. The lowest precipitation was recorded for July, while the highest value was given for September. A negative correlation was shown between precipitation and mean air temperature. No rainfall at all was recorded at Xerocampos, a surveyed beach in the eastern part of the island.

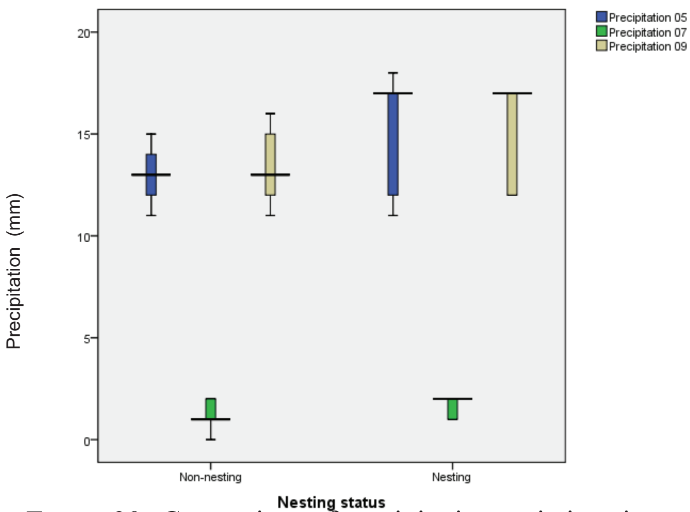


Figure 20. Comparison of precipitation variations in non-nesting and nesting beaches during different month of the nesting season

The statistical test using Independent t-test was applied to examine the equality of means of the precipitations. The test reveals that there is a highly significant difference regarding the precipitation between non-nesting beaches and nesting beaches, in three different months i.e. May, July and September [(t-test, $t = -5.773$, $df = 92$, $p < 0.001$), (t-test, $t = -4.863$, $df = 82.429$ $p < 0.001$), (t-test, $t = -5.127$, $df = 92$, $p < 0.001$), respectively].

c). Solar radiation

The solar radiation was derived from ESRA and is presented in averages of monthly means of daily radiation in watt hour per square meter (Wh/m^2) on flat plane.

The data show that the lowest solar radiation is in the September and the highest is in the July. The solar radiation in non nesting beaches is slightly higher than in nesting beaches. Again, in July, Xerocampos beaches received the highest solar radiation with value of 4850 Wh/m^2.

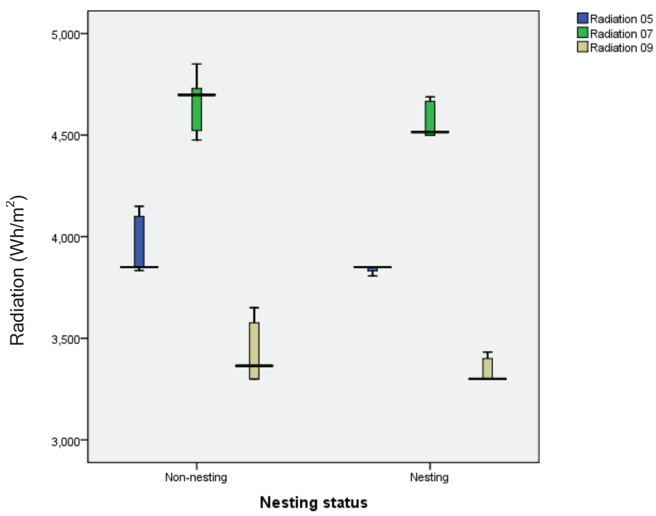


Figure 21. Comparison of solar radiation variations in non-nesting and nesting beaches during different month of the nesting season

A statistical test was applied to find out the difference in mean value of solar radiation between non-nesting beaches and nesting beaches in three different months. The results show that there are highly significant differences. All months reveal a significant p value < 0.001. [(t-test, $t = 6.169$, $df = 92$, $p < 0.001$), (t-test, $t = 4.355$, $df = 92$, $p < 0.001$), (t-test, $t = 4.373$, $df = 92$, $p < 0.001$), respectively]

3.1.3. The important parameters

The important parameters that determine the suitability as a nesting beach was analyzed using a logistic regression technique with a backward stepwise likelihood method.

The data used in the analysis are the parameters which have a significant difference in their means values ($p<0.05$) based on the previous statistical analysis (independent t-test and chi square test). Those parameters are sand parameters i.e. sand salinity, conductivity, NaCl content and grain shape as well as climatic parameters i.e. minimum temperature in the month of May (min_temp05), maximum temperature in May (max_temp05), minimum temperature in July (min_temp07), maximum temperature in July (max_temp07), precipitation in May (precip_05), precipitation in July (precip_07), precipitation in September (precip_09), solar radiation in May (rad_05), solar radiation in July (rad_07) and solar radiation in September (rad_09).

In order to reduce the potential bias and minimize data redundancy in the model, a multicollinearity test was conducted. On the laboratory analysis data, the results show that two parameters that are subjected to the multicollinearity problem, i.e. the conductivity and NaCl content, with a tolerance value of 0.26 and 0.25 and VIF (variance inflation factor) of 38.73 and 39.68, respectively. Therefore, one of the parameters, which has a lowest tolerance value and highest VIF i.e. NaCl content has been removed from the analysis.

The same procedure was applied to the climatic parameters with a different technique. A factor analysis technique with principal component analysis extraction was used in the data preparations for climatic parameters, in order to reduce complexity and to avoid data redundancy.

Factor analysis technique was applied to those climatic parameters that are significantly different of mean values between nesting and non-nesting beaches, based on the result of the independent t-test. The result from the factor analysis with principal component analysis extraction shows that out of ten climatic parameters, there are two representative parameters that could explain around 86 % of the variability of the original ten parameters. These are the parameters with Eigenvalues more than 1 and are shows in the scree plot in the steep sloping axes.

The rotated component matrix showed that there are two components parameters. The first component is highly correlated with minimum and maximum temperature in the months of May and July. The second component is highly correlated with precipitation in the months of May, July and September. Therefore, the most representative parameters are minimum temperature and Precipitation in the month of May (see Appendix D-4 for details of tables and graphs of factor analysis).

After the data preparation was done to the sand characteristics parameters and climatic parameters, logistic regression was applied with backward stepwise likelihood ratio method. The model ran in three steps. During every step one parameter with the lowest significant value was excluded from the model. The first parameter that excluded from analysis was minimum temperature in May, with significant value (p value) = 0.688. Although the nesting chambers are highly affected by temperature because sea turtle is a temperature dependent reptiles, to which the temperature will determine the sex of the hatchling, but in this model other factors were more important. In the second step the conductivity was also excluded. The others factors were also more important than conductivity. The summary of the logistic regression (first level model) is presented in Table 4 (see Appendix D-5 for details).

Finally, for the last step only three parameters remained in the model i.e. salinity, precipitation in the month of May and grain shape. The model shows that these three parameters have more important roles in non-nesting and nesting beaches than others.

Table 4 . Summary of logistic regression (first level model)

	B	S.E.	Wald	Sig. (p)	Exp(B)	95.0% C.I.for EXP(B)	
						Lower	Upper
Grain_shape (rounded)			3.102	.212			
Grain_shape (mixture)	-23.120	1.038E4	.000	.998	.000	.000	.
Grain_shape(angular)	-2.415	1.371	3.102	.078	.089	.006	1.313
Salinity	-12.020	6.322	3.615	.057	.000	.000	1.449
Precip_05	.797	.327	5.931	.015	2.219	1.168	4.214
Constant	-7.148	3.719	3.695	.055	.001		

Note: R^2= 0.608 (Cox & Snell), 0.812 (Nagelkerke).

However, the previous logistic regression model i.e. the first model above, shows there are difficulties to interpret the results, because one of the parameters, the grain shape, is a categorical parameter which has three different variables i.e. rounded, mixture and angular. Therefore, another logistic regression (the second level model) was applied with only one variable in the grain shape.

In order to reduce the grain shape complexity, one variable was chosen by selecting the grain shape variables with a lowest significant p-value. The lowest p-value indicates the importance of the variable to the models. In this case the angular grain shape is the lowest one with significance p value of 0.078. This variable, the angular grain shape, was included in the second model logistic regression model, along with salinity and precipitation in May as an explanatory parameter to determine the most important parameter for the suitability of the nesting beaches.

The second model shows a clear result, in which running in one step, and none of the parameters that were excluded from the analysis. It implied that all the variables have an equal degree of importance to explain the model. The Nagelkerke R square was 0.735, indicating that the model explain around 74 % of the overall variance of the response variable. The three explanatory parameters have a significant p-value below 0.05. The highest significance p-values is precipitation in the month of May (p=0.004), followed by grain shape (p=0.006) and salinity with p-value = 0.037. The summary of the logistic regression (second level model) is presented in Table 5 (see Appendix D-5 for details).

Table 5. Summary of logistic regression (second level model)

	B	S.E.	Wald	Sig. (p)	Exp(B)	95.0% C.I.for EXP(B)	
						Lower	Upper
Salinity	-11.829	5.678	4.339	.037	.000	.000	.497
Grain shape	-3.554	1.305	7.419	.006	34.943	2.709	450.729
Precip_05	.858	.298	8.289	.004	2.358	1.315	4.228
Constant	- 8.019	3.583	5.008	.025	.000		

Note: R^2= 0.550 (Cox & Snell), 0.735 (Nagelkerke).

The model indicates that the salinity has a negative correlation with nesting beaches, where increasing the salinity tends to decrease the occurrences of the nesting beaches. The grain shape has a positive correlation: the more angular the sand shape, the higher the probability the beach being chosen as a nesting beach. The precipitation also has a positive correlation, where the beaches that have high precipitation tend to be a suitable nesting beach.

The salinity level in the beach seems to be one of the most important parameters for the female sea turtle to choose a beach to be a nesting beach. The high salinity could affect the chemical process in the nesting chamber by changing the environment and in turn affect the hatchling success of the sea turtle.

The angular sand particle is the parameter that is related to the cohesion force between the sand particles that is needed in order to built a well-constructed chamber (Miller *et al.*, 2003).

The precipitation in the beginning of the nesting season seems to be one of the major factors that might be influencing the micro-environmental condition of the beaches which distinguishes a nesting beach from a non nesting beach. The micro-environmental condition of the beach as well as the nesting chamber will affect hatchling success.

3.1.4. Summary

The statistical analyses i.e. independent t-test and chi-square test were applied in order to test the differences between the physical parameters in non-nesting beaches and nesting beaches. The results shows that the sand salinity is the only parameter that has a significant difference mean value of the in-situ sand parameters with p value of 0.025. Furthermore, there are three parameters based on laboratory analysis-sand characteristics i.e. conductivity, NaCl content and grain shape which have a significant value with a p-value of 0.021, 0.027 and 0.000, respectively. The analyzed climatic parameters shows that there are ten parameters which have significant p-value < 0.001, i.e. minimum temperature in May (min_temp05), maximum temperature in May (max_temp05), minimum temperature in July (min_temp07), maximum temperature in July (max_temp07), precipitation in May (precip_05), precipitation in July (precip_07), precipitation in September (precip_09), solar radiation in May (rad_05), solar radiation in July (rad_07) and solar radiation in September (rad_09). Therefore, it is evident that the investigated coastal physical parameters do have a significant difference in non-nesting beaches and nesting beaches, thus the null hypothesis ($H1_0$) that the investigated coastal physical parameter do not have a significant difference in non nesting and nesting beaches is rejected, and the alternative hypothesis ($H1_1$) that the investigated coastal physical parameters do have a significant difference in non nesting and nesting beaches is accepted.

Two levels of logistic regression techniques are applied to reveal the important coastal physical parameters that determine the suitability of the nesting beaches. A multicollinearity test has been used in the data preparations along with data reduction techniques using a factor analysis with principal component analysis. The results shows that there are three parameters i.e. precipitation in the month of May (precip_05), grain size and sand salinity that have significant p-value below 0.05 as an indication that these three parameters are the most important parameters that discriminate nesting beaches from non-nesting beaches. Therefore, the null hypothesis ($H2_0$) that there are no coastal physical parameters that are significantly important to nesting beaches is rejected and the alternative hypothesis ($H2_1$) that there are coastal physical parameters that are significantly important to nesting beaches of the Loggerhead sea turtle is accepted.

3.2. Impact Assessment of Sea-Level Rise

The impact assessment of the sea-level rise was studied in three nesting beaches and eight non nesting beaches across the island of Crete. The 11 surveyed beaches represented a total of about 50 km of coastline and an area of about 184 ha. The IPCC projection was used to model three different scenarios i.e. low (0.2 m), moderate (0.4 m) and high level scenario (0.6 m) sea-level rise scenarios. Coastal Elevation Models (CEMs) are the basis of prediction scenarios on which were constructed using TINs (Triangulated Irregular Network) models based on the elevation data of each beaches. The elevation data were derived from beach profile data that were collected during the fieldwork. The CEMs were reclassified to identify the area that would become inundated under sea water as an impacted area and to examine the potential shifts of the nesting range as an adaptation to the impact of sea-level rise. The analysis was based on the knowledge of the current nesting habitat and the assumption of maintenance of the current beach morphology, namely the Bruun theory (Bruun, 1962).

3.2.1. The potential habitat loss

A. The potential habitat loss of nesting beaches

There are three nesting beaches in Crete i.e. Chania, Rethymno and Messara. These beaches represented a total area of about 103 ha. Chania is the largest with total area of about 47 Ha, followed by Rethymno (35 ha) and Messara (21 ha). Although Chania has the largest beach area, Margaritoulis and Reed (2003) stated that the beach of Rethymno has the highest nesting activities, with a nesting density of 35.8 nests/km, followed by Chania with 8.7 nests/km and Messara with 6.6 nests/km.

The elevation ranges of these beaches are different. Rethymno has small variety of elevation that ranging from 0 to 140 cm and becomes the lowest nesting beach. Messara has the widest area that ranging from 0 to 210 cm of elevation and Chania with a moderate elevation range between 0 to 150 cm. Messara bay has wide variety of the elevation range due to the land-cover behind the beach that varied from urban area (town and road) and natural/semi natural area (dune, shrub, agricultural area) to limestone cliffs. Nesting beach profile maps are presented in Figure 22 and Appendix F.

The beach morphology of Rethymno varied from a continuous sandy beach in the western part to the sandy beach interrupted by beach rock in the eastern part. Therefore, in this analysis, Rethymno was divided in 7 different sections. Also Chania beach, stretching from west to east, is separated by beach rock and rocky cliff. Therefore in this analysis, Chania beach was divided in 11 sections. There is an area in the western part of Chania, i.e. Maleme, which has been excluded from analysis due to the area is a military airport and forbidden for public use. Messara bay, the nesting area in the eastern part of Crete, is a beach that is stretching from north to south and is also separated by beach rock and rocky cliff. Therefore in this analysis, Messara bay was divided in 4 sections. There is an area in the northern part of Messara i.e. Tympaki, that also has been excluded from analysis due to the area is a military airport and forbidden for public use.

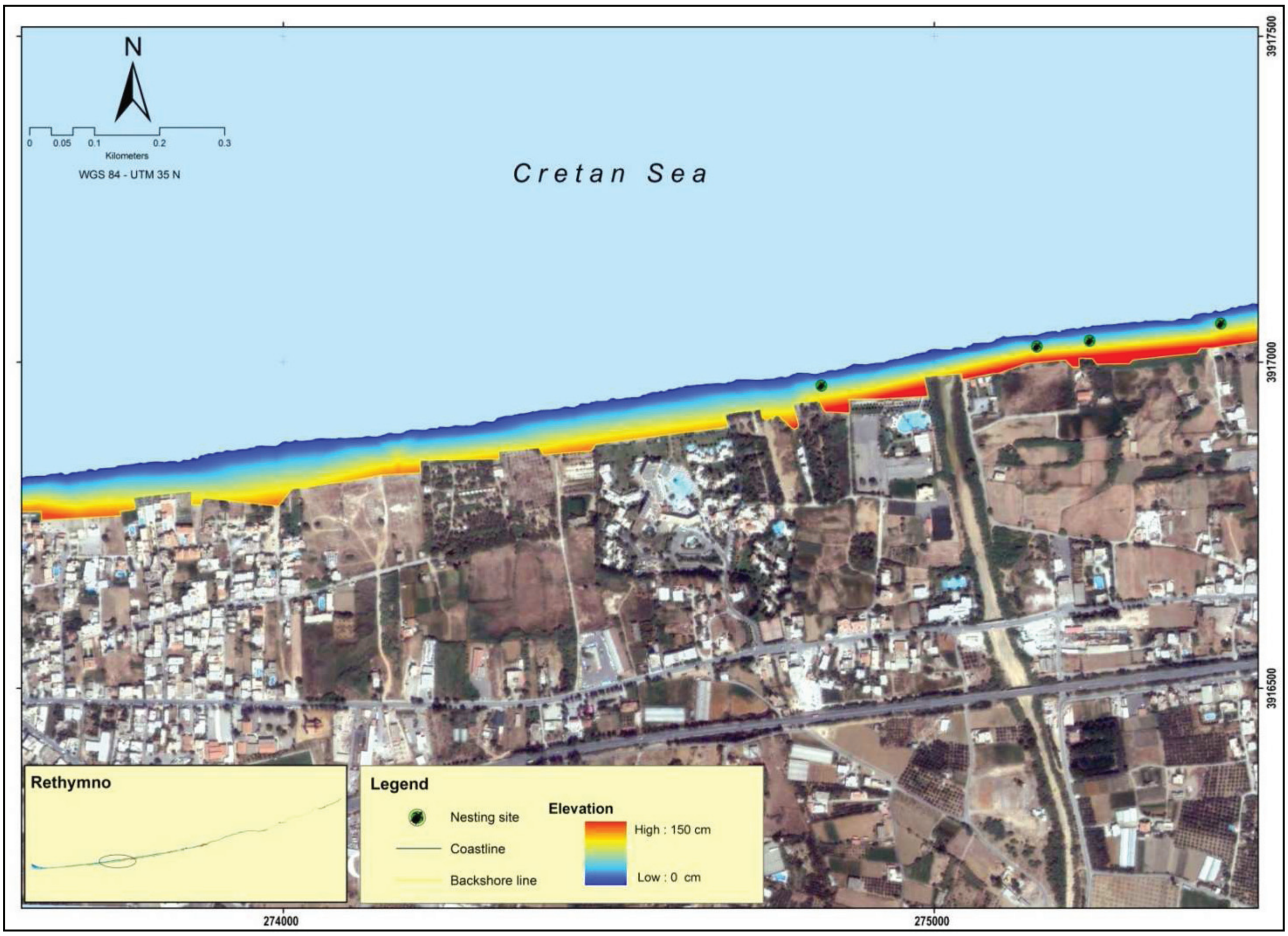


Figure 22. Map of the beach profile of Rethymno beach (section 1)

The result showed that the potential impact of sea-level rise to nesting beaches is varied on each scenario. The total area of nesting beaches that will be potentially lost under low level scenario is 25.6 %. This impact will increase under the moderate scenario (0.4 m) with 49.9 % and in the high scenario (0.6 m) with 69.1 % area will be potentially lost due to sea-level rise. Approximately 26 ha of the nesting beaches will be inundated in the low level scenario and it will increase to 72 ha in the high level scenario

The highest nesting density beach in Crete, Rethymno beach, is the most affected area. From all scenarios, Rethymno beach will be inundated over larger areas than the others area. In the low level scenario, almost one third of the Rethymno beach will be potentially lost and this impact increases nearly two times in the moderate scenario, as 21.68 ha or 61.8 % of its total area will be lost. In the high level scenario, the potential habitat loss will reach up to 82 % of the total area.

