UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL
INSTITUTO DE GEOCIÊNCIAS
PROGRAMA DE PÓS-GRADUAÇÃO EM GEOCIÊNCIAS

INTEGRAÇÃO DE GEOTECNOLOGIAS COMO SUBSÍDIO A GESTÃO INTEGRADA DE ZONAS COSTEIRAS, CAPÃO NOVO (RS-BRASIL) E RAVENNA (ER-ITÁLIA)

INTEGRATION OF THE GEOTECHNOLOGIES AS SUBSIDIES FOR THE INTEGRATED COASTAL ZONES MANAGEMENT, CAPÃO NOVO (RS-BRAZIL) AND RAVENNA (ER-ITALY)

FREDERICO M. SCARELLI

SUPERVISOR – Prof. Dr. Giovanni Gabbianelli (UNIBO)
Prof. Dr. Eduardo G. Barboza (UFRGS)

Porto Alegre - 2016

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Prof. Dr. Francesco Mancini – University of Modena and Reggio Emilia, Department of Engineering "Enzo Ferrari"

Doctorate Thesis presented as partial requirement to obtain the Degree of Doctor of Science.

Porto Alegre – 2016

“Seja você quem for, seja qual for a posição social que você tenha na vida, a mais alta ou a mais baixa, tenha sempre como meta muita força, muita determinação e sempre faça tudo com muito amor e com muita fé em Deus, que um dia você chega lá. De alguma maneira você chega lá”.

Ayrton Senna

“Il male assoluto del nostro tempo è di non credere nei valori. Non ha importanza che siano religiosi oppure laici. I giovani devono credere in qualcosa di positivo e la vita merita di essere vissuta solo se crediamo nei valori, perché questi rimangono anche dopo la nostra morte. Pensate al futuro che vi aspetta, pensate a quello che potete fare, e non temete niente! Meglio aggiungere vita ai giorni, che non giorni alla vita”

Rita Levi Montalcini

“Homens que da sua terra não saem são como navios que acabam no estaleiro: errando por esse mundo, se aprende a não errar”.

José Bonifácio de Andrade e Silva

“You can't always get what you want, But if you try sometimes, yeah! You just might find you get what you need”!

Rolling Stones

“A onda está certa, o que está errado é esse negócio de aterro aí…
… a natureza está certa”

Raul Seixas (Entrevista atropelado por uma onda de ressaca no RJ)

…”Hey you
Don't help them to bury the light
Don't give in, without a fight”…

Pink Floyd

ALL PRAISE TO GOD

John Coltrane

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RESUMO

Esta Tese, realizada em cotutela entre os programas de Pós-Graduação em Geociências da Universidade Federal do Rio Grande do Sul (Brasil) e de Ciências para o Ambiente da *Università di Bologna* (Itália), foi desenvolvida no Litoral Norte do Rio Grande do Sul (RS-Brasil) e na zona costeira do município de Ravenna na região da Emilia-Romagna (ER-Itália). Foram executadas análises com base na integração de tecnologias de forma inédita, (veículo aéreo não tripulado – VANT e *ground penetrating radar* – GPR) e na proposição de novos métodos de trabalho com um custo-benefício que permite a sua aplicação seja por grupos de pesquisa, órgãos governamentais ou companhias privadas em zonas costeiras; especificamente, naquelas caracterizadas por sistemas de tipo barreira-laguna. O estudo foi empreendido em duas diferentes escalas temporais a fim de analisar a evolução recente e a situação atual, devido a fatores naturais e antrópicos que atuam sobre os sistemas costeiros: (i) análise de longo prazo para estudar e entender a evolução costeira de ambos os sistemas barreira-laguna no Holoceno, devido à anomalias climáticas que foram responsáveis pela morfologia atual, das áreas de estudo, como os períodos glaciais na área do RS e outras de ordem menor como a Pequena Idade do Gelo na ER.; (ii) análise em escala temporal de curto prazo para compreender o comportamento e o estado atual das zonas costeiras de interesse através da comparação e do monitoramento sazonal do comportamento do sistema costeiro em uma faixa de costa com segmentos com características natural e antrópica contíguos. Como resultados se obteve um modelo da evolução costeira e uma comparação sazonal do comportamento do sistema praia/duna em Ravenna; e a comparação entre uma área natural adjacente a uma antropizada na área de Capão Novo (RS). Os resultados e interpretações foram integrados, e junto com dados e informações de conhecimento prévio, foram analisados com o objetivo de compreender o comportamento dos sistemas costeiros na sua forma mais complexa. A aplicação das novas tecnologias e do método proposto por esta Tese, contribuem não somente para a pesquisa acadêmica das zonas costeiras, mas também servem como alternativa para gestores locais desenvolverem planos de manejo e de monitoramento de baixo custo, o que pode tornar as decisões dentro das iniciativas de Gestão Integrada das Zonas Costeiras mais eficazes e objetivas a curto e longo prazo, prevenindo perdas de cunho social, econômico e ambiental. Ademais, também é uma proposta que pode ser aplicada e/ou adaptada para o estudo de sistemas costeiros similares.