Messara bay with a wider range of elevation will be the nesting beach that has the lowest impact. The threatened area on Messara bay, according to the low level scenario is 16 % of total area and will increase nearly two times in the moderate scenario. In the high level scenario, 46.8 % of Messara bay area will be inundated due to sea-level rise. The total areas of nesting beaches and the proportions of the beaches that are potentially lost under the different sea-level rise scenarios are presented in Figure 23 and Appendix E-1.

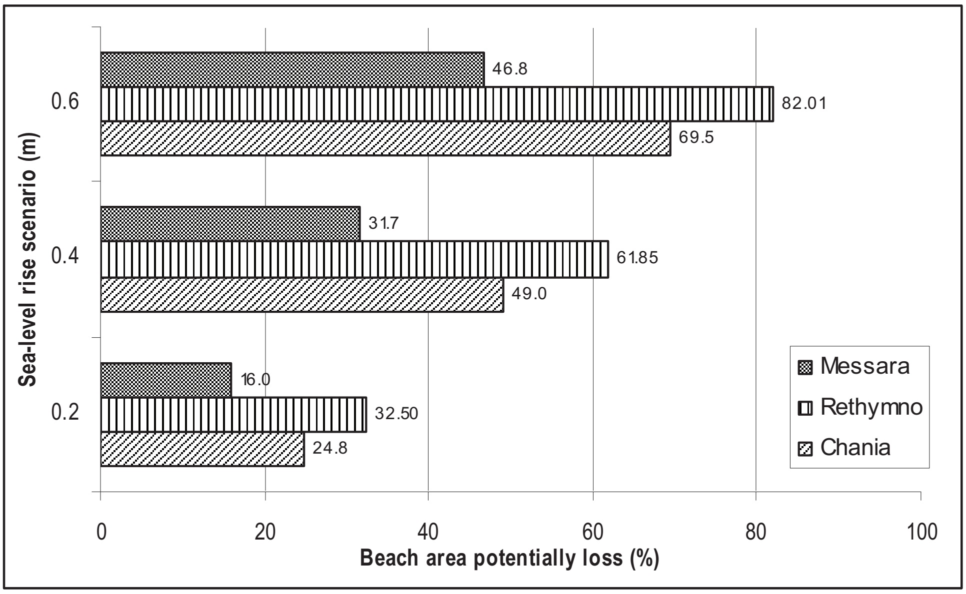


Figure 23. The proportions of nesting beaches area that are potentially lost under different sea-level rise scenarios

B. The potential habitat loss of non-nesting beaches

There are eight non-nesting beaches that are examined in this study, i.e. Phalasarna, Georgeopolis, Iraklion, Xerocampos, Koutsunary, Irapetra, Frangocastelo and Palaechora. These 8 beaches represented an area of about 80 ha with a total coastline of about 16 km.

The morphology of each beach is different. A beach rock divided Phalasarna beach into two distinct beaches, as well as Xerocampos beach that separated by beach rocks into two discrete beaches. Frangocastelo area is separated into four individual beaches, and the beach of Georgeopolis, Iraklion, Koutsunary and Irapetra are continuous and individual beaches.

Non-nesting beaches have high variability either in the total area or in the elevation range. The lowest beach is Phalasarna with a highest elevation of 50 cm and the smallest beach is Xerocampos with total area of 0.84 ha. The widest elevation range is Koutsunary beach with beach elevation up to 240 cm and the largest total area is Georgeopolis beach with total area of 26.54 ha. Non-nesting beach profile maps are presented in the Figure 24 and Appendix F.

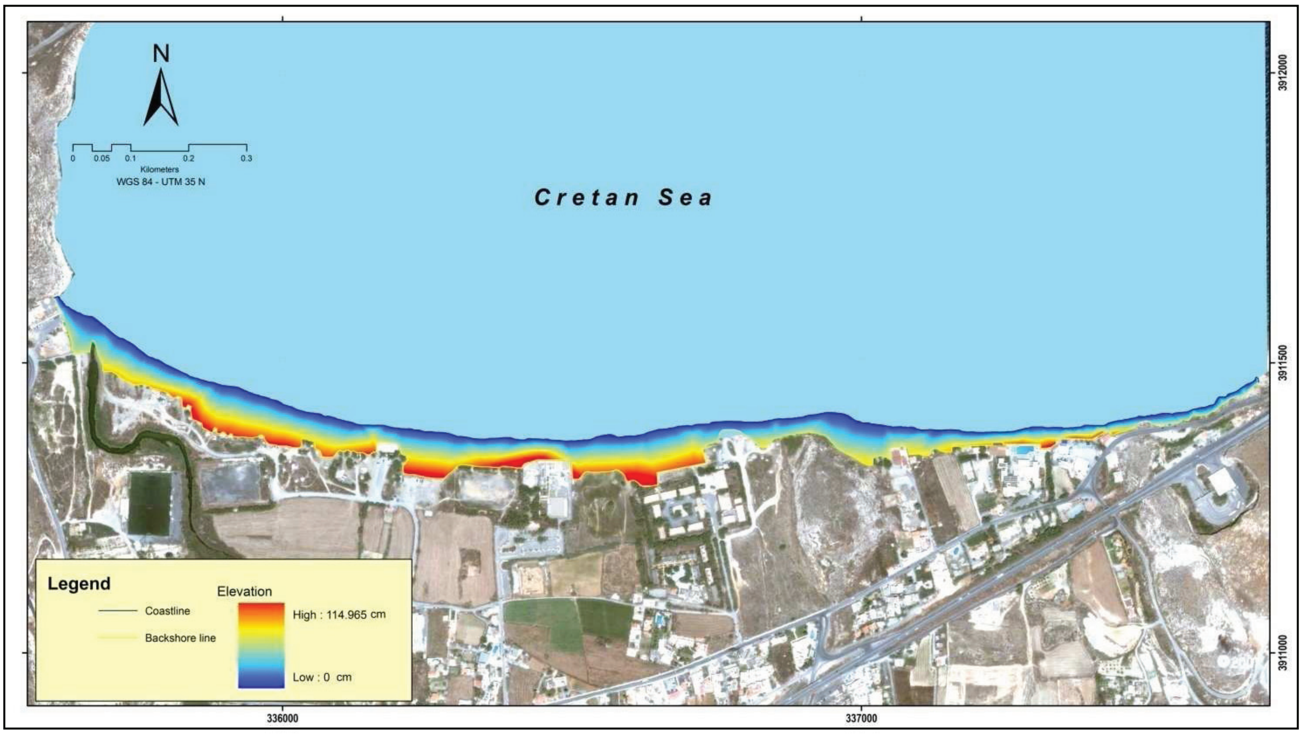


Figure 24 . Map of beach profile of Iraklion beach

The results from the sea-level rise impact analysis to non-nesting beaches showed that in the low level scenario, the affected beaches will vary from more than 10 % to 35 % of total area and will be doubled in the moderate scenario that ranging from 21 % to 73 %. In the high scenario, the potential lost ranging from 32 % to 100 %.

The shallowest beach i.e. Phalasarna and the smallest beaches i.e. Xerocampos will suffer larger impact from the sea-level rise, as in the low level scenario, these two beaches will losses around 35 % of their beach area and in the high level scenario, Phalasarna will be completely inundated by sea water and Xerocampos will be inundated around 90.3 % of its total area. Meanwhile, the highest beach, i.e. Koutsunary, could maintain their beaches and will have potential loss of only 10.6 % of their total area in the low level scenario and 32.4 % in the high level scenario. The total areas and the proportions of non-nesting beaches that are potentially lost under sea-level rise scenario are presented in Figure 25 and Appendix E-2.

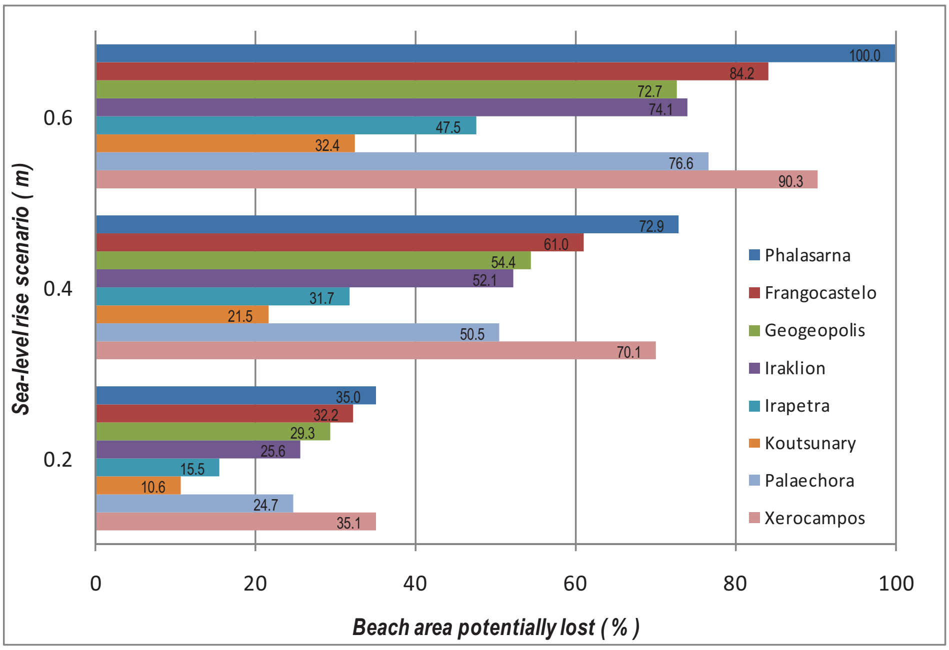


Figure 25. The proportions of the non-nesting beaches area that are potentially lost under different sea-level rise scenarios

3.2.2. The potential shift in the nesting range

The sea turtle in the Crete beach prefer to nest in the elevation range between 0.3 m – 0.7 m above sea-level. These elevation ranges cover an area of about 80.67 ha or represent 43.8 % of the total studied area in the 11 beaches. In order to examine the impact of the sea-level rise to this nesting range comprehensively, this study investigated not only nesting beaches but also non nesting beaches. To analyse this, the potential nesting area was predicted by measuring current nesting area, the area in the elevation range between 0.3-0.7 m, and assuming landward shift of this area in accordance with the increase of sea-level rise.

The result showed that by a sea-level increase of 20 cm (low level scenario), the preferred nesting area remaining is 53.05 ha or 28.8 % from total beaches area. In the moderate scenario, the optimal area decrease to 17.1 % and in high level scenario, the optimal nesting area reduced to 19 ha or 10.3 % from total beaches area.

Analysis of the nesting beaches i.e. Chania, Rethymno and Messara showed that by an increase of 20 cm of the sea water, the preferred nesting area will be reduced from 46.4 ha to 31.20 ha or reduced of 18.51 % from the initial nesting area. In the moderate level scenario, the optimal nesting area remaining is 18.62 ha or reduced of 34.10 % and in the high level scenario, more than 43 % of the optimal nesting area will be reduced from the initial nesting area due to sea-level rise.

In non-nesting beaches, the preferred nesting area in the low sea-level rise scenario will be reduced from 34.54 ha to 21.85 ha or reduced more than 15 % from the initial nesting area. In the moderate scenario the optimal nesting area will be reduced of 26.8 % and in high sea-level scenario, the preferred nesting area will be reduced to 7.9 ha or reduced of 33.2 % from the initial preferred nesting area. The optimal nesting areas remaining after the impact by different sea-level rise scenarios is presented in Figure 26 and Appendix E-3.

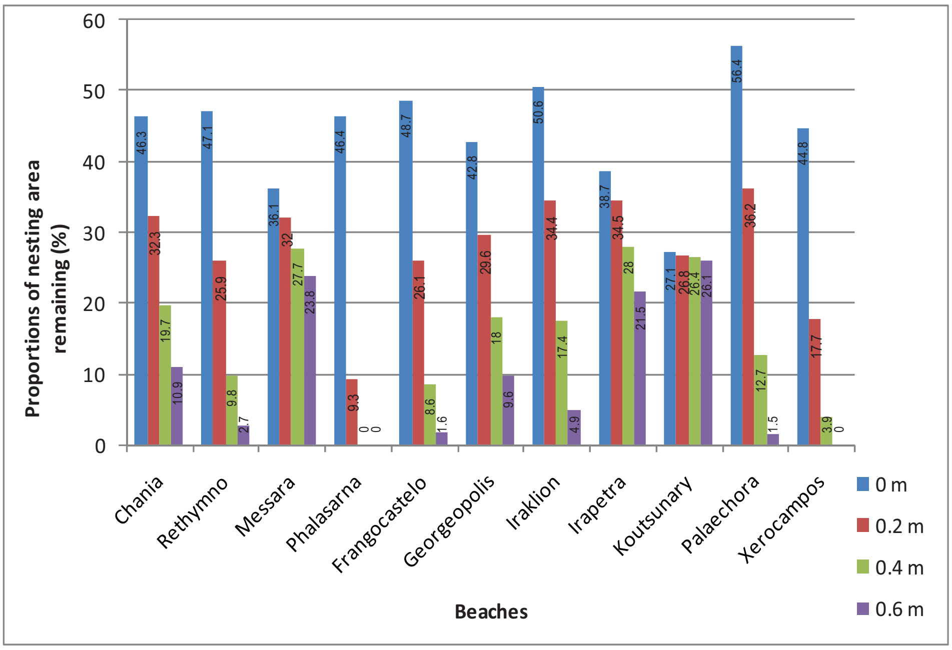


Figure 26. The optimal nesting area remaining after the impact by different sea-level rise scenarios

3.2.3. Potential beach adaptation

To investigate the adaptation pattern of the beach due to sea-level rise, analysis was done by examining the land-cover behind the beach. The land-cover was reclassified into three classes' i.e. urban area, natural area and un-expandable area. These three classes were again sub-divided in two categories i.e. protected and adaptable. Adaptable was assigned if the land-cover is natural and allow the beach to expand to landward and protected if the land-cover are urban area and un-expandable that prevent the beach to expand landward.

The result show that around 31 % of the total length of the land covers behind the beaches in Crete is categorized as adaptable and more than 69 % is categorized as protected. The proportions of the land-cover behind the beach are presented in Figure 27 and Appendix E-4.

Two out of three of the nesting beaches in Crete, i.e. Chania and Rethymno, showed that these areas were highly developed. More than 60 % of the land-cover is classified as urban area, as Chania with 62.0 % and Rethymno with 60.8 %. Moreover, in Messara, even though this area is less developed compared with the other two, with only 30.9 % of urban area, around 36.1 % of the land-cover behind the Messara bay is categorized as un-expandable areas which prevent the beach to expand landwards.

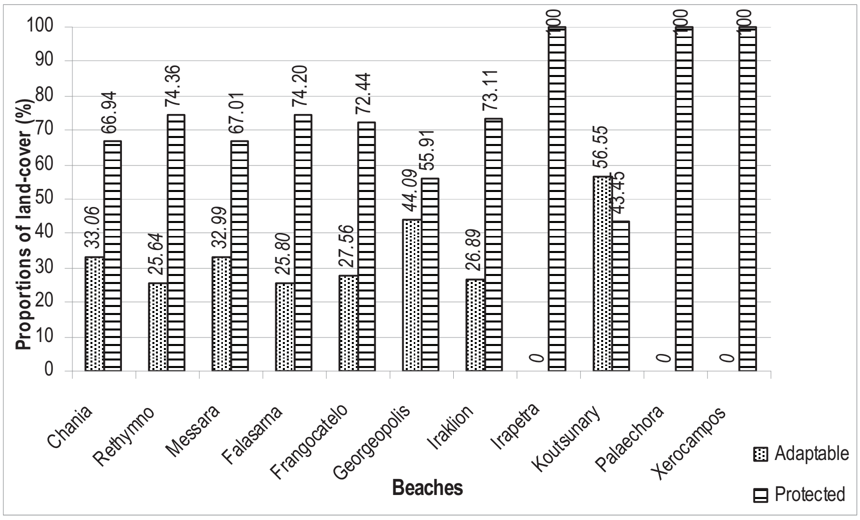


Figure 27. The proportions of the land-cover behind the beaches

The non-nesting beaches, Koutsunary beach and Georgeopolis beach are those that have greater possibility to shift landward as the total length of natural/semi natural area is 56.6 % and 44.1 % of the total beach, respectively. The other non nesting beaches will have smaller probability to adapt with the sea-level rise.

3.2.4. Summary

The analysis of the potential effect of sea-level rise to the beach area revealed that in nesting beaches 25.6 % of the beaches area will be lost due to 20 cm increases of sea-level, 49.9 % by 40 cm increases and 69.1 % of the nesting beaches area will be lost by the increasing of 60 cm of sea water. Furthermore, in non-nesting beaches 25.6 % of the beaches area will be lost by 0.2 m rising of sea water, 50.3 % will be lost by 0.4 m and 70 % will be lost when the sea level increases to around 0.6 m.

The analysis of the potential shift landward in the nesting range of the Loggerhead sea turtle on the nesting beaches showed that the initial nesting range of the Loggerhead is 43.8 % of the total studied area. The increases of 0.2 m of the predicted sea-level will reduce the preferred nesting area to 28.8 % of the total beaches area. In moderate sea-level rise scenario, the preferred nesting range will be reduced to 17.1 %, as well as in the high level scenario (0.6 m), the optimal nesting area will be reduced to 10.3 % of the total beaches area.

The dominant land-cover behind the beaches is categorized as protected, in which more than 69 % are urban area and un-expandable area. There are only 31 % of the land-cover behind the beaches categorized as adaptable that allow the beaches to expand landward as an adaptation of the sea-level rise.

4. Discussion

4.1. Comparing Nesting and Non-Nesting Beaches : an Alternative Approach

The research about the nesting ecology of the sea turtle has been investigated by many researchers, since several years ago. The environmental parameter that govern a sea turtle to choose one beach to become a nesting beach, has become one of the burning issue among the sea turtle scientist. But up until now, many of that research came up with different result and conclusion. Scientist have found contrasting results as to which variables are relevant for sea turtles and no consensus has been found so far (Miller *et al.*, 2003).

This research tries to take a part in this issue by using a different approach. While the previous researches mainly focus on the nesting beaches and explore the pertinent environmental factors that influence the nesting activity, in this research, the study focused mainly on the comparison between the investigated parameters in nesting beaches and non nesting beaches.

The backgrounds thinking why this study carried out in this alternative way are:

- Firstly, the previous researches did not give much attention to the non nesting beaches that have relatively the same general condition and are relatively nearby. By comparing the environmental parameters between nesting and non nesting beaches, at least it will reveal more robust results about the significant parameters associated with nesting activity.
- Secondly, the investigated parameters in this research are the “well established parameters”, in which these parameters have been studied by many researchers and revealed that these parameters are related to the nesting activity, therefore this research becomes a supportive study that could backup earlier claims.

4.2. The Characteristics of the Coastal Physical Parameters

4.2.1. Beach sand characteristics

Miller *et al*. (2003) stated that loggerheads nesting beaches tend to be sandy, wide, open beaches backed by low dunes and fronted by flat sandy beach. The minimum requirements to be a potential nesting beach are : the accessibility, where the beach must be easy to accessed from the ocean; the height, where the beach must be high enough to avoid inundation by sea water; the sand structure, where the sand must enough cohesion to allow nest construction and gas diffusion and also the temperature that is conducive to the egg development (Mortimer, 1995).

This research investigated ten parameters of the sand characteristics. As explained in the result chapter, there are four out of ten parameters that classified as significant different with 95 % level of confidence. The mean values of those parameters are significantly different between non nesting and nesting beaches and become a candidate of the dominant factor that determines the nesting activity in one beach. The other parameters showed that there are no significant differences between nesting and non-nesting beaches.

These significant parameters are salinity, conductivity, NaCl content and grain shape. The salinity has significant value of p = 0.022, the conductivity with significant value of p = 0.021, the NaCl content with p-value = 0.034 and the grain shape with p-value = 0.000.

The results shows the consistency between in-situ measurement with laboratory measurement that using different techniques to infer the data. The salinity, one of the parameter that measured in-situ, showed slightly the same result as conductivity and NaCl content, the parameters that was measured in the laboratory.

The salinity is one of the parameters that determine the micro-environment of the nest, as a function of hydrologic conditions. High salinity in the sand might be lethal to the developing embryo and tend to decrease the hatchling success, because high salinity can affect suffocation and/or chloride toxicity to the hatchling (Hays *et al.*, 1995). Furthermore, the high salinity in the sand is one of indicators that there are intrusions from sea water, as Miller *et al*. (2003) explained that the micro-hydrologic condition of the beach has effect to the weight of the eggs, where after oviposition, the egg will absorb the water vapour from surrounding sand. Hatchling process can only be success if the hatchling could maintain the water contents in the egg in the range of -10 to 30 % from their initial mass. However, extreme salinity or high concentration of the organic material in the surrounding sand, can lead to abnormality of the water exchange and excessive weight lose (more than 40 %) can become crucial to the hatchling success.

One of the factors that might influence the low level of the salinity in nesting beaches are the rivers and fresh ground water. In Rethymno, the beaches are fed by three rivers including Preveli river and several streams. Even some of the nesting chambers were found in the front of dry riverbed. The same condition was also found in Chania bay. Chania bay are fed by three main streams i.e. Tavronitis stream, Gerani/Vrisses stream and Gernados (Platanias) stream. The areas between these streams are the areas where the major concentration of the nesting activity occurs. There were nesting chambers that are also found in the river bank and in the front of dry river bed (see Figure 28). Messara bay, the third largest nesting site in Crete, is backed by Messara plain the main cultivation area in Crete. As a cultivation area, the availability of the ground water is ample in this area. Despite the availability of the fresh ground water, this bay also fed by Geros Patamos river, the river between Agia Triada and Thympaki and several small streams.

The other parameter that showed a significant different between nesting and non-nesting beaches regarding of the means value is the grain shape. The grain shapes were divided as three sections i.e. rounded, mixture and angular shape. The data shows that there is a distinctive difference, in which most of the sand particle in nesting beaches have angular pattern and non-nesting beaches with rounded or mixture sand particles.

Figure 28. Nesting sites of the Loggerhead sea turtle

Note . *Left panel : Nesting chamber in the front of dry stream, Stalos-Chania Beach*
Right panel : A Group of nesting chambers, backed by natural area, Eastern part Rethymno

The beaches with angular sand particles have several advantages. The surface of the angular sand particle has more possibility to interact with other particles than the rounded one. The more interaction occurs, the more cohesion force occurs. The cohesion forces between the sand particles are needed in the chamber building process to prevent the chamber from collapsing (Mortimer, 1995).

The angular sand particles have more space between the particles than the regular one. The spaces between the particles are essential to facilitate the gas and water exchange. Gas ventilating is needed during the development of the embryo, also the water exchange is needed, to prevent the chamber become inundated by high sea tide or because of excessive rainfall.

Miller *et al*. (2003) stated that *the result of beach and nesting site selection is that egg are incubated in* ***a low salinity****, high humidity,* ***well-ventilated substrate*** *that is* ***not inundated*** *during development and provides insulations from the high beach surface temperatures while being in the temperature range that facilitated development.*

Similar study has been done by Moin (2007) that aimed to examine the relationship between the biophysical characteristics with nesting density in two main host of the Loggerhead sea turtle in Greece i.e. Zakynthos Island and Crete Island (Rethymno beach). That study has explored the significant difference of sand characteristics between the high nesting density area versus the low nesting density areas within one nesting beaches. The results are relatively similar. Moin (2007) found that the sand moisture has a significant relationship with the nesting density in Zakynthos beach where the increasing trend of moisture content was observed from highly nested areas towards lower nested areas, but in Rethymno beach, the moisture content did not show a significant difference value. The sand grain size also showed the same trend, where on Rethymno-Crete the middle sand grade

(0.5 > <1.0 mm) contributed to the majority of sand proportion by 53.7% on highly nested areas and declined towards lower nested areas. These findings are similar with this research where the middle sand grade contributed 44 % of the sand proportions in the nesting beaches. Moin (2007) also found that the NaCl content is highly correlated to the nesting density in Zakynthos beach where the increases of NaCl concentration reduce the nesting density. These finding are similar with this research that the salinity, NaCl content and conductivity are the factors that might determines the suitability of the nesting beaches.

4.2.2. Beach climatic characteristics

Climatic conditions are among the major factors that influence and determine the micro-environment of the beaches. Therefore, in order to understand the underlying causes behind the state of the sand characteristic in the beach, this research investigated three main climatic parameters i.e. air temperature (average minimum and maximum), precipitation and solar radiation.

The data has been analyzed in three different months i.e. May, July and September, as a representation of the beginning, middle and end of the sea turtle nesting season.

There are highly significant differences of the climatic conditions between the non-nesting beaches and the nesting beaches. Almost all of the parameters showed significant p-value of < 0.001, except for the minimum and maximum temperature in the month of September.

Factor analysis with principal component analysis extraction was applied to reduce the complexity of the data. This analysis came up with two parameters that are categorized as representative variables i.e. minimum temperature and precipitation in month of May.

The minimum temperature and the precipitation in the beginning of the nesting season seem to be major discriminate factor between non-nesting beaches and nesting beaches. These climatic parameters might affect to the micro-condition of the sand beaches such as sand temperature, moisture, salinity and exchange of the heat, water and gasses that in turn affect to the sea turtle nesting chamber as well as the hatchling success.

The air temperature is one of the major factors that influence the sand temperature. The relation between the sand temperatures with the hatchling process has been explained by many researchers. Miller *et al*. (2003) explained that the turtle egg should incubate in a relative constant temperature in the range of 24 °C to 33 °C. Below the stated minimum value or above the stated maximum value, the eggs seldom hatch. The sea turtle also exhibits a temperature-dependent sex determination (TSD), where the sex of the hatchling is influenced by the incubation temperature (Yntema and Mrosovsky, 1980, Mrosovsky, 1994). According to Carthy *et al*. (2003), in the incubation temperature of 29 °C, it will produce the equal number of male and female hatchling, where cooler incubation temperature produces more males and warmer incubation temperature produce more females.

Precipitation is one of the main sources of fresh water in the sand that could increase the water content and decrease the sand salinity (Ackerman, 1997). Precipitation in the nesting beaches are relatively higher than in the non-nesting beaches, and is also one of the major contributed parameters to lower sand salinity in the nesting beaches.

4.3. The Impact Assessment of Sea-Level Rise

The potential impact of the sea-level rise to the ecosystem as well as to the nesting habitat of sea turtle is problematic and subject to uncertainty. This uncertainty arises from the uncertainty of the sea-level rise itself (Fish *et al.*, 2008) and how the physical change of the beach due to sea-level rise will influence the diverse environment as well as the species (Baker *et al.*, 2006). However, the information about how the sea-level rise events affect nesting beaches are necessary and essential to prepare useful management decision to ensure the sustainability of these endangered species decades later.

In this study, a modelling technique was applied to examine the possible impact of the sea-level rise to the nesting beach, to identify the beach area that will be affected rise and how the nesting area will be likely to adapt to this impact. This study was based on the Bruun model with assumptions that the beach could maintain their long–term profiles and the system is essentially closed with no loss of sediment landward, offshore or alongshore (Bruun, 1962). This model has been criticized and is controversial, because the assumption might violate the nature condition (Fish *et al.*, 2008), nevertheless the application of the Bruun model has been widely accepted by many scientists to explore the response of the natural system to the impact of the sea-level rise (Nicholls *et al.*, 2007)

4.3.1. Potential effect of sea-level rise to nesting beaches

Jeff Miller, *a member of the IUCN Marine Turtle Specialist Group,* in SWOT (2006) said that “At best we can only speculate about the long-term impacts of the changing climate on sea turtle survival, but we can identify some vulnerable parts of their lifecycle where climate change will likely have impact. Not surprisingly, in 2005, the IUCN Marine Turtle Specialist Group identified climate change as one of the five key hazards to sea turtles worldwide, making the issue as a high priority for further study”. This research becomes one of the studies that try to owing some insight in this issue. The use of GIS techniques were explored to model one of the possible impacts of the climate change i.e. sea-level rise, to sea turtle vulnerable habitat, their nesting habitat and to explore how the nesting habitat will be likely to adapt with this event.

This study was done in the Crete Island–Greece, the third most popular tourist destination in the Mediterranean and also the first most popular sea turtle destination to nest in Mediterranean Sea. Both of them, the sun seeking tourist and the sand seeking turtle, meet in the same period of time i.e. in summer time, and they are looking for a same destination i.e. sandy beaches. In this part there are spatial and seasonal conflicts between both of them; furthermore they will share the same effect from climate change, losing their destination.

There are three major nesting beaches at the Island of Crete. These three beaches are also major tourist destinations in Crete. The model showed that all of the nesting beaches will be impacted by sea-level rise even in the low level scenario. More than 25 % of the total nesting beaches will be lost if the sea-level increases 20 cm and increased to 46 % till 82 % of the total area if the worst scenario (0.6 m) of the climate change applied. This means a substantial loss of beach area as well as the nesting habitat of the sea turtle.

The same condition occurs in non-nesting beaches, the result from sea-level rise impact analysis to the non-nesting beach showed that in the low level scenario, 25.6 % of the total area or around 20.58 ha will be potentially inundated by sea water. This impact will increase two times in the moderate scenario, in which around 50.3 % of the area will be threatened by the sea-level rise. In the high level scenario, at least 70 % of the total area or around 56.27 ha will be potentially lost.

An average up to 50.1 % (92.14 ha) of the beaches area will be lost under the moderate scenario (0.4 m) with potential losses ranging from 21.5 % to 72.9 %. The narrow and the low elevation beaches will gain greater impact, where it is likely a result of its natural condition. Although all of the nesting beaches i.e. Chania, Rethymno and Messara, are wide beaches, they are also impacted by the sea-level rise and any loss of the habitat has an implication to the nesting success because it reduces the availability of the suitable area for nesting as well as it could changes the micro-environmental condition such as sand characteristics of the beaches.

Several studies that examine the impact of the sea-level rise to the beach habitat also found a relatively similar result. Fish *et al*. (2005) found that an average up to 31 % of the total beach area of Bonaire-Caribbean will be lost under 0.5 m sea-level rise scenario with losses ranging from 11 –83 %. In the North-western Hawaiian Island, Baker *et al.* (2006) highlighted that the terrestrial habitat will be lost with range from 3 – 65 % with the sea-level rise by 0.48 m. The similar condition was studied by Fish *et al*. (2008) in Barbados, where up to 26 % of the total beach area would be lost if the sea-level increases by 0.5 m.

4.3.2. The nesting shift and adaptation

The nesting shift is the assumption that the female sea turtle will likely adapt to the sea-level rise and tend to move their nesting sites to the higher elevation area. In the beaches area, the shifting process will follow the natural elevation pattern of the beach, where the nesting site will shift to the higher elevation and landward direction. But, at the edge of the beach area, the land-cover behind the beach will be the factor that determines whether or not the nesting could continue to move to landward.

The result showed that in the beach area, by increased sea-level of 20 cm (low level scenario), the nesting area will be declined by 15 % or around 27.6 ha from the total initial nesting area. Thus, the beach area within the preferred nesting range will be decreased by 26.7 % and 33.5 % from the total original nesting area on moderate and high level rise scenario, respectively.

Analysis from land-cover behind the beach showed that, in total there is 69.1 % of the total land-cover behind the beach that is categorized as protected where the land-cover prevent the beaches to move landward. Only 31 % is categorized as adaptable where the land-cover is a natural and allows the beaches to move landward.

Observation from fieldwork showed that tourism-associated infrastructures are the most dominant along the Cretan coast-line. Hotels, tavernas, restaurants, pubs and other tourist activities are concentrated on the beach that in turn decreases the number of the natural area along the beach.

Arianoutsou (1998) stated that the tourism development is considered as a main threat to nesting beaches in Greece. As tourism industry increases, the demand for tourism infrastructure also increases. Lima (2008) found that the number of tourist arrival to Crete increased 179 % in 35 years, where the tourist arrivals in 1971 were 15.000, and increased to 2.778.340 in 2006. In the Rethymno prefecture, since 1995 to 2004, there was an increase of 27 % of tourist arrivals, 14 % of hotels and 36 % of bedrooms and bed places. These finding showed the rapid growth of the tourism-associated development where most of the tourist infrastructure were built nearby or adjacent to the coastline.

4.4. The Environmental Parameters Related to Sea-Level Rise

Fish *et al*. (2005) stated that the consequences of the nesting habitat loss will be hard to evaluate without a prior knowledge of the micro-environmental parameters that characterize the nesting beaches. This research revealed that the sand salinity, sand grain shape and precipitation are the important parameters that determine the suitability of the nesting beaches.

All of those parameters are subjected by climate change and sea-level rise. However, to what extent sea-level rise can affect the physical and chemical characteristics of that parameters still need further research.

Pittock (2005) described that in a small island the salinity will increase parallel with the rising of the sea water and the average rainfall as well as the inter-annual variability will change due to changes in the global weather pattern and regional climatic pattern. Furthermore, Giannakopoulos *et al*. (2005) stated that by an increase of 2°C of the global temperature, in the period of year 2031-2060, the annual temperature in the coastal area in the Mediterranean region will increase 1-2 °C in average. The average annual precipitation in the southern part will drop by 10-20 % compared to the years 1961-1990.

Robinson *et al*. (2008) stated that increased temperature and changed precipitation are among the impacts of climate change that will threaten the sea turtle. The changes of the important parameters for nesting beaches undoubtedly will influence nesting activity of the sea turtle as well as the viability of the sea turtle population.

4.5. Beach Management Considerations

Understanding the impact of climate change on nesting site of sea turtle is one step to understand the overall impact of climate change to these endangered species, because the nesting activity and nesting site is not the only one phase and location where the impact of the climate change will likely to threaten this species.

SWOT (2007), stated that perhaps the most vulnerable area for sea turtle is the nesting area, where the stability of this area will contributed to hatchling production and hatchling success. The stability of nesting beach characteristics becomes an important factor because nesting sites are used by successive generations. The sea turtles will return to their natal beaches to incubate and hatch a new generation (Demetropoulos, 2000). Furthermore, female sea turtle is a “faithfully” species, as it will come back to the same area or rookeries to nest. Schroeder *et al*., (2003) stated that Loggerheads shows strong site fidelity, where 21 % fidelity to a 1.0 km away from their first nesting site and 80 % fidelity to the particular rookeries (Kikukawa *et al.* 1999).

Based on the fact above, increasing the sustainability of nesting habitat becomes a priority. As sea-level rise threaten nesting beaches, a management strategy to mitigate the impact has to be undertaken in order to ensure the survival of nesting beaches as well as sea turtle itself. Jones *et al*. (2004) suggested proactive and preventive management by increasing resilience of ecosystem, such as protection and stabilization of dunes and the provision of buffer zones or setback regulations that allow the coastline to migrate landward, is one approach. Fish *et al*. (2008) suggested that a setback regulation, the regulation to disallow the construction of the infrastructure within a set range from the sea, is one of the potential approaches that could mitigate loss of the beaches habitat. The setback regulation has been classified as a managed risk/risk reduction concept by Dolan and Walker (2004), where setback regulation will be likely to minimize the impact from sea-level rise by providing a natural area and allowing the beaches to recuperate naturally.

Furthemore, in the area where the beaches are relatively un-developed, the implementation of such a kind of strategy could be straight forward, but it might be socially unacceptable in extensively developed areas where the societal asset already built in the beach area (Jones *et al.*, 2004). Fish et *al.* *(*2008) proposed that in the developed area, the coastal realignment will be an alternative or complementary approach. The setback strategy could be enforced when the infrastructure reaches the end of their life span and need to be fully renovated or teardown completely, and then the setback strategy could be implemented by removing the infrastructure.

It is obvious that the implementation of a coastal management plan that incorporates the impact from the sea-level rise becomes a priority. The goals of the coastal management plan should ideally ensure that the ecological system such as sea turtle nesting habitat is sustainable, while the economical system such as tourism industry is kept viable and acceptable for the social system.

Although the climate change model is subject to uncertainties and the sea-level rise model that explored in this study is based on a simplistic model, some important points have been delivered that there is a direct threat from climate change to the nesting beaches of the sea turtles. The threat from sea-level rise coupled with the uncontrolled coastal development will affect the viability of sea turtle decades later.

5. Conclusions and Recommendations

5.1. Conclusions

- This study shows that there are coastal physical parameters that might determine the suitability of nesting habitat for the Loggerhead sea turtle.
- The sand salinity, conductivity, NaCl content and grain shape are the sand characteristics parameters that different significantly in nesting and non-nesting beaches. In addition, there are ten parameters of the climatic characteristics parameters that are significantly different on nesting and non-nesting beaches. Those parameters are minimum and maximum temperatures in the months of May and July, as well as precipitation and solar radiation in the months of May, July and September.
- The coastal physical parameters that are categorized as important parameters and possibly influence the suitability of the nesting habitat of the Loggerhead sea turtle are precipitation in the month of May, sand grain shape and sand salinity. The precipitation in the month of May that coincides with the initiation phase of the nesting season are suspected to be one of the major factors that are influencing the micro-environmental condition of nesting beaches, as nesting beaches received more rainfall than non-nesting beaches. Moreover, the angular sand grain shape of nesting beaches is suspected to be an advantageous factor in building a well-constructed nesting chamber. Thus, the low level sand salinity of nesting beaches is the factor that contributes to a proper chemical process in nesting chambers that is important for the development of sea turtle's eggs. Despite receiving more rainfall, nesting beaches are also fed by freshwater from rivers and groundwater, so influencing to the low level salinity in nesting beaches as well.
- The impact assessment of the predicted sea-level rise to the beaches area shows that 25.6 % of the total beaches will be lost due to low level scenario (0.2 m), 50.1 % will be lost by moderate level scenario (0.4 m), and 69.5 % of the beach area will be lost by high level scenario (0.6 m) of the predicted sea-level rise.
- The analysis of the potential shift in the nesting range of the Loggerhead sea turtle as an adaptation of the sea-level rise shows that the initial nesting range of the loggerhead is 43.8 % of the total beaches area. By a sea-level increase 0.2 m, the nesting range will shift landward and as a consequence, the suitable nesting range will be reduced to 28.8 % of the total beaches area. This impact will be doubled if the sea-level increases to 0.4 m, and the optimal nesting

range will be reduced to 17.1 %. In the high level scenario, i.e. 0.6 cm, the optimal nesting range will be reduced to 10.3 % of the total beaches area.