RIASSUNTO

Questa Tesi, fatta in co-tutela tra i programmi di dottorato in Geoscienze dell'UFRGS (Brasile) e di Scienze per l'Ambiente dell'UNIBO (Italia), è stata svolta nel settore nord della costa del Rio Grande do Sul (RS-Brasile) e nella zona costiera del comune di Ravenna nella Regione Emilia-Romagna (ER-Italia). Sono state fatte analisi integrando nuove tecnologie (aeromobile a pilotaggio remoto – APR e *ground penetrating radar* – GPR) e proponendo nuove metodologie di lavoro, con un buon rapporto costi-benefici, il quale permette che siano applicate sia da gruppi di ricerca, enti pubblici o compagnie private, nelle zone costiere, specificatamente, in zone costiere caratterizzate dai sistemi del tipo barriera-laguna. Gli studi sono stati svolti in due scale temporali diverse, con gli obbiettivi di analizzare l'evoluzione recente e la situazione attuale, dovute ai fattori naturali e antropici che agiscono sui sistemi costieri: (i) analisi sul lungo periodo per studiare e capire l'evoluzione costiera di entrambi i sistemi barriera-laguna nell'Olocene, dovuta alle anomalie climatiche che sono state responsabili per la morfologia attuale delle aree in studio, come i periodi glaciale nel RS o altre di ordini minori come la Piccola Età del Ghiaccio nell'ER.; (ii) analisi in scala temporale di corto periodo per capire il comportamento e lo stato attuale delle zone costiere studiate, tramite il confronto tra una zona costiera naturale e antropica adiacenti e il monitoraggio stagionale del comportamento del sistema costiero. I risultati ottenuti sono stati un modello della evoluzione costiera e una comparazione stagionale del comportamento del sistema duna/spiaggia di Ravenna e il paragone tra una area naturale adiacente a una antropizzata nella zona di Capão Novo (RS). I risultati delle analisi fatti per entrambe le scale temporali in studio, sono stati integrati e insieme ai dati e informazioni delle conoscenze previe, sono stati analizzati con l'obbiettivo di comprendere il comportamento dei sistemi costieri nella loro forma più complessa. L'applicazione delle nuove tecnologie e dei metodi proposti per questa Tesi hanno contribuito non solo alle ricerche delle zone costiere in ambito accademico, essendo anche una alternativa per i gestori locali sviluppare piani gestionale e di monitoraggio con basso costo, il quale può consentire che le decisioni all'interno della Gestione Integrata delle Zone Costiere, di corto e lungo periodo siano più efficaci e obbiettivi, prevenendo perdite di carattere sociali, economiche e ambientali. Esso inoltre, rappresenta anche un esempio di studio che può essere applicato e/o adattati agli studi in altri sistemi costieri similari.

ABSTRACT

This Thesis, realised in co-tutorship among the doctorates programs in Geoscience in in the UFRGS (Brazil) and in Science for the Environmental in the UNIBO (Italy), was done in the north sector of the Rio Grande do Sul (RS-Brazil) and in the Ravenna municipality coastal zone in the Emilia-Romagna region (ER-Italy). Analyses were carried out using integrating new technologies (unmanned aerial vehicle – UAV and ground penetrating radar – GPR) and proposing new work methodologies with a benefit-cost ratio that allows them to be used by the research group, governmental agencies or private companies, and to be applied in studies in the coastal zones, particularly in the barrier-lagoon coastal systems type. The studies were done investigating two different temporal scales, in order to analyse the recent evolution and the actual state, due the natural and anthropic factors that act above the coastal systems: (i) a long period analyse was carried out to study and understand the coastal evolution during the Holocene in each barrier-lagoon system, due to climatic anomalies that are responsible for the actual morphology in both areas, as the glacial period for the RS or other with an minor order as the Little Ice Age in the ER; (ii) a short period analyse was done to investigate the behaviour and the actual state of coastal zones under study, comparing a natural coastal zone with an adjacent anthropic coastal zone, and monitoring seasonally the behaviour of the coastal system. The results obtained were the coastal evolution model and a seasonal comparison in the beach/dune system in the Ravenna zone; and the comparison between a natural adjacent at an anthropogenic zone at Capão Novo (RS). The results from the analyses, done for each temporal scale under study were integrated with the data and the information from the previous work were analysed with the aim to investigate the behaviour of the coastal systems in their most complex form. The application of the new technologies and the methodology proposed by this Thesis had a contribute not only for the research in the academics field, but may also be applied as an alternative by the local authorities to develop the management plan and monitoring programs with low cost, which allow make the decision inside the Integrated Coastal Zone Management, in both the long and short period, with more effectivity and objectivity. Furthermore, is propose that may be applied and/or adapted for the studies in similar coastal system.

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THESIS STRUCTURE

This PhD thesis was structured in paper format, as requested by the *Programa de Pós-Graduação em Geociências* (PGGEO) of Universidade Federal do Rio Grande do Sul (UFRGS). The papers were elaborated during the doctorate period and submitted to an indexed scientific journal.