- The major land-cover behind the beach is “protected” land-cover that prevents the landward expansion of the beach. More than 69 % of land-cover is categorized as urban area and un-expandable area. The natural/semi natural land-cover, which is categorized as “adaptable” land-cover, occupied 31 % of the total land-cover behind the beaches.

5.2. Recommendations

Considering the abovementioned results, discussions and conclusions, for further analysis there are several recommendations:

- To improve the robustness of the nesting habitat suitability assessment, extensive data collections are needed. Increasing the number of sampling locations and investigated parameters will probably yield a better understanding of the important factors that determine nesting habitat suitability.
- A different climatic zone in the northern and southern part of Crete Island could influence the nature of coastal physical parameters at beach scale. Therefore, the uses of validation and calibration techniques are needed to reduce the uncertainties due to climatic differentiation.
- By using Bruun model, the uncertainty surrounding this theory was also affecting this research. Cooper and Pilkey (2004) explained that although widely used as a management tool and as a scientific concept, Bruun model ignore various principles of oceanography and geology Therefore it is recommended to improve the use of Bruun model by incorporating such an oceanographical and geological parameters to the sea-level rise model.
- The use of more sophisticated tools and technique to collect beach profile data such as LiDAR image as well as DGPS (differential GPS) device will possibly lead to higher quality beach profile data that can be used to develop and produce more robust results.
- Analysis of the correlation between physical parameters of the nesting beach (length, wide, slope, elevation, aspect, and land-cover behind the beach) with vulnerability to the sea-level rise are required in order to understand how these beach parameters deal with sea-level rise.

Bibliography

Ackerman, R.A. (1997) The nest environment and the embryonic development of sea turtles. *The Biology of Sea Turtles* (eds P. L. Lutz & J. A. Musick), pp. 83-106. CRC Press, Boca Raton-Florida.

Alderton, D. (1998) *Turtle and tortoises of the world.* Facts on File, Inc, New York.

Arianoutsou, M. (1988) Assessing the impacts of human activities on nesting of loggerhead sea turtles (Caretta caretta) on Zakynthos island, Western Greece. *Conservation Biology,* 15, 327-334.

Baker, J.D., Littnan, C.L. & Johnston, D.W. (2006) Potential effects of sea level rise on the terrestrial habitats of endangered and endemic megafauna in the Northwestern Hawaiian Islands. *Endangered Species Research,* 2, 21–30.

Bindoff, N.L., Willebrand, J., Artale, V., Cazenave, A., Gregory, J., Gulev, S., Hanawa, K., Le Quéré, C., Levitus, S., Nojiri, Y., Shum, C.K., Talley, L.D. & Unnikrishnan, A. (2007) Observations: Oceanic Climate Change and Sea Level. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor & H. L. Miller). Cambridge University Press, Cambridge, United Kingdom and New York, NY,USA.

Bolten, A.B. (2003) The Loggerhead sea turtle-A most excellent fishe. *Loggerhead sea turtles* (eds A. B. Bolten & B. E. Witherington), pp. 1-3. Smithsonian Institution Press, Washington D.C.

Bolten, A.B. & Witherington, B.E. (2003) Loggerhead sea turtles. Smithsonian Institution Press Washington.

Bowen, B.W. (2003) What is a Loggerhead turtle? ; The genetic perspective. *Loggerhead sea turtles* (eds A. B. Bolten & B. E. Witherington), pp. 7-27. Smithsonian Institution Press, Washington D.C.

Brander, K. (2003) Climate change and fisheries. *Global Climate Change and Biodiversity* (eds R. E. Green, M. Harley, L. Miles, J. Scharlemann, A. Watkinson & O. Watts). Norwich, UK.

Bruun, P. (1962) Sea level rise as a cause of shore erosion. *Journal of the Waterways and Harbors Division,* 88.

Cambers, G. (1998) Coast and beach stability in the Caribbean islands (COSALC) St John, United States Virgin Islands, beach monitoring field manual. UNESCO-CSI and the University of Puerto Rico Sea Grant College Program., Paris.

Caminas, J.A. (2004) Sea turtles of the Mediterranean Sea: population dynamics, sources of mortality and relative importance of fisheries impacts. *FAO Fisheries Report*. FAO.

Carthy, R.R., Foley, A.M. & Matsuzawa, Y. (2003) Incubation Environment of Loggerhead Turtle Nest : Effect on Hatching Success and Hatchling Characteristic. *Loggerhead sea turtles* (eds A. B. Bolten & B. E. Witherington), pp. 144–154. Smithsonian Institution Press, Washington D.C.

Cooper, J.A.G. & Pilkey, O.H. (2004) Sea-level rise and shoreline retreat: time to abandon the Bruun Rule. *Global and Planetary Change,* 43, 151-171.

Cross, H., Khalil, M. & Venilos, L. (2005) Population status and Conservation Activities on Se aturtle Nesting Beaches in South Lebanon. *Marine Turtle Conservation in the Meditteranean*.

Daniels, R.C., W.White, T. & Chapman, K.K. (1993) Sea-Level Rise: Destruction of Threatened and Endangered Species Habitat in South Carolina *Environmental Management* 17, 373-385.

Dasgupta, S., Laplante, B., Meisner, C., Wheeler, D. & Yan, J. (2007) The Impact of Sea Level Rise on Developing Countries: A Comparative Analysis. . *World Bank Policy Research Working Paper 4136*. World Bank.

Demetropoulos, A. (2000) Impact of tourism development on marine turtle nesting: strategies and actions to minimise impact. 32.

Dolan, A.H. & Walker, I.J. (2004) Understanding vulnerability of coastal communities to climate change related risks. *Journal of Coastal Research,* Special Issue 39.

Encalada, S.E., Bjorndal, K.A., Bolten, A.B., Zurita, J.C., Schroeder, B., Possardt, E., Sears, C.J. & Bowen, B.W. (1998) Population structure of loggerhead turtle (*Caretta caretta*) nesting colonies in the Atlantic and Mediterranean as inferred from mitochondrial DNA control region sequences. *Marine Biology,* 130, 567-575.

Explore-Crete (2008) The travel guide for real Crete. Online sources http://www.explorecrete.com/crete.html.Accessed on December 20th 2008

Field, A.P. (2005) *Discovering Statistics using SPSS* SAGE Publications Ltd, London.

Fish, M.R., Coˆte´ , I.M., Gill, J.A., Jones, A.P., Renshoff, S. & Watkinson, A.R. (2005) Predicting the Impact of Sea-Level Rise on Caribbean Sea Turtle Nesting Habitat. *Conservation Biology,* 19, 482-491.

Fish, M.R., Coˆte´ , I.M., Horrocks, J.A., Mulligan, B., Watkinson, A.R. & Jones, A.P. (2008) Construction setback regulations and sea-level rise: Mitigating sea turtle nesting beach loss. *Ocean & Coastal Management,* 51, 330-342.

Garson, D. (2008) Multiple regression; Statnotes: Topics in Multivariate Analysis. Online sources http://www2.chass.ncsu.edu/garson/pa765/statnote.htm. Accessed on December 17th 2008

Giannakopoulos, C., Bindi, M., Moriondo, M., LeSager, P. & Tin, T. (2005) Climate change impacts in the Mediterranean resulting from a 2 C global temperature rise pp. 76. WWF, Gland - Switzerland

Gilman, E., Van Lavieren, H., Ellison, J., Jungblut, V., Wilson, L., Ereki, F., Brighouse, G., Bungitak, J., Dus, E., Henry, M., Sauni, I., Kilman, M., Matthews, E., Teariki-Ruatu, N., Tukia, S. & Yuknavage, K. (2006) Pacific Island mangroves in a changing climate and rising sea. *UNEP Regional Sea Reports and Studies 179*, pp. 58 United Nations Environment Programme, Regional Sea Programme, Nairobi.

Hays, G.C., Mackay, A., Adams, C.R. & Mortimer, J.A. (1995) Nest site selection by sea turtles. *Marine Biological Association of the United Kingdom,* 75, 667

Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. & Jarvis, A. (2005) Very high resolution interpolated climate surfaces for global land areas. *Inetranational Journal of Climatology,* 25.

IAC-Seaturtle (2008) The sea turtle life cycle Online sources http://www.iacseaturtle.org/English/download/ciclo%20de%20vida%20ENG.pdf.Accessed on December 30th 2008

IPCC (2007a) Summary for Policymakers *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor & H. L. Miller). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (2007b) Summary for Policymakers. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden & C. E. Hanson). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC (2007c) Synthesis Report. *Climate Change 2007: Synthesis Report* (eds Lenny Bernstein, Peter Bosch, Osvaldo Canziani, Zhenlin Chen, Renate Christ, Ogunlade Davidson, William Hare, Saleemul Huq, David Karoly, Vladimir Kattsov, Zbigniew Kundzewicz, Jian Liu, Ulrike

Lohmann, Martin Manning, Taroh Matsuno, Bettina Menne, Bert Metz, Monirul Mirza, Neville Nicholls, Leonard Nurse, Rajendra Pachauri, Jean Palutikof, Martin Parry, Dahe Qin, Nijavalli Ravindranath, Andy Reisinger, Jiawen Ren, Keywan Riahi, Cynthia Rosenzweig, Matilde Rusticucci, Stephen Schneider, Youba Sokona, Susan Solomon, Peter Stott, Ronald Stouffer, Taishi Sugiyama, Rob Swart, Dennis Tirpak, Coleen Vogel & G. Yohe), pp. 73

IUCN (2007) 2007 IUCN Red List of threatened species. Online sources http://www.iucnredlist.org. Accessed on July 12th 2008

Jones, A., Gladstone, W. & Hacking, N. (2004) Sandy-beach ecosystems and climate change: potential ecological consequences and management implications. *Coast to coast 2004 : Australia's national coastal conference*, pp. 6. Hobart.

Kamezaki, N. (2003) What is Loggerhead Turtle ? The Morphological Perspective. *Loggerhead sea turtles* (eds A. B. Bolten & B. E. Witherington), pp. 28–43. Smithsonian Institution Press, Washington D.C.

Kikukawa, A., Kamezaki, N. & Ota, H. (1999) Factors affecting nesting beach selection by loggerhead turtles (*Caretta caretta*): a multiple regression approach. *Journal of Zoology,* 249, 447-454.

Lima, P. (2008) *Tourism impact on nesting habitat of loggerhead sea turtle in Crete, Greece*. ITC, Enschede.

Lowry, R. (1999) Concepts and applications of inferential statistics Online sources http://faculty.vassar.edu/lowry/webtext.html.Accessed on October 21th 2008

Maktav, D., Sunar, F., Yalin, D. & Aslan, E. (2000) Monitoring Loggerhead Sea Turtle (Caretta caretta) nests in Turkey using GIS. *Coastal Management,* 28, 123 - 132.

Margaritoulis, D., Argano, R., Baran, I., Bentivegna, F., Bradai, M.N., Camiñas, J.A., Casale, P., Metrio, G.D., Demetropoulos, A., Gerosa, G., Godley, B.J., Haddoud, D.A., Houghton, J., Laurent, L. & Lazar, B. (2003) Loggerhead turtles in the Mediterranean Sea: present knowledge and conservation perspectives. *Loggerhead sea turtles* (eds A. B. Bolten & B. E. Witherington), pp. pp 175–198. Smithsonian Institution Press, Washington D.C.

Margaritoulis, D. & Rees, A.F. (2003) Loggerhead Nesting Effort and Conservation Initiatives at the Monitored Beaches of Greece during 2002 *Marine Turtle Newsletter,* 102, 11-13.

Mazaris, A.D., Matsinos, Y.G. & Margaritoulis, D. (2006) Nest site selection of loggerhead sea turtles: The case of the island of Zakynthos, W Greece. *Journal of Experimental Marine Biology and Ecology,* 336, 157–162

McGranahan, G., Balk, D. & Anderson, B. (2007) The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. *Environment & Urbanization,* 19, 17-37.

Miller, J.D., Limpus, C.J. & Godfrey, M.H. (2003) Nest site selection, oviposition, eggs, development, hatching, and emergences of loggerhead turtles. *Loggerhead sea turtles* (eds A. B. Bolten & B. E. Witherington), pp. 125–143. Smithsonian Institution Press, Washington DC.

Moin, N. (2007) *Modelling critical coastal ecosystems : a study on the marine turtles nesting habitats in the mediterranean*. ITC, Enschede.

Mortimer, J.A. (1990) The influence of beach sand characteristics on the nesting behaviour and clutch survival of Green Turtles (Chelonia mydas). *Copeia,* (5), 802–817.

Mortimer, J.A. (1995) Factor Influencing beach selection by nesting sea turtle. *Biology and conservation of sea turtles* (ed K. A. Bjorndal), pp. 45-51 Smithsonian Institution Press, Washington, D.C.

Mrosovsky, N. (1994) Sex ratios of sea turtles. *Experimental Zoology,* 270, 16-27.

Nicholls, R.J., Wong, P.P., Burkett, V.R., Codignotto, J.O., Hay, J.E., McLean, R.F., Ragoonaden, S. & Woodroffe, C.D. (2007) Coastal systems and low-lying areas *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds M. L. Parry, O. F.

Canziani, J. P. Palutikof, P. J. Van der Linden & C. E. Hanson), pp. 315-356. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, .

Pittock, A.B. (2005) *Climate change : Turning up the heat.* CSIRO Publishing, Collingwood-Australia.

Robinson, R.A., Crick, H.Q.P., Learmonth, J.A., Maclean, I.M.D., Thomas, C.D., Bairlein, F., Forchhammer, M.C., Francis, C.M., Gill, J.A., Godley, B.J., Harwood, J., Hays, G.C., Huntley, B., Hutson, A.M., Pierce, G.J., Rehfisch, M.M., Sims, D.W., Santos, M.B., Sparks, T.H., Stroud, D.A. & Visser, M.E. (2008) Review : Travelling through a warming world: climate change and migratory species. *Endangered Species Research*.

Roessig, J.M., Woodley, C.M., Joseph J. Cech, J. & Hansen, L.J. (2004) Effects of global climate change on marine and estuarine fishes and fisheries *Fish Biology and Fisheries,* 14, 251-275.

Snoussi, M., Ouchani, T. & Niazi, S. (2008) Vulnerability assessment of the impact of sea-level rise and flooding on the Moroccan coast: The case of the Mediterranean eastern zone. *Coastal and Shelf Science* 77, 206-213.

Solomon, S., Qin, D., Manning, M., Alley, R.B., Berntsen, T., Bindoff, N.L., Chen, Z., Chidthaisong, A., Gregory, J., Hegerl, G.C., Heimann, M., Hewitson, B., Hoskins, B.J., Joos, F., Jouzel, J., Kattsov, V., Lohmann, U., Matsuno, T., Molina, M., Nicholls, N., Overpeck, J., Raga, G., Ramaswamy, V., Ren, J., Rusticucci, M., Somerville, R., Stocker, T.F., Whetton, P., Wood, D.W. & Wratt, D. (2007) Technical Summary. *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (eds S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor & H. L. Miller). Cambridge University Press, Cambridge, United Kingdom and New York, NY,USA.

SWOT (2006) SWOT Report I - The State of the world's sea turtle Arlington.

SWOT (2007) SWOT Report II - The State of the world sea turtle Arlington.

Thumerer, T., Jones, A.P. & Brown, D. (2000) A GIS based coastal management system for climate change associated food risk assessment on the east coast of England. *International journal of geographical information science,* 14, 265-281.

UNEP (2006) Marine and coastal ecosystems and human wellbeing: A synthesis report based on the findings of the Millennium Ecosystem Assessment., pp. 76. UNEP.

West-Crete (2008) The geography of Crete . Online Sources http://www.west-crete.com/geography-crete.htm. Accessed on October 20th 2008

Wood, D.W. & Bjorndal, K.A. (2000) Relation of Temperature, Moisture, Salinity, and Slope to Nest Site Selection in Loggerhead Sea Turtles. *Copeia,* 2000, 119-119.

Yntema, C.L. & Mrosovsky, N. (1980) Sexual differentiation in hatchling loggerhead (*Caretta caretta*) incubated at different controlled temperatures. *Herpetologica,* 36.

Appendices

Appendix A . The emission scenarios of the IPCC-special reports on emission scenarios (SRES) (IPCC, 2007a)

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more effi cient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil-intensive **(A1FI)**, non-fossil energy sources **(A1T)** or a balance across all sources **(A1B)** (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-effi cient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1 and B2. All should be considered equally sound.