Chapter 1 – Presents the introduction of this thesis, the state of the art, the objectives, the premises, the hypothesis, and the methods. Chapters 2, 3 and 4 contain the submitted papers, and present the main results obtained in this work. The papers which compose this thesis are presented here in the same format as sent to the scientific journals, thus some recurrence may occur on the text.

Chapter 2 – Presents the reconstruction of the coastal evolution model in the Ravenna Coastal Plain (Italy). This article is entitled "**Surface and subsurface data integration, using new data to rebuild the surface geological model, from the Little Ice Age to the present, in the Ravenna coastal Plain, northwest Adriatic Sea (Emilia-Romagna, Italy)"**, and it was submitted to *CATENA Journal* (ISSN - 0341-8162) in February 2016**.** This chapter presents the integration of the research conducted in the Ravenna coastal plain with the subsurface data from the GPR. These data were acquired in high-resolution 2D, following methods and applications that have already been used in the PCRS, to reconstruct and understand the local coastal evolution.

Chapter 3 – Presents the seasonal dune monitoring using high-resolution data from an aerial photogrammetry survey using an unnamed aerial vehicle (UAV). The paper is entitled "***Seasonal dune and beach monitoring using photogrammetry from UAV surveys in Ravenna coast (Emilia-Romagna, Italy)***", and it was submitted to *Geormophology Journal* (ISSN - 0169-555X) in December 2015. This work allowed the study of the urbanization impact in the beach/dune system, and the comparison between natural and anthropic coastal systems dynamics.

Chapter 4 – Presents the paper submitted to the *International Coastal Symposium*, 2016 in Sydney (Australia), and published in the *Journal of Coastal Research* (ISSN - 0749-0208) entitled "***Natural and Anthropic adjacent coastal system compare using DSM from low cost UAV survey (Capão Novo, RS/Brazil)***". This work proposes a new method to acquire a Digital Surface Model and high resolution orthophotos using a low coast UAV.

Chapter 5 – Presents the conclusion, integrating the results obtained and presented in the previous chapters.

The references cited in the chapters 1 and 5 are placed at the end of this Thesis, the references cited in the papers are placed at the end of each paper.

Chapter 1

1 –INTRODUCTION

Coastal zones are subject of research in most parts of the world, since man noted the complexity of this system (Carter, 1988), which includes all geospheres, forming an extremely dynamic environment (Davidson-Arnott, 2010). Research about coastal environments started few decades ago with scientific interest mainly by geomorphologists, geologists and biologists.

When the coastal zones were no longer a boundary between ocean and land in the middle of the twenty-century, man began to exploit their resources, increasing the pressure on coastal zones to a global level (Tagliani *et al.*, 2003). Thus, coastal studies began to be inserted in other disciplines, in order to understand the interaction between man and nature.

Nowadays, man exploits the coastal zones to obtain natural resources such as sand from the dunes, to be applied in the construction industry or in beach places (Roy *et al.*, 1992); for the construction of commercial harbors or even for recreation by building summer houses, commercial establishments and facilities near the dunes and the beaches. This intense use and the anthropization of the coastal zones, in other words, man-made transformations to the coastal environment, caused many changes on the system, reflecting mainly on its dynamic.

Depositional systems such as the barrier-lagoon, which occur mainly in coastal areas where the sediment supply is abundant and the topography is suave (Dillenburg & Hesp, 2009), have an active dynamic with quick responses to changes to the system controlling variables (Davis, 1994; Hayes, 1979), whether these changes are caused by small or large temporal-spatial scale events. In addition, this kind of system may change suddenly in a short time due a storm, for example, and recover in a longer period of time (Short, 1999).

The anthropization of the coastal zones increases the variables that may cause changes in the barrier-lagoon system dynamic, as, for example, the construction of breakwaters or dikes for coastal protection, which affect the sediment distribution. The anthropic occupation, started, in most of the cases, without territorial planning (Esteves *et al.*, 2003) or knowledge about the environment behavior, which, combined with the coastal system dynamic, increases the vulnerability of the municipalities located in the coastal zone, and also represents an economical loss for the local governments. Due to this fact, the scientific research has been focusing on understanding the interaction between the natural and anthropic factors that act on the coastal system dynamic. These studies also came to be of great interest to local authorities, decision-makers and coastal planers since they increase the knowledge about the coastal zones and help them with their actions, thus reducing the damage and the vulnerability of the coastal zones.

Several international organizations have defined guidelines to be applied by the local authorities for an Integrated Coastal Zone Management (ICZM) (GESAMP, 1996) as the International Union for Conservation of Nature (IUCN) (Pernetta and Elder, 1993), World Bank (World Bank, 1996), UNESCO (UNESCO, 2006), UNEP (Coccossis, 1997). Some countries also started to fund studies related to the coastal zones, such as the European Union (EU WG-ID, 2004; European Parliament, 2002) and the Brazilian Environment Agency (MMA). These focus on the elaboration of national guidelines for the ICZM (Brasil, 1988; Projeto Orla, 2002) and on projects to characterize the state of the art (MMA, 2006) and apply the guidelines in the best possible way.