The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

Appendix B. Fieldwork sampling sheet

SAMPLING SHEET (Beach and Sand Characteristic)

Beach ____________________ **Date** ____________

Sample No ____________________ **Time** ____________________________

Coordinate **Picture** ____________________________

X ____________________

Y ____________________

General Condition

Sea condition	*Cloud cover*	
Calm moderate rough	Clear light	heavy

Type of Beach activity		*distance*	*number*
	Hotel	m	
	Sunbeds	m	
	Sports	m	
	Playingground	m	

Sand characteristics		
	Temperature	
	Salinity	
	Moisture	
	particle size	
	Stonines	
	Aspect	

Landuse behind the beach

Remarks

LEVELER SHEET (Beach Profile)

Beach ____________________

Date ____________________

Time ____________________

No Sta	Position	Lev. Hight (cm)	Details	Angle (α)	Distance (m)	Hight (cm)	Note/ Land-use
1	X		a				
	Y		b				

Appendix C. Data set of sand characteristics and climatic characteristics

Appendix C-1. In situ data of beach sand characteristics – non nesting beaches

Location [a]	Geographic Location [b]		Temperature (^{0} C) [c]	Moisture (wvf) [d]	Salinity (gr/ltr) [e]	Distance from waterline (m) [f]
	X	Y				
Xerocampos - beach 1	428643	3877290	32.9	0.21	0.51	12.0
Xerocampos - beach 2	428856	3877362	33.4	0.04	0.12	13.0
Falasarna - beach 1	189530	3934260	24.6	0.07	0.14	16.8
Falasarna - beach 1	189741	3933330	24.9	0.07	0.09	15.4
Falasarna - beach 2	189735	3933210	25.6	0.07	0.13	20.4
Falasarna - beach 2	189657	3932830	27.2	0.08	0.13	22.0
Palaechora - Limpaki beach	197479	3904056	26.2	0.03	0.07	21.0
Palaechora - Limpaki beach	197514	3904011	24.5	0.03	0.07	42.0
Palaehora - Pahia amnos	197693	3903810	26.2	0.03	0.07	21.0
Palaehora - Pahia amnos	197739	3903696	26.4	0.01	0.04	22.0
Georgeopolis	253691	3915800	28.8	0.06	0.09	30.0
Georgeopolis	254592	3915580	27.9	0.02	0.18	26.4
Georgeopolis	253223	3915880	28.2	0.01	0.08	37.2
Georgeopolis	252845	3915970	28.7	0.03	0.06	38.2
Georgeopolis	252005	3916250	26.1	0.02	0.07	26.1
Frangocastelo	247475	3897100	33.4	0.10	0.06	21.2
Frangocastelo	247601	3896990	34.3	0.05	0.14	15.0
Frangocastelo	247669	3896900	34.1	0.04	0.24	15.2
Frangocastelo	246424	3897970	30.4	0.04	0.31	10.2
Frangocastelo	246509	3897900	30.4	0.12	0.47	7.8
Frangocastelo	246607	3897790	35.7	0.10	0.36	14.5
Iraklion - Karteros beach	335831	3911470	24.6	0.03	0.20	10.2
Iraklion - Karteros beach	336156	3911380	24.6	0.06	0.25	9.2
Iraklion - Karteros beach	336517	3911360	25.4	0.04	0.27	16.2
Iraklion - Karteros beach	336711	3911380	26.9	0.08	0.33	18.0
Iraklion - Amnisos beach	336855	3911380	26.9	0.02	0.18	7.2
Iraklion - Amnisos beach	337367	3911390	27.2	0.11	0.23	12.4
Iraklion - Amnisos beach	337549	3911420	28.0	0.05	0.20	12.2
Koutsunary	393594	3874670	30.5	0.11	0.24	4.3
Koutsunary	393274	3874590	29.7	0.08	0.33	4.1
Koutsunary	392669	3874370	28.0	0.05	0.27	3.5
Koutsunary	392425	3874260	28.3	0.04	0.27	5.6
Koutsunary	392258	3874180	29.4	0.04	0.25	5.1
Koutsunary	391979	3874040	28.9	0.05	0.30	6.5
Koutsunary	393635	3874670	24.7	0.02	0.19	8.2
Koutsunary	393836	3874800	26.6	0.05	0.24	6.4
Koutsunary	393959	3874840	27.0	0.04	0.20	6.0
Irapetra	386464	3874620	29.1	0.09	0.31	5.1
Irapetra	386762	3874460	30.7	0.10	0.35	5.6
Irapetra	386971	3874350	32.4	0.08	0.51	4.9
Irapetra	387225	3874200	33.0	0.06	0.17	9.4
Irapetra	387617	3873950	35.0	0.08	0.56	11.8

[a] *Name of the beach*
[b] *Location in WGS-84 UTM 35 N*
[c] *^{o}C : Temperature in degree celcius*
[d] *wfv : moisture in water fraction by volume*
[e] *gr/ltr : salinity in NaCl gram per litre*
[f] *m : meter*

Appendix C-2. In situ data of beach sand characteristics – nesting beaches

Location [a]	Geographic Location [b]		Temperature (^{0} C) [c]	Moisture (wvf) [d]	Salinity (gr/ltr)[e]	Distance from waterline (m) [f]
	X	Y				
Rethymno old (sfakaki beach)	279285	3917970	28.9	0.05	0.20	11.2
Rhetymno old (sfakaki beach)	280388	3918112	31.4	0.09	0.24	11.0
Rhetymno old (sfakaki beach)	280435	3918128	33.0	0.04	0.05	6.2
Rethymno Alkionis	281015	3918406	29.7	0.04	0.07	18.2
Rethymno Soda	282773	3919028	30.8	0.02	0.06	22.0
Rethymno-Adele	276748	3917280	30.4	0.02	0.07	16.0
Rethymno-Adele	276580	3917238	30.1	0.04	0.09	16.0
Rethymno (Pirgianos)	279502	3918040	32.3	0.01	0.09	8.2
Rethymno (Pirgianos)	278078	3917600	31.3	0.03	0.09	10.6
Rethymno (Prigianos)	280476	3918146	30.2	0.01	0.12	10.2
Rethymno city	271559	3916690	24.9	0.02	0.06	18.0
Rethymno city	271846	3916640	23.8	0.05	0.19	17.3
Rethymno city	272488	3916680	24.7	0.02	0.08	15.8
Rethymno city	272818	3916710	25.9	0.02	0.16	11.2
Rethymno city	272932	3916730	27.9	0.06	0.37	8.8
Rethymno city	273618	3916800	29.5	0.03	0.15	17.4
Rethymno city	274170	3916880	33.0	0.11	0.38	13.2
Rethymno city	274827	3916960	34.4	0.13	0.26	15.4
Rethymno city	275159	3917030	32.0	0.02	0.13	8.1
Chania (Nea Chora)	228077	3934000	32.8	0.05	0.35	8.2
Chania (Nea Chora)	228431	3934120	27.6	0.21	0.22	11.0
Chania (Nea Chora)	228621	3934250	30.8	0.23	0.36	12.1
Chania (Aptera)	227138	3933930	24.0	0.02	0.10	13.2
Chania (Kalamaki 1)	227039	3934010	25.4	0.05	0.14	15.4
Chania (Kalamaki 2)	226919	3934160	26.2	0.02	0.07	11.1
Chania (Oasis 1)	226405	3934240	27.2	0.01	0.04	12.8
Chania (Oasis 2)	226028	3934230	26.9	0.01	0.03	13.0
Chania (Stalos)	223728	3934180	31.7	0.17	0.10	15.2
Chania (Stalos)	223445	3934230	34.0	0.06	0.13	11.3
Chania (Agia Marina)	222468	3934620	31.5	0.04	0.09	6.2
Chania (Platanias)	220472	3934970	29.9	0.02	0.17	10.6
Chania (Platanias)	219432	3935030	33.0	0.02	0.09	11.2
Chania (Gerani)	218453	3935160	33.5	0.04	0.25	8.7
Chania (Gerani)	216336	3935470	26.4	0.02	0.15	8.1
Messara (Komos Beach)	295554	3876200	21.7	0.02	0.10	8.2
Messara (Komos Beach)	295621	3876530	21.9	0.02	0.10	10.7
Messara (Komos Beach)	295637	3877180	24.0	0.03	0.11	8.1
Messara Beach (Kalamaki	295612	3877560	25.6	0.02	0.11	9.7
Messara Beach (Kalamaki	295569	3877970	27.3	0.05	0.31	5.6
Messara Beach (Kalamaki	295521	3878510	29.1	0.13	0.46	3.4
Messara Beach (Kalamaki	295485	3878810	28.3	0.03	0.10	6.8
Messara Beach (Tympaki	294356	3883740	29.2	0.08	0.39	4.0
Messara Beach (Tympaki	294167	3884130	29.5	0.08	0.34	5.0
Messara Beach (Tympaki	294037	3884320	30.0	0.06	0.27	6.0
Messara Beach (Matala beach)	294616	3874790	23.4	0.03	0.26	8.0
Messara Beach (Matala beach)	294617	3874710	22.2	0.08	0.07	8.4
Messara Beach (Matala beach)	294536	3874560	22.0	0.02	0.08	5.2
Messara - Agia Triada	295406	3879450	22.0	0.02	0.07	8.2
Messara - Agia Triada	295362	3879740	22.4	0.02	0.12	15.2
Messara - Agia Triada	295290	3880180	22.2	0.02	0.13	13.2
Messara - Agia Triada	295234	3880518	22.4	0.02	0.15	15.2
Messara - Agia Triada	295205	3880800	22.6	0.03	0.18	17.0

[a] *Name of the beach*
[b] *Location in WGS-84 UTM 35 N*
[c] *^{o}C : Temperature in degree celcius*
[d] *wfv : moisture in water fraction by volume*
[e] *gr/ltr : salinity in NaCl gram per litre*
[f] *m : meter*

Appendix C-3. Analytical/laboratory result of beach sand characteristics

Location [a]	Geographic Location [b]		pH	Conductivity	NaCl	$CaCO_3$	Microscopic	
	X	Y		(µS/cm) [c]	*(ppm)* [d]	*(%)* [e]	Grain shape [f]	Cleanliness [g]
Non-Nesting Beaches								
Xercampos	428643	3877290	9.44	1034.00	351	1.89	2	1
Falasarna	189530	3934260	9.68	295.00	84	1.89	1	1
Falasarna	189735	3933210	9.72	373.00	108	1.73	2	1
Palaechora	197479	3904056	9.63	96.40	15	1.92	1	2
Palaechora	197514	3904011	9.60	94.90	9	1.82	3	1
Palaechora	197693	3903810	9.64	130.10	20	1.86	2	1
Palaechora	197739	3903696	9.47	100.80	9	1.82	2	1
Georgeopolis	254592	3915580	9.39	153.20	26	7.55	1	1
Georgeopolis	252845	3915970	9.46	143.50	24	1.89	1	1
Frangocastelo	247601	3896990	9.46	601.00	152	1.89	2	1
Frangocastelo	246607	3897790	9.41	1871.00	506	1.89	2	1
Frangocastelo	247924	3896630	9.24	732.00	152	1.79	3	1
Frangocastelo	246509	3897900	9.41	493.00	115	1.82	3	1
Iraklion - Karteros beach	335831	3911470	9.56	619.00	206	1.92	1	2
Iraklion - Karteros beach	336517	3911360	9.76	583.00	207	1.98	1	1
Iraklion - Amnisos beach	336855	3911380	9.64	733.00	231	1.86	1	2
Iraklion - Amnisos beach	337367	3911390	9.44	710.00	213	6.72	1	1
Koutsunary	392425	3874260	9.62	721.00	254	7.42	1	1
Irapetra	386464	3874620	9.51	1115.00	361	1.92	1	2
Irapetra	387225	3874200	9.37	1649.00	531	1.92	1	1
Irapetra	387734	3873860	9.47	1240.00	397	1.92	1	1
Nesting Beaches								
Rethymno	279285	3917970	9.63	159.30	54	1.95	3	1
Rethymno	280435	3918128	9.39	1270.00	379	1.89	3	1
Rethymno	281015	3918406	9.55	152.80	35	1.92	3	1
Rethymno	282773	3919028	9.69	144.10	37	2.37	3	3
Rethymno	276748	3917280	9.71	213.90	61	2.24	3	3
Rethymno	276580	3917238	9.60	169.20	42	1.95	2	1
Rethymno	278078	3917600	9.60	111.10	23	1.95	3	1
Rethymno	271559	3916690	9.58	124.60	26	1.92	3	1
Rethymno	272488	3916680	9.58	229.00	61	1.86	3	1
Rethymno	272818	3916710	9.50	127.90	24	1.79	3	1
Rethymno	272932	3916730	9.51	187.20	43	1.92	3	1
Chania	228431	3934120	9.37	191.10	43	1.89	3	1
Chania	227039	3934010	9.53	165.80	38	1.95	3	1
Chania	225869	3934170	9.52	121.10	19	1.95	2	1
Chania	216336	3935470	9.49	276.00	73	1.02	3	1
Messara	295637	3877180	9.72	353.00	103	1.95	3	1
Messara	295569	3877970	9.55	578.00	153	1.89	2	1
Messara	295485	3878810	9.36	886.00	271	1.76	3	1
Messara	294167	3884130	9.57	792.00	280	1.70	3	1
Messara	294616	3874790	9.56	854.00	287	1.82	3	1
Messara	294536	3874560	9.59	141.90	31	1.98	3	2
Messara	295362	3879740	10.01	314.00	118	1.89	2	2
Messara	295234	3880518	9.89	244.00	89	1.82	2	2
Messara	295205	3880800	10.01	169.70	65	1.89	2	2

[a] *Name of the beach*
[b] *Location in WGS-84 UTM 35 N*
[c] *µS/cm : Conductivity in micro Siemens per centimetre*
[d] *ppm : NaCl content in part per-million*
[e] *% : $CaCO_3$ content in percentage*

[f] *: Grain Shape*
1: rounded
2. mixture
3. angular

[g] *Cleanliness*
1. low dust
2 .moderate dust
3. high dust

Appendix C-4. Sand sieving proportions based on 6 grading size

Location [a]	Grading Size / Sieve Fraction					
	≥ 2	*1.00 ≥ <2.0*	*0.50 ≥ < 1.0*	*0.25 ≥ < 0.5*	0.10 ≥ < 0.25	0.10 mm <
	%	%	%	%	%	%
Non-Nesting Beaches						
Xercampos	0.0	5.1	5.6	***59.8***	29.4	0.0
Falasarna	5.4	25.7	22.7	***35.2***	11.0	0.0
Falasarna	6.1	25.2	***37.0***	20.3	6.6	4.8
Palaechora	5.4	***21.1***	14.9	18.5	35.7	4.5
Palaechora	5.2	19.6	***24.3***	22.4	24.0	4.5
Palaechora	5.1	5.2	18.7	***45.6***	20.6	4.9
Palaechora	0.0	6.5	***36.8***	25.0	26.3	5.3
Georgeopolis	0.0	5.1	5.3	18.9	***65.5***	5.2
Georgeopolis	5.4	5.4	7.6	25.7	***51.0***	4.9
Frangocastelo	5.7	5.3	11.6	***52.7***	19.8	4.9
Frangocastelo	5.8	12.1	11.2	22.7	***43.1***	5.1
Frangocastelo	5.6	6.4	13.4	***47.0***	22.1	5.5
Frangocastelo	5.3	6.7	23.3	***37.3***	22.2	5.1
Iraklion - Karteros beach	0.0	5.3	7.0	***43.1***	39.5	5.2
Iraklion - Karteros beach	6.0	5.2	12.8	***51.8***	19.4	4.8
Iraklion - Amnisos beach	0.0	5.2	7.7	***55.6***	26.4	5.0
Iraklion - Amnisos beach	0.0	8.7	***56.0***	29.0	6.4	0.0
Koutsunary	20.3	***43.9***	5.8	10.7	14.7	4.5
Irapetra	4.7	5.6	35.7	***39.6***	9.7	4.7
Irapetra	4.7	7.3	***47.0***	27.2	9.2	4.6
Irapetra	7.3	26.0	***28.3***	17.9	14.5	6.0
Nesting Beaches						
Rethymno	5.5	5.6	13.7	***58.2***	12.1	4.8
Rethymno	0.0	6.1	41.1	***46.2***	6.6	0.0
Rethymno	0.0	5.6	10.9	***50.1***	28.0	5.4
Rethymno	9.0	9.7	20.9	***43.7***	11.5	5.2
Rethymno	4.0	5.3	27.1	***53.8***	5.9	3.9
Rethymno	0.0	4.3	7.2	***77.7***	6.6	4.3
Rethymno	8.0	7.2	14.7	***55.6***	7.6	6.9
Rethymno	4.5	4.5	24.2	***55.1***	7.1	4.6
Rethymno	5.0	4.8	16.3	***58.9***	10.3	4.7
Rethymno	4.7	5.0	***43.3***	36.6	5.9	4.5
Rethymno	0.0	5.5	18.6	***59.2***	11.7	5.0
Chania	0.0	5.3	6.0	35.3	***48.0***	5.4
Chania	0.0	5.0	5.9	***53.8***	30.0	5.2
Chania	0.0	5.1	12.0	***64.0***	13.9	5.0
Chania	5.3	10.9	30.6	***36.4***	12.3	4.6
Messara	5.4	5.8	37.6	***39.2***	7.4	4.6
Messara	0.0	5.3	37.6	***51.0***	6.1	0.0
Messara	4.9	5.1	28.9	***44.4***	11.9	4.8
Messara	6.8	19.8	17.9	***30.9***	19.9	4.7
Messara	9.0	23.8	***29.5***	23.7	8.9	5.0
Messara	5.4	12.6	***49.4***	23.0	4.9	4.8
Messara	7.1	***35.2***	17.8	17.1	17.7	5.2
Messara	10.2	***33.3***	16.2	18.7	16.3	5.2
Messara	6.6	***26.2***	25.4	23.6	13.6	4.6

[a] *Name of the beach*

Appendix C-5. Climatic parameters data of non-nesting beaches

Location [a]	Minimum Temperature (^{o}C)[b]			Maximum Tempearture (^{o}C)[c]			Precipitation (mm)[d]			Solar Radiation (Wh/m^2)[e]		
	May	*July*	*Sept*	*May*	*July*	*Sept*	*May*	*July*	*Sept*	*May*	*July*	*Sept*
Xerocampos - beach 1	19.6	25.6	24.0	22.8	28.2	26.6	12	0	11	4150	4850	3650
Xerocampos - beach 2	19.6	25.6	24.0	22.8	28.2	26.6	12	0	11	4150	4850	3650
Falasarna - beach 1	19.5	25.4	23.0	23.2	28.7	26.1	12	1	13	3833	4590	3300
Falasarna - beach 1	20.1	25.8	23.7	23.7	28.9	26.6	11	1	12	3836	4600	3300
Falasarna - beach 2	20.1	25.8	23.7	23.7	28.9	26.6	11	1	12	3839	4610	3300
Falasarna - beach 2	20.1	25.8	23.7	23.7	28.9	26.6	11	1	12	3839	4610	3300
Palaechora - Limpaki beach	20.3	26.0	24.0	24.1	29.2	27.0	12	1	13	3883	4700	3383
Palaechora - Limpaki beach	20.3	26.0	24.0	24.1	29.2	27.0	12	1	13	3883	4700	3383
Palaehora - Pahia amnos	20.3	26.0	24.0	24.1	29.2	27.0	12	1	13	3883	4700	3383
Palaehora - Pahia amnos	20.3	26.0	24.0	24.1	29.2	27.0	12	1	13	3883	4700	3383
Georgeopolis	20.5	26.3	23.9	24.5	30.0	27.4	15	2	14	3850	4511	3300
Georgeopolis	20.5	26.4	23.9	24.5	30.0	27.4	15	2	14	3850	4511	3300
Georgeopolis	20.5	26.3	23.9	24.5	30.0	27.4	15	2	14	3850	4517	3300
Georgeopolis	20.5	26.5	23.9	24.5	30.1	27.4	15	2	14	3850	4523	3300
Georgeopolis	20.5	26.4	23.9	24.5	30.1	27.4	14	2	14	3850	4529	3300
Frangocastelo	20.4	26.2	23.9	24.4	29.8	27.3	15	2	15	3850	4691	3362
Frangocastelo	20.4	26.2	23.9	24.4	29.8	27.3	15	2	15	3850	4691	3362
Frangocastelo	20.4	26.2	23.9	24.4	29.8	27.3	15	2	15	3850	4692	3367
Frangocastelo	20.3	26.2	23.8	24.3	29.8	27.3	15	2	15	3850	4698	3357
Frangocastelo	20.3	26.2	23.8	24.3	29.8	27.3	15	2	15	3850	4698	3357
Frangocastelo	20.3	26.2	23.8	24.3	29.8	27.3	15	2	15	3850	4695	3362
Iraklion - Karteros beach	19.6	25.9	23.5	22.8	28.6	26.1	14	1	16	3846	4476	3300
Iraklion - Karteros beach	19.8	26.0	23.6	23.0	28.7	26.2	14	1	16	3846	4476	3300
Iraklion - Karteros beach	19.8	26.0	23.6	22.9	28.7	26.2	14	1	16	3849	4476	3300
Iraklion - Karteros beach	19.8	26.0	23.6	23.0	28.7	26.2	14	1	16	3849	4476	3300
Iraklion - Amnisos beach	19.8	26.0	23.6	23.0	28.7	26.2	14	1	16	3849	4476	3300
Iraklion - Amnisos beach	19.8	26.0	23.6	23.0	28.7	26.2	14	1	16	3850	4476	3301
Iraklion - Amnisos beach	19.8	26.0	23.6	23.0	28.7	26.2	14	1	16	3850	4476	3301
Koutsunary	19.5	25.6	23.8	22.7	28.2	26.4	12	1	12	4100	4735	3579
Koutsunary	19.5	25.6	23.8	22.7	28.2	26.4	12	1	12	4100	4740	3582
Koutsunary	19.4	25.5	23.6	22.6	28.1	26.2	13	1	12	4100	4735	3579
Koutsunary	19.5	25.6	23.8	22.6	28.1	26.2	13	1	12	4100	4735	3579
Koutsunary	19.5	25.6	23.8	22.5	28.1	26.2	13	1	12	4100	4730	3576
Koutsunary	19.5	25.6	23.8	22.5	28.1	26.2	13	1	12	4100	4730	3576
Koutsunary	19.5	25.6	23.8	22.7	28.2	26.4	12	1	12	4100	4735	3579
Koutsunary	19.5	25.6	23.8	22.7	28.2	26.4	12	1	12	4100	4735	3579
Koutsunary	19.6	25.7	23.9	22.8	28.3	26.5	12	1	12	4100	4740	3583
Irapetra	19.6	25.7	23.8	22.8	28.3	26.4	12	1	12	4068	4713	3557
Irapetra	19.6	25.7	23.8	22.8	28.3	26.4	12	1	12	4079	4718	3562
Irapetra	19.4	25.5	23.7	22.6	28.1	26.3	12	1	12	4079	4718	3562
Irapetra	19.4	25.5	23.7	22.6	28.1	26.3	13	1	12	4085	4718	3564
Irapetra	19.4	25.5	23.7	22.6	28.1	26.3	13	1	12	4085	4718	3564

[a] *Name of the beach*
[b] *^{o}C : Minimum temperature in Celcius*
[d] *mm : Precipitation in millimeter*
[e] *Wh/m^2: Radiation in watt hour per square meter*

Appendix C-6. Climatic parameters data of nesting beaches

Location [a]	Minimum Temperature (°C)[b]			Maximum Tempearture (°C)[c]			Precipitation (mm)[d]			Solar Radiation (Wh/m^2)[e]		
	May	*July*	*Sept*	*May*	*July*	*Sept*	*May*	*July*	*Sept*	*May*	*July*	*Sept*
Rethymno old (sfakaki beach)	20.2	26.3	23.8	24.0	29.7	27.0	17	2	17	3830	4500	3300
Rhetymno old (sfakaki beach)	20.2	26.2	23.8	24.0	29.6	27.0	17	2	17	3821	4500	3300
Rhetymno old (sfakaki beach)	20.2	26.2	23.8	24.0	29.6	27.0	17	2	17	3821	4500	3300
Rethymno Alkionis	20.2	26.3	23.8	24.0	29.7	27.0	17	2	17	3819	4500	3300
Rethymno Soda	20.2	26.2	23.8	24.0	29.6	27.0	17	2	17	3807	4500	3300
Rethymno-Adele	20.3	26.2	23.7	24.0	29.6	27.0	17	2	17	3846	4500	3300
Rethymno-Adele	20.3	26.2	23.7	24.1	29.7	27.0	17	2	17	3846	4500	3300
Rethymno (Pirgianos)	20.2	26.3	23.8	24.0	29.7	27.0	17	2	17	3830	4500	3300
Rethymno (Pirgianos)	20.3	26.3	23.8	24.1	29.7	27.1	17	2	17	3839	4500	3300
Rethymno (Prigianos)	20.2	26.2	23.8	24.0	29.6	27.0	17	2	17	3821	4500	3300
Rethymno city	20.2	26.3	23.8	24.1	29.8	27.1	17	2	17	3850	4500	3300
Rethymno city	20.3	26.3	23.8	24.2	29.8	27.1	17	2	17	3850	4500	3300
Rethymno city	20.1	26.1	23.6	24.2	29.9	27.2	17	2	17	3850	4500	3300
Rethymno city	20.1	26.1	23.6	24.2	29.9	27.2	17	2	17	3850	4500	3300
Rethymno city	20.1	26.1	23.6	24.2	29.9	27.2	17	2	17	3850	4500	3300
Rethymno city	20.2	26.2	23.8	24.1	29.7	27.1	17	2	17	3850	4500	3300
Rethymno city	20.2	26.2	23.8	24.1	29.7	27.1	17	2	17	3850	4500	3300
Rethymno city	20.2	26.2	23.8	24.1	29.7	27.1	17	2	17	3850	4500	3300
Rethymno city	20.2	26.2	23.8	24.1	29.7	27.1	17	2	17	3850	4500	3300
Chania (Nea Chora)	20.6	26.1	23.9	24.3	29.1	26.7	12	1	12	3831	4515	3300
Chania (Nea Chora)	20.6	26.1	23.9	24.3	29.1	26.7	12	1	12	3831	4515	3300
Chania (Nea Chora)	20.6	26.1	23.9	24.3	29.1	26.7	12	1	12	3831	4515	3300
Chania (Aptera)	20.6	26.1	23.9	24.2	29.1	26.6	12	1	12	3839	4520	3300
Chania (Kalamaki 1)	20.5	26.1	23.8	24.2	29.1	26.6	12	1	12	3838	4515	3300
Chania (Kalamaki 2)	20.5	26.1	23.8	24.2	29.1	26.6	12	1	12	3838	4515	3300
Chania (Oasis 1)	20.5	26.1	23.8	24.2	29.1	26.6	12	1	12	3841	4515	3300
Chania (Oasis 2)	20.5	26.1	23.9	24.2	29.1	26.7	12	1	12	3841	4515	3300
Chania (Stalos)	20.5	26.1	23.9	24.2	29.1	26.7	12	1	12	3849	4515	3300
Chania (Stalos)	20.5	26.1	23.9	24.2	29.1	26.7	12	1	12	3846	4515	3300
Chania (Agia Marina)	20.4	26.0	23.6	24.1	29.1	26.5	12	1	12	3842	4515	3300
Chania (Platanias)	20.4	26.1	23.8	24.1	29.1	26.6	12	1	12	3832	4515	3300
Chania (Platanias)	20.4	26.1	23.9	24.1	29.1	26.5	12	1	12	3829	4515	3300
Chania (Gerani)	20.5	26.1	23.9	24.2	29.1	26.7	11	1	12	3819	4511	3300
Chania (Gerani)	20.4	26.1	23.9	24.1	29.1	26.7	11	1	12	3811	4511	3300
Messara (Komos Beach)	19.7	25.8	23.4	23.3	28.9	26.5	17	2	17	3850	4678	3418
Messara (Komos Beach)	19.7	25.8	23.4	23.3	28.9	26.5	17	2	17	3850	4678	3418
Messara (Komos Beach)	19.7	25.7	23.6	23.3	28.9	26.6	17	2	17	3850	4675	3413
Messara Beach (Kalamaki	19.9	26.0	23.7	23.3	28.9	26.6	17	2	17	3850	4675	3413
Messara Beach (Kalamaki	19.9	26.0	23.7	23.5	29.1	26.7	17	2	17	3850	4672	3408
Messara Beach (Kalamaki	19.9	26.0	23.7	23.5	29.1	26.7	17	2	17	3850	4672	3408
Messara Beach (Kalamaki	19.9	26.0	23.7	23.5	29.1	26.7	17	2	17	3850	4672	3408
Messara Beach (Tympaki	20.0	26.1	23.8	23.6	29.2	26.8	17	2	17	3850	4646	3400
Messara Beach (Tympaki	20.0	26.1	23.8	23.6	29.2	26.8	17	2	17	3850	4639	3400
Messara Beach (Tympaki	20.0	25.9	23.6	23.6	29.2	26.8	17	2	17	3850	4639	3400
Messara Beach (Matala beach)	19.8	25.8	23.5	23.4	28.9	26.6	17	2	17	3850	4685	3427
Messara Beach (Matala beach)	19.8	25.8	23.5	23.3	28.9	26.5	17	2	17	3850	4685	3427
Messara Beach (Matala beach)	19.8	25.8	23.5	23.3	28.9	26.5	17	2	17	3850	4688	3432
Messara - Agia Triada	19.8	26.0	23.7	23.4	29.1	26.7	17	2	17	3850	4669	3403
Messara - Agia Triada	19.9	26.0	23.7	23.5	29.1	26.7	17	2	17	3850	4664	3400
Messara - Agia Triada	20.0	26.1	23.7	23.6	29.2	26.7	17	2	17	3850	4669	3400
Messara - Agia Triada	20.0	26.1	23.7	23.6	29.2	26.7	17	2	17	3850	4669	3400
Messara - Agia Triada	20.0	26.1	23.7	23.6	29.2	26.7	17	2	17	3850	4662	3400

[a] *Name of the beach*
[b] *°C : Minimum temperature in Celcius*
[d] *mm : Precipitation in millimeter*
[e] *Wh/m^2: Radiation in watt hour per square meter*

Appendix D. Detail results of statistical analysis

Appendix D-1. Independent t-tests of sand characteristics

a. Independent sample T-test of sand temperature, sand moisture and sand salinity

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Sand Temperature	Equal variances assumed	3.619	.060	1.117	92	.267	.83141	.74401	-.64625	2.30907
	Equal variances not assumed			1.140	91.920	.257	.83141	.72942	-.61729	2.28011
Sand Moisture	Equal variances assumed	.563	.455	1.196	92	.235	.01092	.00913	-.00721	.02904
	Equal variances not assumed			1.228	91.891	.223	.01092	.00889	-.00674	.02857
Sand Salinity	Equal variances assumed	1.350	.248	2.328	92	.022	.05749	.02470	.00844	.10654
	Equal variances not assumed			2.278	78.600	.025	.05749	.02524	.00725	.10773

b. Independent Samples T- Test of pH, NaCl content, conductivity, $CaCO_3$ content and grain size (0.25 ≥<0.5 mm)

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
pH	Equal variances assumed	.067	.796	-1.848	43	.071	-.08458	.04577	-.17689	.00773
	Equal variances not assumed			-1.879	42.486	.067	-.08458	.04502	-.17540	.00624
Conductivity	Equal variances assumed	3.843	.056	2.510	43	.016	309.96012	123.51219	60.87405	559.04619
	Equal variances not assumed			2.432	32.167	.021	309.96012	127.43630	50.43375	569.48648
NaCl content	Equal variances assumed	5.340	.026	2.287	43	.027	90.97024	39.77977	10.74668	171.19380
	Equal variances not assumed			2.219	32.617	.034	90.97024	40.99559	7.52686	174.41362
CaCO3 content	Equal variances assumed	17.566	.000	1.902	43	.064	.75280	.39579	-.04539	1.55099
	Equal variances not assumed			1.780	20.499	.090	.75280	.42301	-.12820	1.63380
Grain Size 0.25 ≥ < 0.5	Equal variances assumed	.041	.841	-2.290	43	.027	-10.38929	4.53725	-19.53952	-1.23906
	Equal variances not assumed			-2.304	42.910	.026	-10.38929	4.50929	-19.48368	-1.29489

Appendix D-2. Chi-square t-tests of Sand Characteristics

a. Chi-square test of major grain-size

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	5.439[a]	3	.142
Likelihood Ratio	5.629	3	.131
Linear-by-Linear Association	.375	1	.540
N of Valid Cases	45		

a. 6 cells (75.0%) have expected count less than 5. The minimum expected count is 1.87.

b. Chi-square test of sand grain shape

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	22.615[a]	2	.000
Likelihood Ratio	28.323	2	.000
Linear-by-Linear Association	21.940	1	.000
N of Valid Cases	45		

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 5.60.

c. Chi-square test of sand cleanliness

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.837[a]	2	.399
Likelihood Ratio	2.601	2	.272
Linear-by-Linear Association	.786	1	.375
N of Valid Cases	45		

a. 4 cells (66.7%) have expected count less than 5. The minimum expected count is .93.

Appendix D-3. Independent t-tests of Climatic Characteristics

a. Independent t-tests of minimum temperature

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Min.Temp.05	Equal variances assumed	24.847	.000	-3.902	92	.000	-.2698	.0691	-.4071	-.1324
	Equal variances not assumed			-3.737	67.754	.000	-.2698	.0722	-.4138	-.1257
Min.Temp.07	Equal variances assumed	40.117	.000	-4.265	92	.000	-.2004	.0470	-.2937	-.1071
	Equal variances not assumed			-3.988	56.158	.000	-.2004	.0502	-.3010	-.0997
Min.Temp.09	Equal variances assumed	1.468	.229	1.046	92	.298	.0339	.0324	-.0305	.0982
	Equal variances not assumed			1.010	71.750	.316	.0339	.0336	-.0330	.1008

b. Independent t-tests of maximum temperature

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Max.Temp.05	Equal variances assumed	95.109	.000	-4.212	92	.000	-.4962	.1178	-.7301	-.2622
	Equal variances not assumed			-3.920	54.208	.000	-.4962	.1266	-.7499	-.2424
Max.Temp.07	Equal variances assumed	34.026	.000	-3.928	92	.000	-.4334	.1103	-.6526	-.2143
	Equal variances not assumed			-3.663	54.996	.001	-.4334	.1183	-.6706	-.1963
Max.Temp.09	Equal variances assumed	49.012	.000	-1.890	92	.062	-.1400	.0741	-.2871	.0071
	Equal variances not assumed			-1.763	55.244	.083	-.1400	.0794	-.2991	.0191

c. Independent t-tests of precipitations

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Precipitation 05	Equal variances assumed	27.107	.000	-5.773	92	.000	-2.372	.411	-3.188	-1.556
	Equal variances not assumed			-6.102	83.182	.000	-2.372	.389	-3.145	-1.599
Precipitation 07	Equal variances assumed	.000	.984	-4.930	92	.000	-.497	.101	-.698	-.297
	Equal variances not assumed			-4.863	82.429	.000	-.497	.102	-.701	-.294
Precipitation 09	Equal variances assumed	10.934	.001	-5.127	92	.000	-2.153	.420	-2.987	-1.319
	Equal variances not assumed			-5.307	90.804	.000	-2.153	.406	-2.959	-1.347

d. Independent t-tests of solar radiation

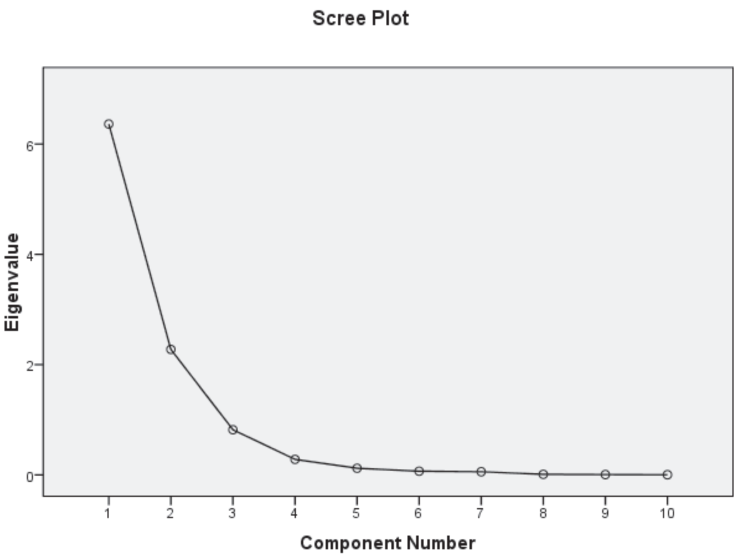
		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Radiation 05	Equal variances assumed	497.998	.000	6.169	92	.000	105.454	17.094	71.505	139.404
	Equal variances not assumed			5.549	41.634	.000	105.454	19.005	67.090	143.819
Radiation 07	Equal variances assumed	8.164	.005	4.355	92	.000	84.898	19.496	46.177	123.619
	Equal variances not assumed			4.205	71.882	.000	84.898	20.191	44.648	125.149
Radiation 09	Equal variances assumed	113.454	.000	4.373	92	.000	86.353	19.745	47.137	125.568
	Equal variances not assumed			4.050	52.074	.000	86.353	21.324	43.565	129.140

Appendix D-4. Factor analysis of climatic parameters

Initial Eigenvalues

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	6.363	63.630	63.630
2	2.276	22.764	86.393
3	.819	8.186	94.579
4	.281	2.812	97.391
5	.121	1.205	98.596
6	.066	.662	99.258
7	.056	.560	99.817
8	.010	.103	99.920
9	.006	.057	99.977
10	.002	.023	100.000

Extraction Method: Principal Component Analysis.



Rotated Component Matrix[a]

	Component	
	1	2
Min.Temp.05	.952	-.073
Min.Temp.07	.867	.362
Max.Temp.05	.926	.116
Max.Temp.07	.806	.487
Precipitation 05	.079	.983
Precipitation 07	.282	.904
Precipitation 09	.137	.956
Radiation 05	-.817	-.375
Radiation 07	-.772	-.093
Radiation 09	-.916	-.180

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 3 iterations.

Appendix D-5. Logistic regression of important parameters

a. Logistic regression of important parameters –first level model

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	18.109[a]	.624	.834
2	18.141[a]	.624	.834
3	20.021[a]	.608	.812

a. Estimation terminated at iteration number 20 because maximum iterations has been reached. Final solution cannot be found.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	.691	7	.998
2	.811	7	.997
3	.823	7	.997

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95.0% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Grain_shape_1			2.554	2	.279			
	Grain_shape_1(1)	-23.677	8.911E3	.000	1	.998	.000	.000	.
	Grain_shape_1(2)	-2.456	1.537	2.554	1	.110	.086	.004	1.744
	Conductivity	-.004	.004	1.358	1	.244	.996	.989	1.003
	Salinity	-9.082	6.371	2.032	1	.154	.000	.000	30.112
	Min_05	.785	4.366	.032	1	.857	2.191	.000	1.140E4
	Precip_05	1.095	.656	2.786	1	.095	2.990	.826	10.816
	Constant	-26.199	94.096	.078	1	.781	.000		
Step 2[a]	Grain_shape_1			2.619	2	.270			
	Grain_shape_1(1)	-23.573	9.583E3	.000	1	.998	.000	.000	.
	Grain_shape_1(2)	-2.472	1.528	2.619	1	.106	.084	.004	1.685
	Conductivity	-.004	.003	1.411	1	.235	.996	.989	1.003
	Salinity	-8.903	6.224	2.046	1	.153	.000	.000	27.019
	Precip_05	1.023	.493	4.313	1	.038	2.782	1.059	7.307
	Constant	-9.347	5.112	3.343	1	.068	.000		
Step 3[a]	Grain_shape_1			3.102	2	.212			
	Grain_shape_1(1)	-23.120	1.038E4	.000	1	.998	.000	.000	.
	Grain_shape_1(2)	-2.415	1.371	3.102	1	.078	.089	.006	1.313
	Salinity	-12.020	6.322	3.615	1	.057	.000	.000	1.449
	Precip_05	.797	.327	5.931	1	.015	2.219	1.168	4.214
	Constant	-7.148	3.719	3.695	1	.055	.001		

a. Variable(s) entered on step 1: Grain_shape_1, Conductivity, Salinity, Min_05, Precip_05.