Therefore, it is fundamental to study the coastal zones using a multidisciplinary approach, in order to understand how the natural and anthropic factors act on the local coastal environment behavior, analyzing the events in different space-temporal scales. Through this integrated knowledge, it is possible to have the best response of the ICZM guidelines execution, reducing the coastal facilities vulnerability, and the social and economic losses while also increasing the coastal environment resilience.

This work is part of the RIGED-RA (Recover and Management of the Ravenna municipality Dunes) project, which suggests a new methodology to study the coastal system in the Ravenna Coast, integrating the scientific works with the local authorities and stakeholders, and thus improving the communication between scientific community and decision makers, as requested by international organizations (UNEP, 2015).

Moreover, this Thesis was conducted in a co-tutorship between University Federal do Rio Grande do Sul (UFRGS) and University of Bologna (UNIBO), joining two research groups, IGEO-UFRGS (Instituto de Geociências) and IGRG-UNIBO (Integrated Geoscience Research Group), with international experience, and promoting a know-how exchange in the research on coastal systems, more specifically in the Marine Geology and Integrated Coastal Zone Management fields.

In the RIGED project and in this thesis, were used new technologies with a good cost-benefit to be applied in studies on coastal zones and on the ICZM by research groups, government agencies and private companies. This allows the integration of existing databases and knowledge about the area under study, and also the monitoring of coastal environments.

This know-how exchange was the main motivation for realizing this work, as the Europe Union, for example, considers international cooperation activities as top priority in the Seventh Framework Program for Research (FP7), with funds of €8.1 billion for environmental research (EU, 2015). The exchange allows the enlargement of knowledge of this complex system, in order to mitigate the impacts in the coastal zone due to natural and anthropic factors, benefiting both partner countries.

1.1 –State of the art

1.1.1 –Barrier-lagoon systems

In order to talk about depositional systems of the barrier-lagoon type, it is necessary to define the nomenclature used in this Thesis. In many works, the barrier-lagoon system is referred to using different nomenclatures and this may cause confusion, increasing the difficulty to understand more about this system and to apply local ICZMs.

To avoid confusion, it has been decided through a consensus by the coastal scientific community, that coastal barriers are a structure parallel to the coastline, formed by sand, gravel, shells and small amounts of organic matter accumulated due to the action of tides, wind and waves. It has a subaqueous part, called shoreface, and a sub-aerial part, that may have from tens of meters to a few kilometers, and that may be permanently or partially exposed above sea level during high tides (Dillenburg & Hesp, 2009).

Therefore, this Thesis understands the barrier-lagoon depositional systems as three depositional subsystems that are genetically related. According Villwock & Tomazelli (2006) they are: the barrier system (i) which are basically the coastal barriers, in other words, the beaches and the adjacent dune fields, which literally represent a physical barrier between the sea and the land. The lagoon subsystem (ii), which is located in the back-barrier and corresponds to the region with a low topographic area between the coastal barrier and the older terrains (these can correspond to older barrier subsystems that are located inland). This subsystem may be characterized by the presence of different depositional environments, with the presence or not of lagoon bodies, as, for example, lagoons, coastal lakes, swamps, channels, and intra-lagoonal deltas. Finally, the inlets subsystem (iii), where the connection between the sea and the lagoon subsystem happens.

The barrier-lagoon nomenclature will be used for both depositional systems under study in this work, the Ravenna Coastal Plain and the Rio Grande do Sul Coastal Plain, which will be described with more details along the text.

Others terms that will be used and must be defined when mentioned in the scientific works about coastal zones are transgression and regression. These terms have been used according to Curray (1964) and are linked with the shoreline movement. The term transgression is associated with shoreline movement towards the continent, and the term regression with the shoreline movement towards the ocean. Regression may occur due to two factors: relative sea level RSL fall and, in this case, it is called forced regression; or it may be controlled by the sediment supply, being then called normal regression (Posamentier *et al.,* 1992). During the regression it is possible to have a regressive barrier (Dillenburg *et al.*, 2004; FitzGerald *et al.*, 2007; Roy *et al.*, 1994) forming strandplains, which may present the beach ridges, foredune ridges, cheniers or transgressive dune fields; all these are morphologic features that define the genesis of these plains (Hesp *et al.,* 2005).

The terms progradation, aggradation and retrogradation, in their turn, refer to the depositional architecture on the sedimentary basin and they are the result of the balance between the creation of accommodation space and the sediment supply (Van Wagoner *et al.*, 1990).

According to Van Wagoner *et al.* (1990), progradation occurs when the sediment supply is larger than the accommodation space creation, and the system moves towards the ocean direction. Retrogadation happens when the accommodation space creation is larger than the sediment supply and the system moves in the inland direction. When the sediment supply and the accommodation space creation are in equilibrium, aggradation occurs. There is another use for the term progradation according to Galloway & Hobday (1983), who consider progradation as a movement due to sediment supply without a specific direction.

Others terms that will be used in this work and need a definition are: i) susceptibility, which according to UNDP (2004), is the assessment of a system affected by a harmful event, where the physical conditions of the environment are the primarily influence, independently of human influences; ii) vulnerability, which, according to UNDP (2004), is the exposure of the system to natural hazards combined with human damage; the vulnerability is also dependent on the susceptibility of the system (Bonetti *et al.*, 2015; Muller & Bonetti, 2014); iii) resilience, which, according to IPCC (2012), is “the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures and functions”.

After defining the terms, it is necessary to define the state of the art research of the barrier-lagoon systems under study in this Thesis. The state of the art definition in the areas was done through research of previous published works regarding: recent evolution of the system; the current trend in each area with the main factors (natural and anthropogenic) that act on the areas; the main management and monitoring methods, identifying the most used guidelines to define the local coastal management in both areas.

Integrating the knowledge and incorporating the previous works with new technologies and with geological reasoning, it is possible to better understand these environments. The identification of the main problems allows this study to propose better methods, based on scientific studies, to be applied in the ICZM and in short and long term territorial plans of the barrier-lagoon systems under study and other with similar characteristics.

1.1.2 –The barrier-lagoon system at Rio Grande do Sul Coastal Plain (Brazil)

The occupation in the coast zone of RS and the studies about PCRS, which is the emerged part of the Pelotas Basin, started after the middle of the twenty century. The first works to characterize the PCRS were done using the litostragraphy correlation method (Carraro *et al.*, 1974; Delaney, 1965), when the first PCRS geological map was proposed by Delaney (1965). From the middle of the 1980s, a new methodology, based on the cronostratigraphy correlation method, started to be used for the studies about the geology of the PCRS (Tomazelli & Villwock, 2005).

The chronostratigraphy methodology allowed correlation and assembly of the depositional systems, based on the facies recognition (Figure 1). The methodology change allowed a more consistent reconstruction of the local coastal evolution, representing with better resolution the special distribution of the sedimentary deposits on the PCRS (Barboza *et al*., 2009; Tomazelli & Villwock, 2005).

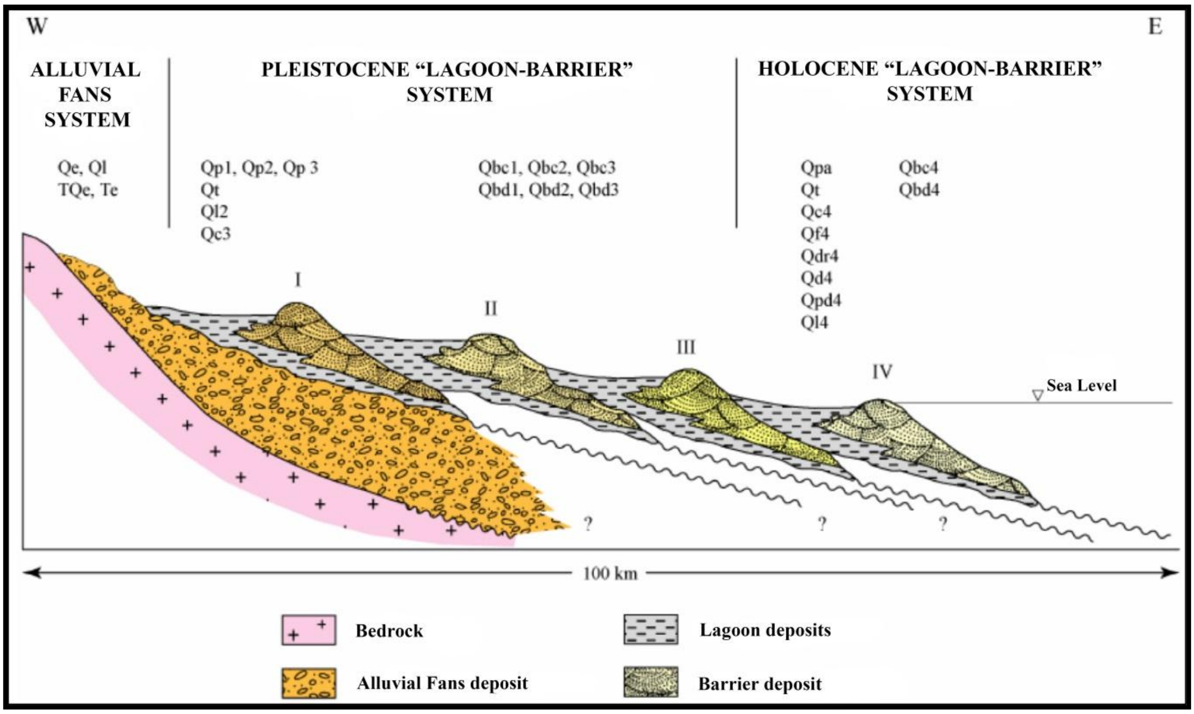

Figure 1: A cross-section profile of the PCRS obtained from the chronostratigraphic correlation showing the four barrier and lagoon deposits (modified from Tomazelli & Villwock, 2000).

Using the facies association from chonoestragraphy it was possible to study the coastal plain with more details, identifying and characterizing four different barrier-lagoon systems in the PCRS (Villwock, 1984; Villwock & Tomazelli, 1995; Villwock *et al.*, 1986). These barrier-lagoon systems were formed during the Quaternary and, currently, their geomorphology is preserved in the PCRS. The authors denominate these four systems as Barrier I, II, III and IV. Barrier I, the oldest one, formed during the Pleistocene, and Barrier IV the newest one, formed during the Holocene (Villwock & Tomazelli, 1995).