Correlation Matrix

		Constant	Grain_shape (1)	Grain_shape (2)	Conductivity	Salinity	Min_05	Precip_05
Step 1	**Constant**	1.000	.000	-.010	.180	.195	-.998	-.678
	Grain_shape_1(1)	.000	1.000	.000	.000	.000	.000	.000
	Grain_shape_1(2)	-.010	.000	1.000	.428	.513	.028	-.383
	Conductivity	.180	.000	.428	1.000	.141	-.143	-.674
	Salinity	.195	.000	.513	.141	1.000	-.180	-.471
	Min_05	-.998	.000	.028	-.143	-.180	1.000	.638
	Precip_05	-.678	.000	-.383	-.674	-.471	.638	1.000
Step 2	**Constant**	1.000	.000	.310	.653	.286		-.952
	Grain_shape_1(1)	.000	1.000	.000	.000	.000		.000
	Grain_shape_1(2)	.310	.000	1.000	.428	.526		-.513
	Conductivity	.653	.000	.428	1.000	.118		-.754
	Salinity	.286	.000	.526	.118	1.000		-.471
	Precip_05	-.952	.000	-.513	-.754	-.471		1.000
Step 3	**Constant**	1.000	.000	.196		.347		-.921
	Grain_shape_1(1)	.000	1.000	.000		.000		.000
	Grain_shape_1(2)	.196	.000	1.000		.564		-.468
	Salinity	.347	.000	.564		1.000		-.646
	Precip_05	-.921	.000	-.468		-.646		1.000

Model if Term Removed

	Variable	Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	**Grain_shape_1**	-17.059	16.008	2	.000
	Conductivity	-10.002	1.895	1	.169
	Salinity	-10.354	2.600	1	.107
	Min_05	-9.071	.033	1	.857
	Precip_05	-12.960	7.810	1	.005
Step 2	**Grain_shape_1**	-17.380	16.619	2	.000
	Conductivity	-10.011	1.880	1	.170
	Salinity	-10.355	2.569	1	.109
	Precip_05	-15.080	12.020	1	.001
Step 3	**Grain_shape_1**	-18.957	17.892	2	.000
	Salinity	-12.832	5.642	1	.018
	Precip_05	-15.286	10.551	1	.001

Variables not in the Equation

			Score	df	Sig.
Step 2[a]	Variables	Min_05	.032	1	.857
	Overall Statistics		.032	1	.857
Step 3[b]	Variables	Conductivity	1.293	1	.256
		Min_05	.018	1	.894
	Overall Statistics		1.350	2	.509

a. Variable(s) removed on step 2: Min_05.

b. Logistic regression of important parameters –second level model

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	26.206[a]	.550	.735

a. Estimation terminated at iteration number 7 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	2.869	7	.897

Variables in the Equation

								95.0% C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Step 1[a]	Grain_shape	-3.554	1.305	7.419	1	.006	.029	.002	.369
	Salinity	-11.829	5.678	4.339	1	.037	.000	.000	.497
	Precip_05	.858	.298	8.289	1	.004	2.358	1.315	4.228
	Constant	-8.019	3.583	5.008	1	.025	.000		

a. Variable(s) entered on step 1: Grain_shape, Salinity, Precip_05.

Correlation Matrix

		Constant	Salinity	Precip_05	Grain_shape
Step 1	Constant	1.000	.192	-.915	.229
	Salinity	.192	1.000	-.524	.566
	Precip_05	-.915	-.524	1.000	-.526
	Grain_shape	.229	.566	-.526	1.000

Appendix E. Detail results of impact assessment of sea-level rise

Appendix E-1. The total areas of nesting beaches that are potentially lost under sea-level rise scenarios

Beach	Beach area potentially loss (ha) (% of total area)		
	0.2 m	***0.4 m***	***0.6 m***
Chania	11.84	23.39	33.12
	(24.8)	(49.0)	(69.5)
Rethymno	11.39	21.68	28.74
	(32.5)	(61.8)	(82.0)
Messara	3.34	6.63	9.79
	(16.0)	(31.7)	(46.8)
Total	***26.57***	***51.69***	***71.66***
	(25.6)	***(49.9)***	***(69.1)***

Appendix E-2. The total area of the non-nesting beaches that are potentially lost under sea-level rise scenarios

Beach	Beach area potentially loss (ha) (% of total area)		
	0.2 m	***0.4 m***	***0.6 m***
Phalasarna	4.24	8.84	12.12
	(35.0)	(72.9)	(100)
Frangocastelo	2.05	3.89	5.37
	(32.2)	(61.0)	(84.2)
Georgeopolis	7.76	14.45	19.30
	(29.3)	(54.4)	(72.7)
Iraklion	2.35	4.78	6.80
	(25.6)	(52.1)	(74.1)
Irapetra	1.07	2.19	3.28
	(15.5)	(31.7)	(47.5)
Koutsunary	1.31	2.66	4.01
	(10.6)	(21.5)	(32.4)
Palaechora	1.49	3.05	4.62
	(24.7)	(50.5)	(76.6)
Xerocampos	0.29	0.59	0.76
	(35.1)	(70.1)	(90.3)
Total	***20.58***	***40.45***	***56.27***
	(25.6)	***(50.3)***	***(70.0)***

Appendix E-3. The optimal nesting area after the impact of different sea-level rise scenario

Beach	Optimal nesting area remaining (ha) (% of total area)			
	0 m	***0.2 m***	***0.4 m***	***0.6 m***
Nesting Beaches				
Chania	22.10	15.42	9.38	5.17
	(46.3)	(32.3)	(19.7)	(10.9)
Rethymno	16.49	9.09	3.44	0.95
	(47.1)	(25.9)	(9.8)	(2.7)
Messara	7.54	6.69	5.80	4.97
	(36.1)	(32.0)	(27.7)	(23.8)

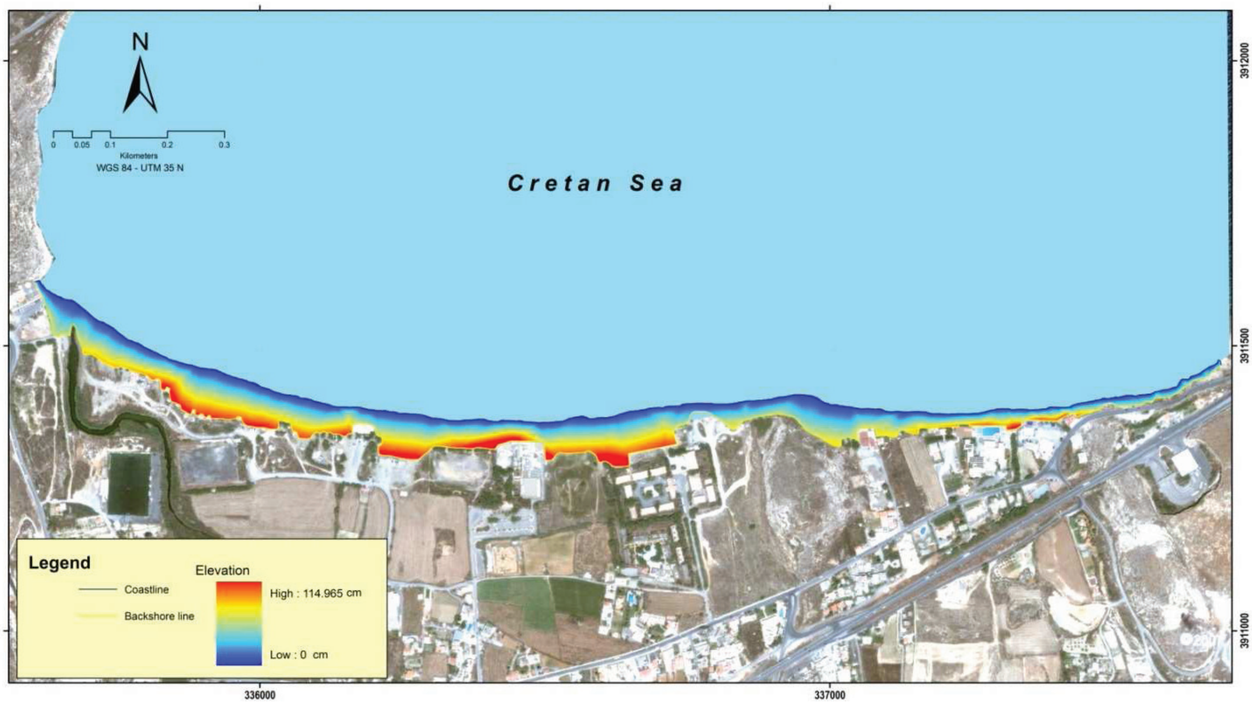
Continued Appendix E-3.				
Non-nesting beaches				
Phalasarna	5.62	1.12	-	-
	46.4	9.3	-	-
Frangocastelo	3.10	1.66	0.55	0.10
	(48.7)	(26.1)	(8.6)	(1.6)
Georgeopolis	11.36	7.87	4.77	2.54
	(42.8)	(29.6)	(18.0)	(9.6)
Iraklion	4.65	3.16	1.60	0.45
	(50.6)	(34.4)	(17.4)	(4.9)
Irapetra	2.67	2.38	1.93	1.49
	(38.7)	(34.5)	(28.0)	(21.5)
Koutsunary	3.36	3.32	3.27	3.23
	(27.1)	(26.8)	(26.4)	(26.1)
Palaechora	3.40	2.19	0.77	0.09
	(56.4)	(36.2)	(12.7)	(1.5)
Xerocampos	0.38	0.15	0.03	-
	(44.8)	(17.7)	(3.9)	-
Total	***80.67***	***53.05***	***31.55***	***19.00***
	43.8%	***28.8%***	***17.1%***	***10.3%***

Appendix E-4. The proportions of the land-cover behind the beach

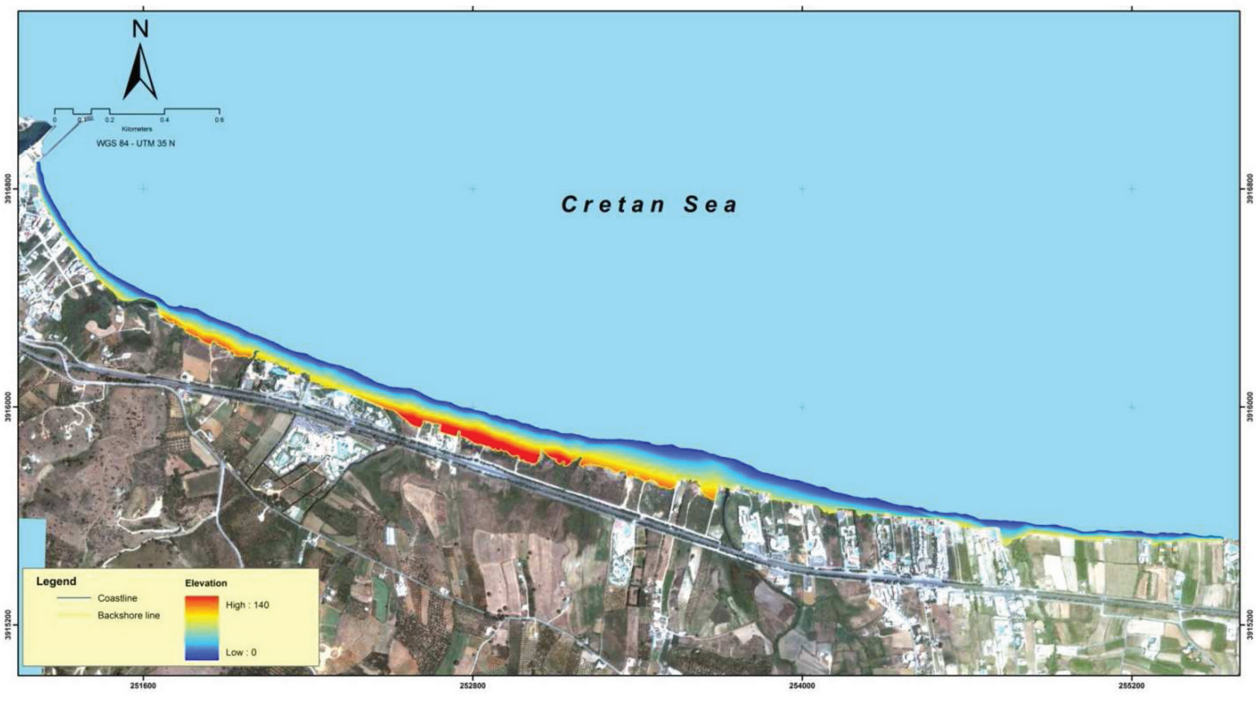
Beach	**Land-cover behind the beach (m) (% of total length)**		
	Urban	***Natural***	***Un-expandable***
Nesting beaches			
Chania	11611.62	6194.77	929.12
	(62.0)	(33.1)	(5.0)
Rethymno	6108.91	2577.12	1363.28
	(60.8)	(25.6)	(13.6)
Messara	1830.44	1953.08	2136.33
	(30.9)	(33.0)	(36.1)
Non-nesting beaches			
Phalasarna	90.49	306.10	789.79
	(7.6)	(25.8)	(66.6)
Frangocastelo	1077.44	452.89	112.91
	(65.6)	(27.6)	(6.9)
Georgeopolis	2687.03	2118.62	-
	(55.9)	(44.1)	-
Iraklion	1070.45	611.06	591.16
	(47.1)	(26.9)	(26.0)
Irapetra	950.68	-	779.49
	(54.9)	-	(45.1)
Koutsunary	589.52	1426.98	506.68
	(23.36)	(56.55)	(20.08)
Palaechora	647.90	-	394.05
	(62.2)	-	(37.8)
Xerocampos	240.27	-	363.22
	(39.8)	-	(60.2)
Total	26904.75	15640.62	7966.04
	53.3	31.0	15.8

Appendix F. Maps of beach profile

Appendix F-1. Beach profile of Iraklion beach



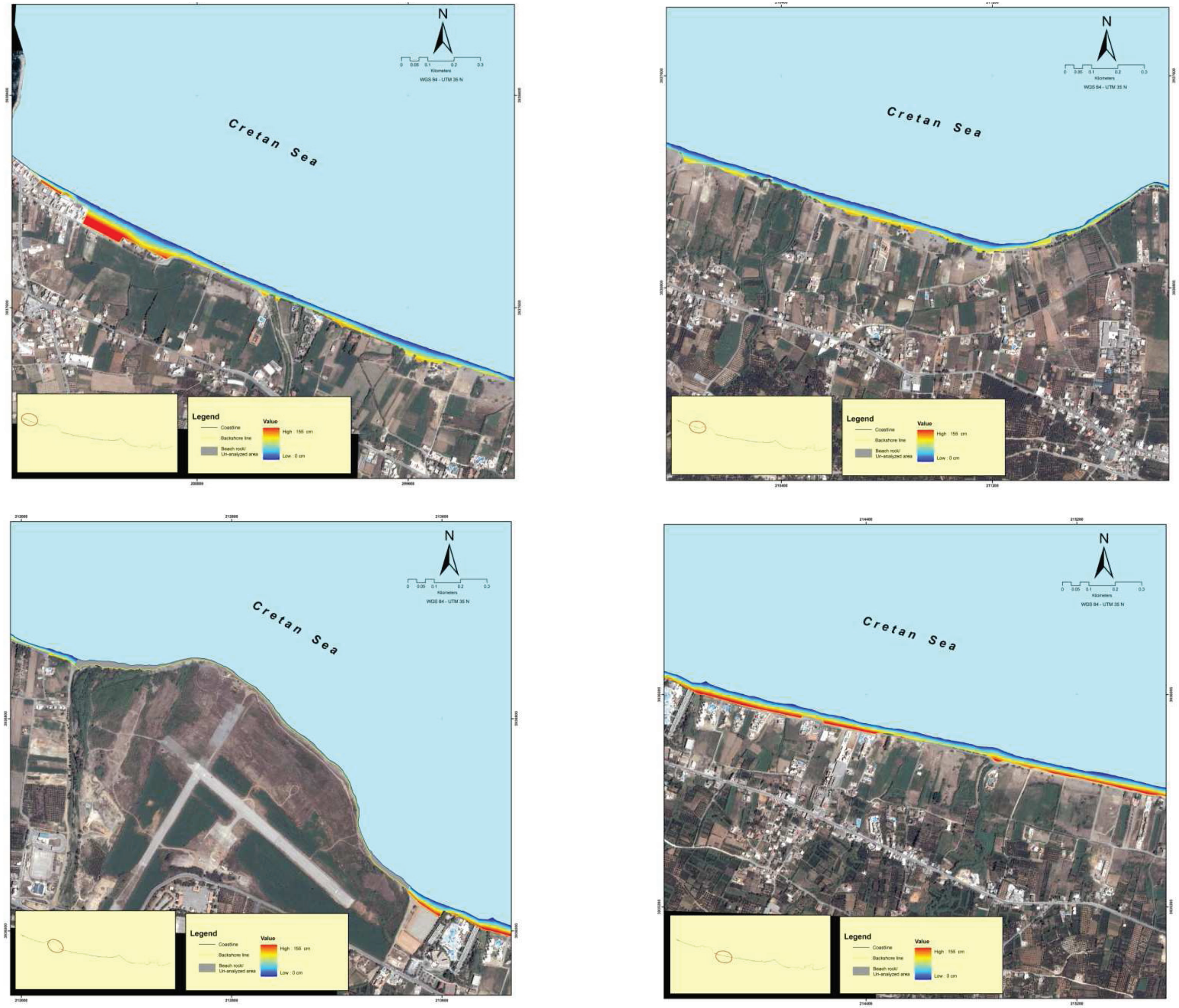
Appendix F-2. Beach profile of Georgeopolis beach



Appendix F-3. Beach profile of the Rethymno beach (part 1-4)

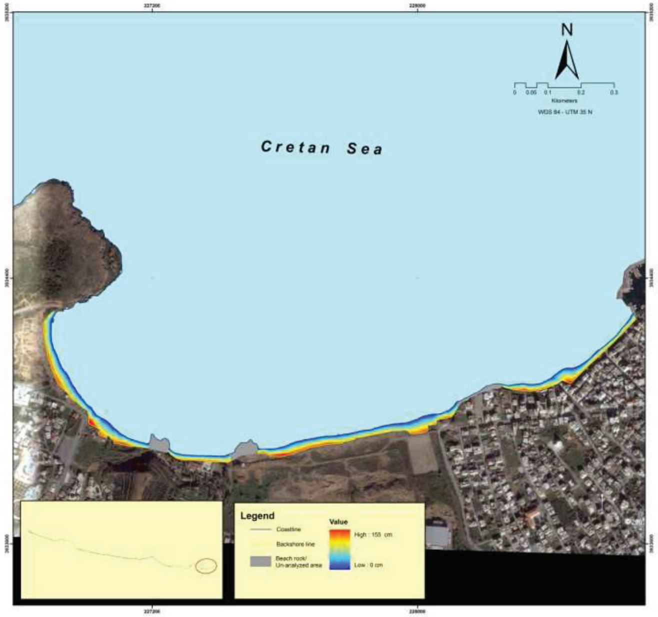
Continued Appendix F-3. Beach profile of the Rethymno beach (part 5-7)