These barrier-lagoon systems represent the four regressive-transgressive cycles controlled by the glacioeustasy, and the morphology preserved on the terrain marks the maximum transgression of the system for each cycle (Villwock & Tomazelli, 1995) (Figure 2). The ages of the Barriers I, II, III, and IV, proposed by Villwock and Tomazelli (1995) have been correlated with the peaks 11, 9, 5 and 1, respectively, on the oxygen isotopic stages curve by Shackleton & Opdyke (1973) and Imbrie *et al.* (1984), and correspond to the ages 400, 325, 125 and 7 ky B.P..

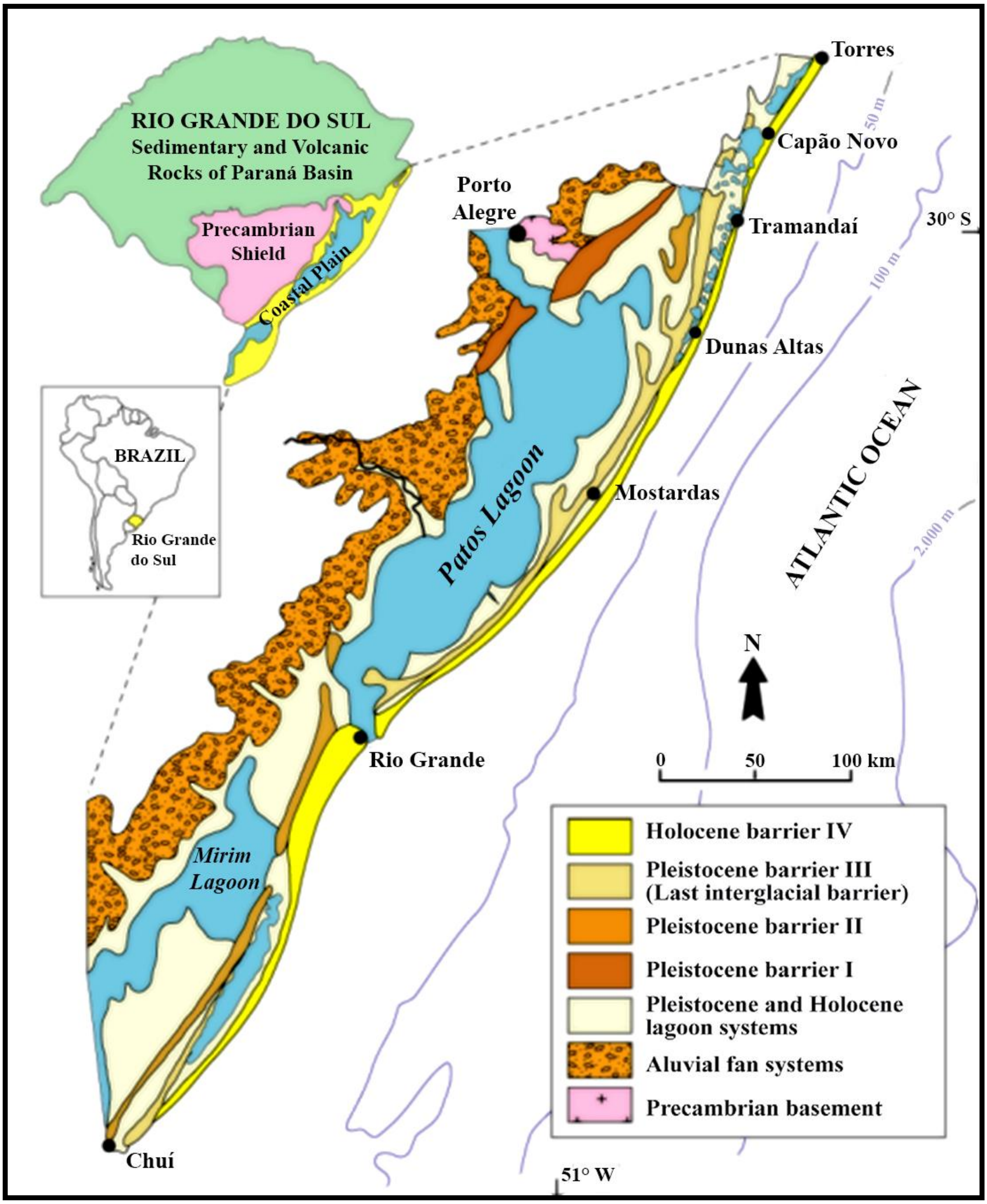

Figure 2: PCRS geological map (modified from Tomazelli & Villwock, 1996).

To corroborate these correlations, dating of ^{14}C and Optically Stimulated Luminescence (OSL) have been done, however, recently fossil teeth have been found and dated in the Barrier II, suggesting that the barrier-lagoon system II corresponds with the pick 7 in the isotopic oxygen curve (Lopes *et al.*, 2009,2011). Due to the new ages obtained, recent works (Rosa, 2012) suggest that the age of the Barrier II is around 200 ky, consequently changing the age of the Barrier I to approximately 325 ky, being more recent than as suggested by Villwock & Tomazelli (1995).