Appendix F-4. Beach profile of Chania beach (part 1-4)

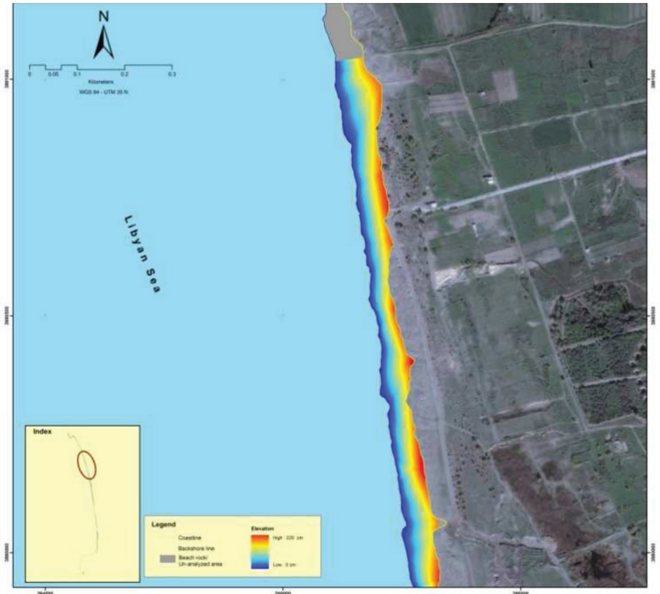


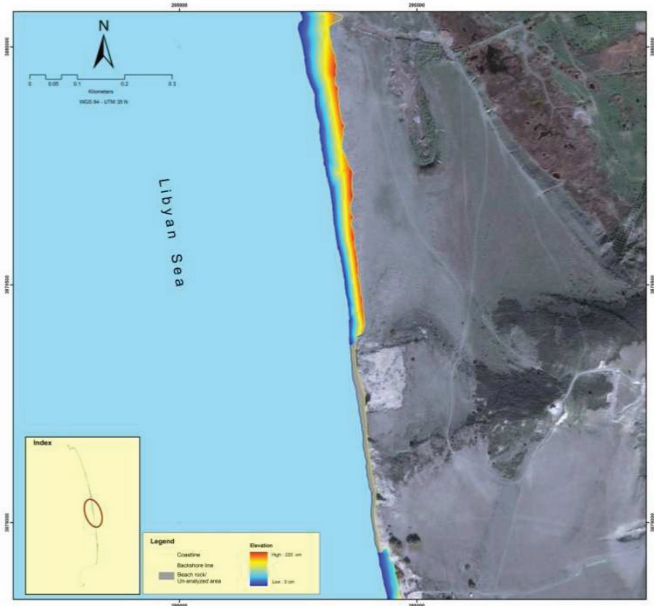
Continued Appendix F-4. Beach profile of Chania beach (part 5-8)

Continued Appendix F-4. Beach profile of Chania beach (part 9-11)

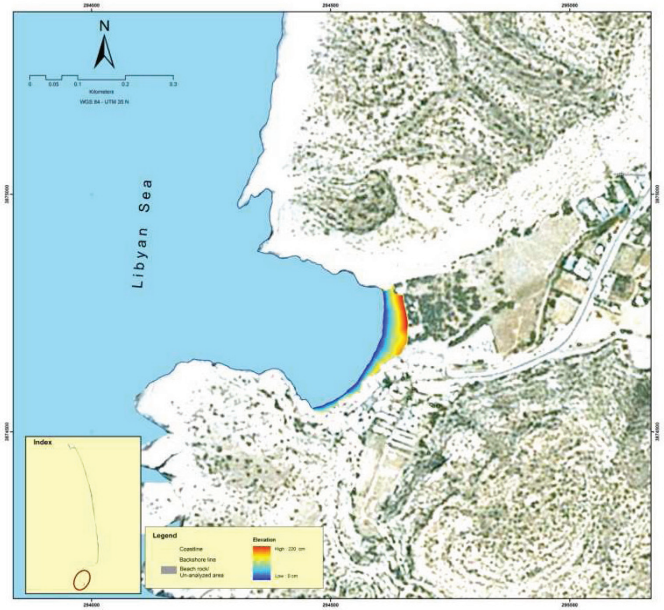


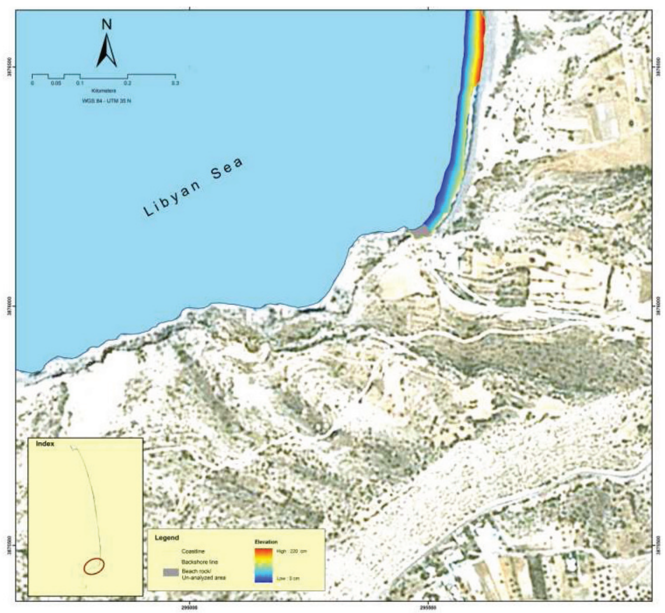
Appendix F-5. Beach profile of Messara beach (part 1-4)



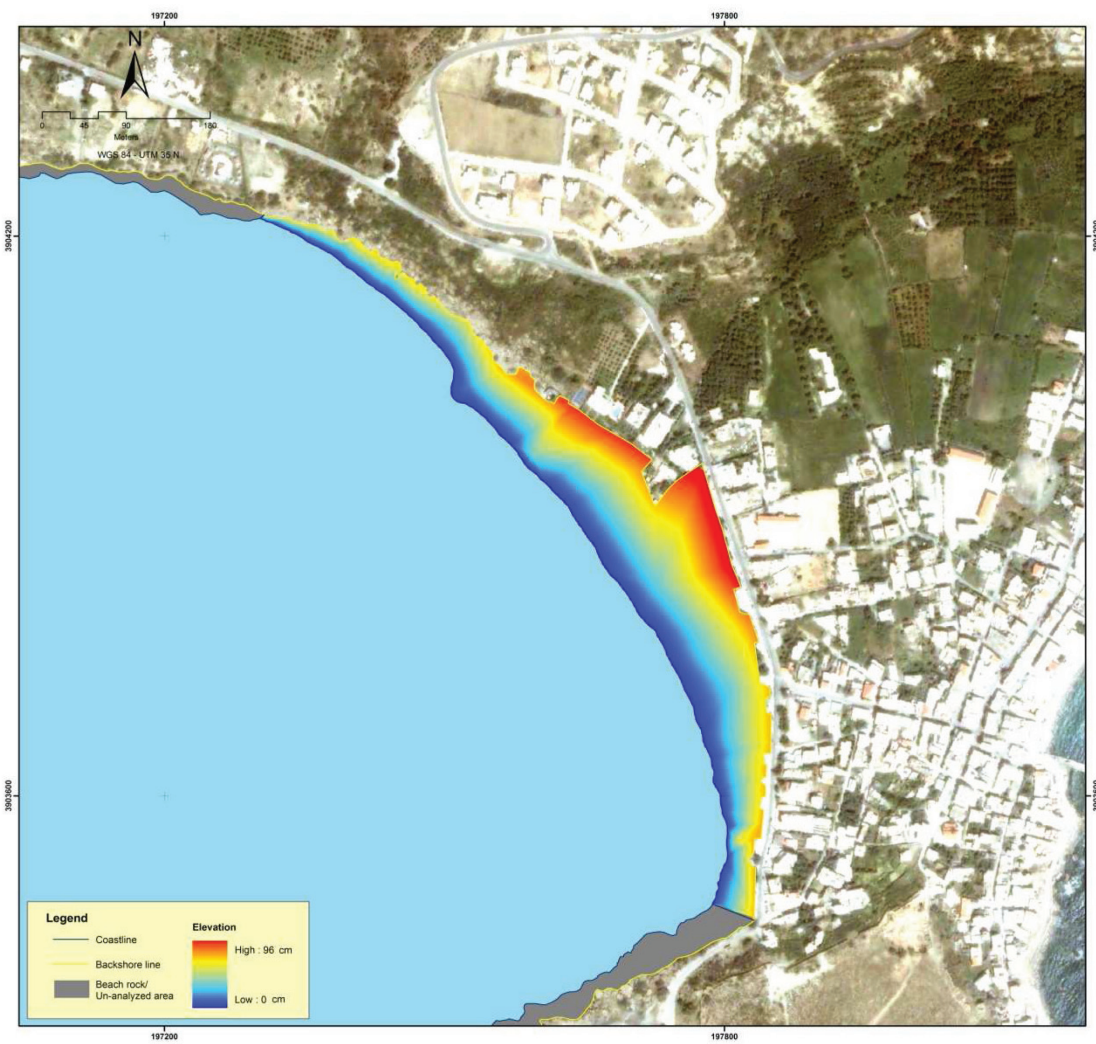


Continued Appendix F-5. Beach profile of Messara beach (part 5-7)

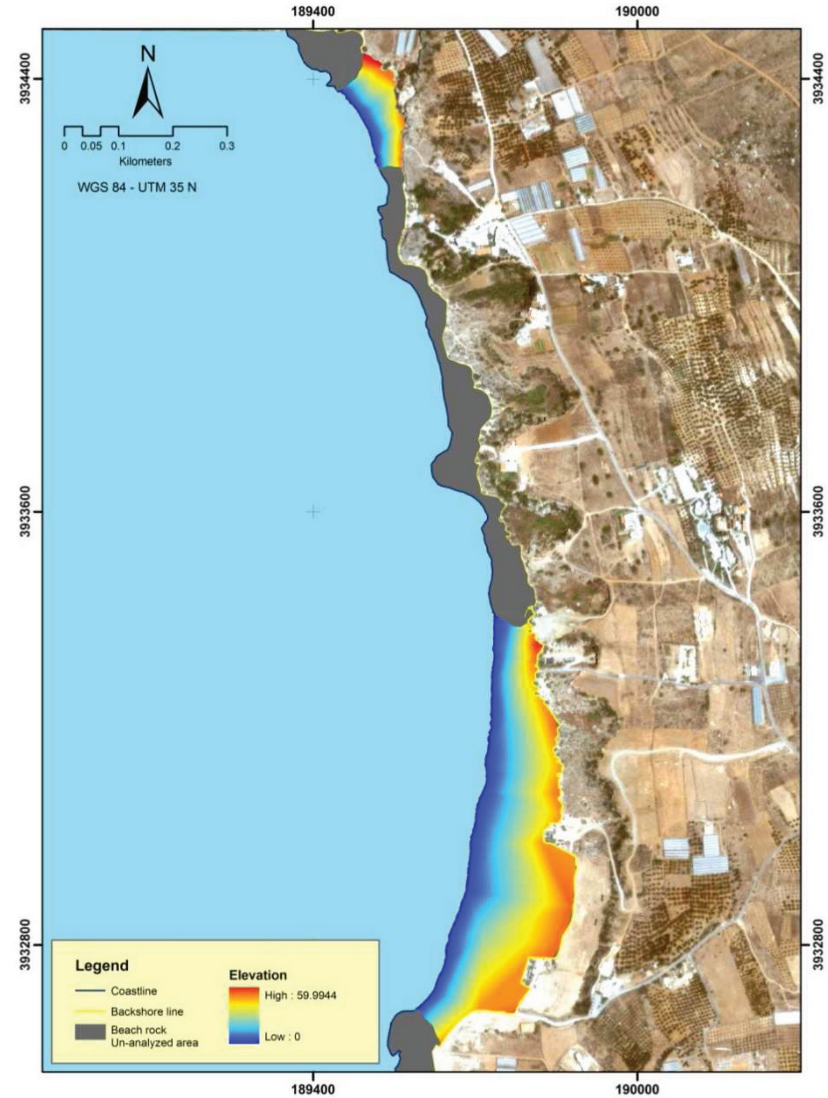




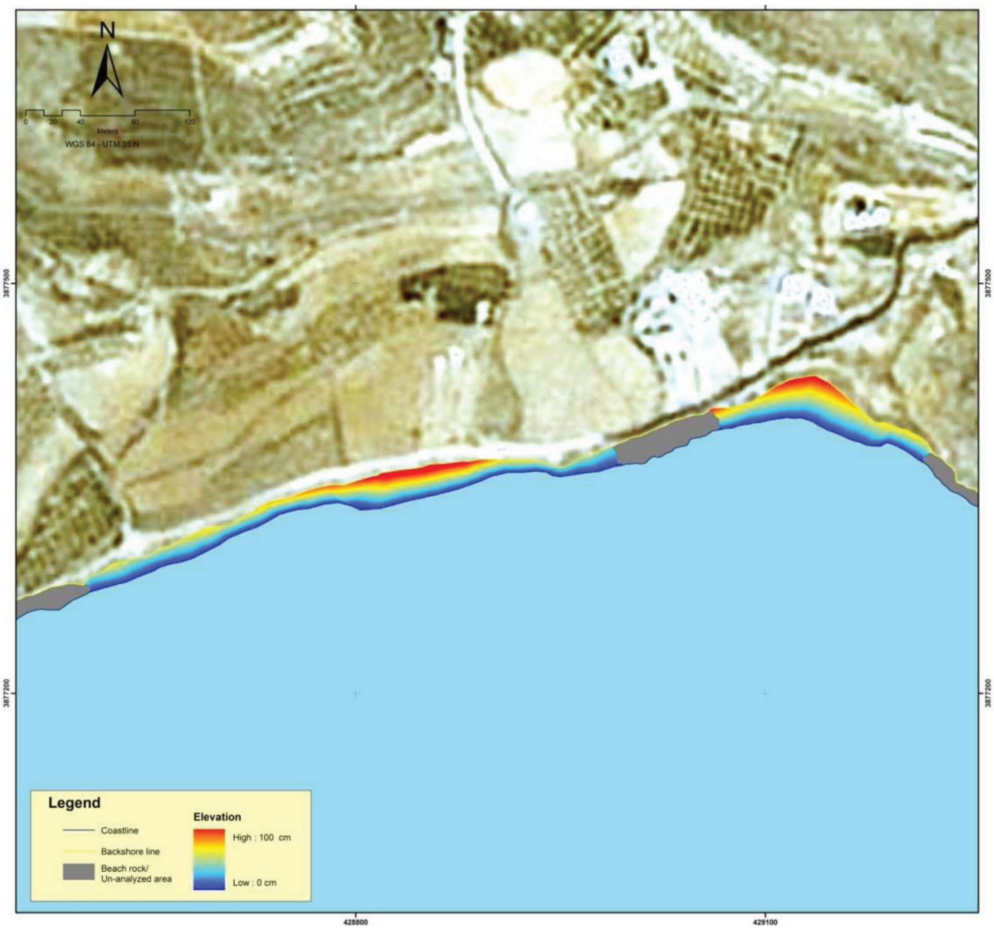
Appendix F-6. Beach profile of Palaechora beach



Appendix F-7. Beach profile of Phalasarna beach

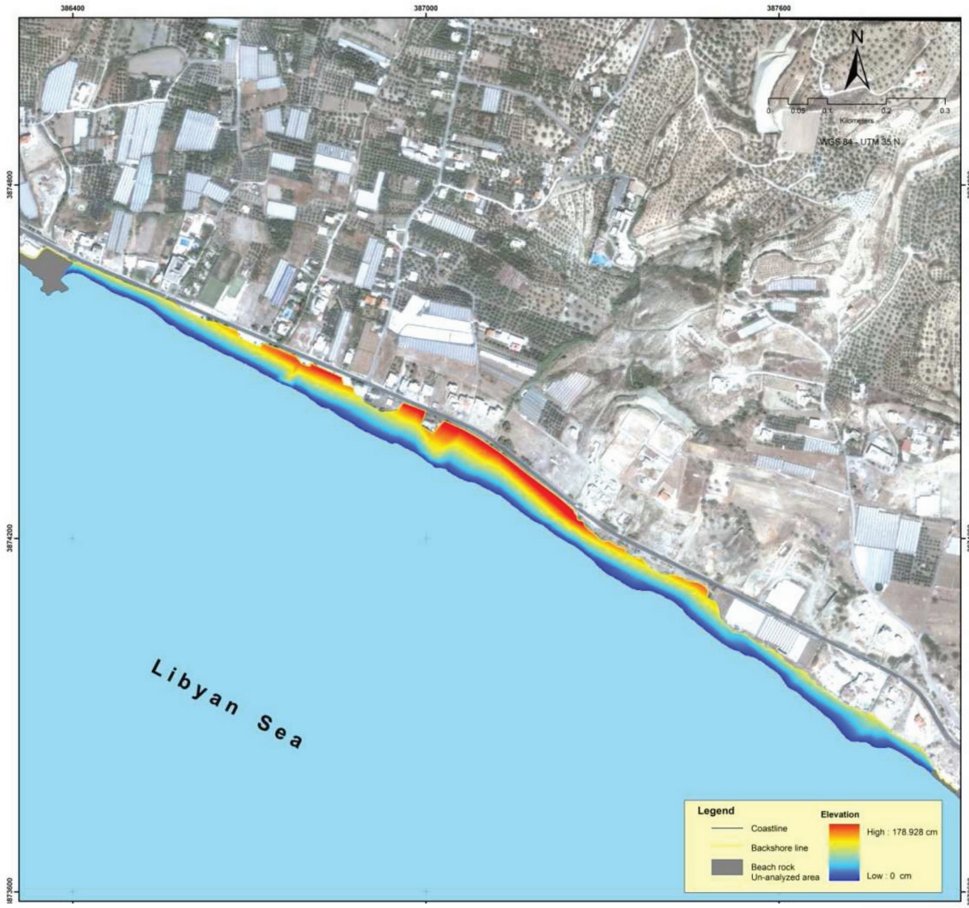


Appendix F-8. Beach profile of Xerocampos beach



Appendix F-9. Beach profile of Koutsunary beach

Appendix F-10. Beach profile of Irapetra beach



Appendix F-11. Beach profile of Frangocastelo beach

Appendix G. Pictures of beach profile

Comos beach-Messara

Amnisos beach-Iraklion

Phasalarna beach

Xeracampos beach

Koutsunary beach

Irapetra beach

Frangocastelo beach

Palaechora beach