The studies in the PCRS were renewed in 2007, when the Ground Penetrating Radar (GPR) started to be used to investigate the subsurface of coastal environments (Barboza, 1999, Tomazelli *et al.*, 2008a), integrating the knowledge obtained with the previous works.

Different than other methods commonly used in geological studies as, for example, the penetrometric or the stratigraphic from core drills that consent a one-dimension view of the deposits, the, GPR method allows the investigation of the subsurface deposits using a continuous two-dimensional view, based on the stratigraphy of coastal deposits and on its depositional geometry (Barboza *et al.,* 2009, 2011).

The GPR increased the quality and the resolution of the records on the sedimentary deposits, and it has been applied mainly on the deposits from the Holocene age due to the better results (Rosa, 2012).

Thereafter, many works have been developed in the PCRS to improve the coastal model (Barboza, 1999; Barboza *et al.*, 2009, 2010, 2011, 2013; Caron *et al.*, 2011; Dillenburg & Barboza, 2014; Dillenburg *et al.*, 2009, 2011, 2014; Silva *et al.*, 2010; Tomazelli *et al.*, 2008) including PhD Theses (Rosa, 2012; Caron, 2014). Also, on the coastal evolution studies, with a hierarchical approach for the stratigraphy sequence concept (Rosa, 2010; Rosa *et al.,* 2011a; Rosa *et al.,* 2011b; Rosa, 2012).

Moreover, investigating the subsurface in continuous mode in 2D, it was possible to characterize the facies genesis on the sedimentary deposits, identifying the upper and lower shoreface, the backshore/foreshore, the foredune ridges (Barboza *et al.*, 2011, 2013; Hesp *et al.*, 2007; Silva *et al.*, 2010).

This type of data in subsurface allowed the description of the coast line behavior since the Holocene until the present, distinguishing, the transgressive zone localized in the projections of the PCRS and the regressive zones localized on the embayment (Barboza *et al.*, 2011; Dillenburg *et al.*, 2009).

The methodology approach change and the data integration on the coastal environments studies in the PCRS propitiated an important contribution to the scientific community that works in the Pelotas Basin, enabling the expansion of, the knowledge to multidisciplinary fields such as biological science and oceanography. Currently, these data from the GPR are fundamental for an effective ICZM application and to assist the construction of a long period coastal territory development plan (Rosa *et al.,* 2011a).

The period when the main geological works along the PCRS started (Villwock, 1984; Villwock *et al.,* 1986) also corresponds to the period when the coastal occupation in the RS coastal zone began. The 620 km of the RS coastline (Figure 2) was subdivided in three sectors in 1988 (FEPAM, 2015): North Coast (northern sector, from Torres to Dunas Altas, Figure 2); Middle Coast (central sector from Dunas Altas to São José do Norte at north of the Patos Lagoon inlet); and South Coast (southern part from Patos Lagoon inlet to Chuí). Currently, the North Coast sector is the most urbanized (Esteves *et al.*, 2003; Strohaecker, 2007; Strohaecker & Toldo, 2011; Tomazelli *et al.*, 2008b).

During the 1980s, an intense urbanization started in the northern sector of RS coast (Strohaecker, 2007), following the main three urbanization vectors observed along the Brazilian coast: i) urbanization, ii) industrialization, e iii) touristic activities (Moraes, 1999). In many cases, these new coastal towns, in the north sector of RS coastal, have been established on dune field areas. Presently, in the RS north coast, there are only two dune fields, which are under high pressure mainly due to urban sprawl (Tomazelli *et al.,* 2008b).

The coastal towns in the north coast of RS are visited mainly during the summer season, when the coastal population increases considerably. Combined with this urbanization, which happened disorderly without an appropriated management plan (Esteves *et al.,* 2003), mainly in the northern sector, others factors that contribute to increase the pressure on the coastal system happened, mainly through the construction of footbridges, houses and facilities on the dunes.

The consequence of this unplanned urbanization at the beginning of the occupation in the northern sector, reflects nowadays in a higher vulnerability of the coastal towns and in an increased susceptibility of the coastal environment. In order to mitigate the problem and reduce the future losses from an economic, social and environmental point of view, the coastal districts in the RS north coast require a management plan for the long and short terms together with the application of the ICZM following international (e.g. AGENDA 21), national (e.g. Projeto Orla) and regional (Regional Coastal Management Program) guidelines (Gruber *et al.*, 2003; Nicolodi *et al.*, 2002; Portz, 2012). Nowadays, many coastal districts in the north coast have commissioned the development of master plans and/or management plans with the guidelines that support the local ICZM application (Gruber, 2005; Gruber *et al.*, 2008).

Other important elements in the RS coast are the drainage channels (washouts) between the foredunes and beach, called "*sangradouros*", which drain the water from the dunes to the sea, eroding dunes and beaches. In many cases, the *sangradouros* are modified by the man, intensifying the erosive process and reducing the coastal environment resilience (Tabajara & Weschenfelder, 2011). These drainage channels represent a high hazard element in the entire RS coastline; they require a specific management plan to decrease the damages they may cause (Figueiredo & Calliari, 2005).

For the studies done in the PCRS, this Thesis was focused in the Capão Novo coastal town (Figure 2) at the north sector in the RS coast. The locality presents an area with all the anthropic elements cited above, and, adjacent to the coastal town, there is an area with natural elements and low anthropization, which was used for comparison. This coastal town was established in an area where, previously, there was a non-vegetated dune field (Figure 3B), currently extinct, with barchans dunes that migrate inland, nourished mainly by sediments transported by the northeast wind. The barchan dunes moved above aeolian deposits, formed by phases of transgressive dune fields and parallel to the coast line, which were covered by the vegetation, as can be observed in Figure 3 (Hesp *et al.,* 2005, 2007).

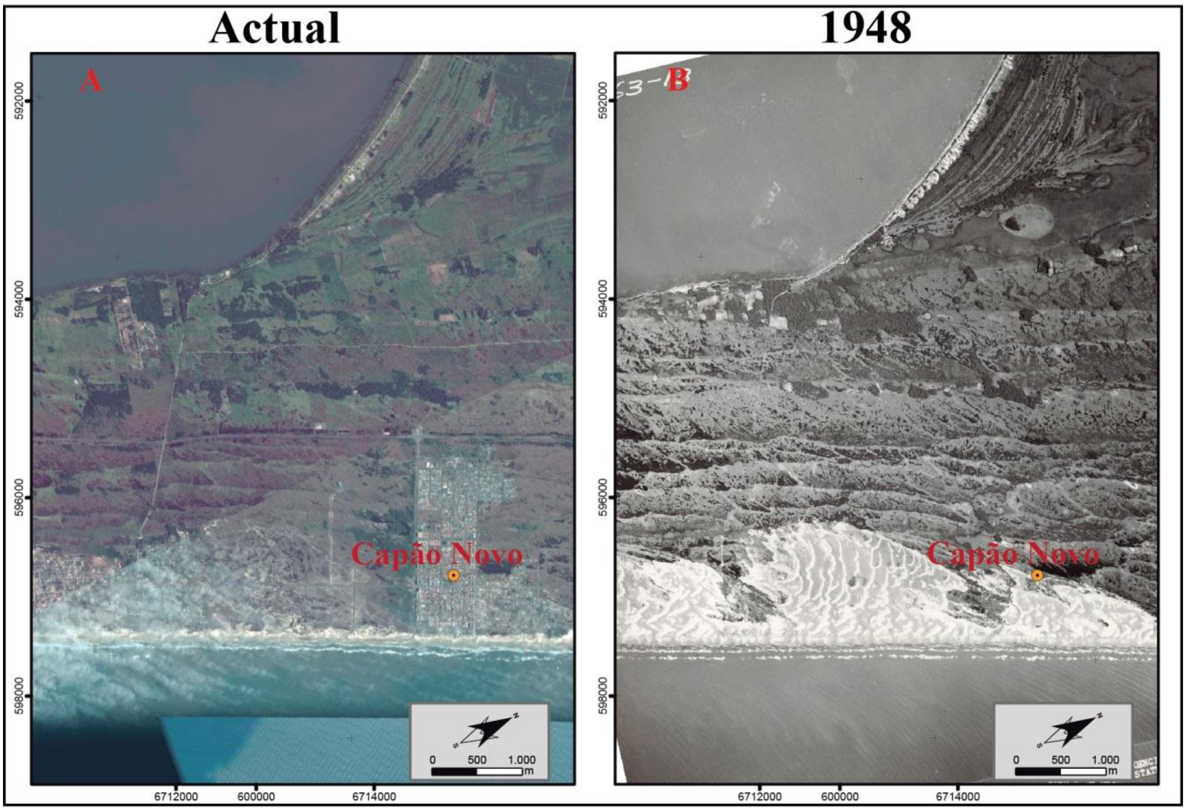

Figure 3: Comparing the study area. A) Present image by Google Earth showing the Capão Novo town; B) aerial photo from 1948 showing the dune fields with barchans dunes above the vegetated transgressive dune fields.

Capão Novo is located in a regressive sector of the PCRS (Dillenburg & Barboza, 2014; Dillenburg *et al.*, 2009) and presents a positive sediment budget. However, the local human occupation is an important factor that increases the system vulnerability, mainly due the footbridges and houses constructed on the dunes (Esteves *et al.,* 2003).

The characteristics of the PCRS coast and that can be verified in Capão Novo are: beaches classified as dissipative and intermediate,, with around 60 m of width; microtidal regime; coast dominated by waves, where the sediment supply is controlled by the longshore drift in the northeast direction; beach sediments dominated by quartz, with sizes from very fine to medium sand (Dillenburg & Barboza, 2014; Gruber *et al*., 2006).

The characteristics of Capão Novo, which were cited above, led to choice of this coastal town as the study object in this Thesis. In the study area, it was possible to analyze the behavior of the coastal environment due the natural and anthropic factors that act locally. The studies also contributed to complement the database in this area, besides serving as subsidies to help the local monitoring and management programs in the coastal zones. The characteristics of the study area will be described and discussed with more details throughout this thesis.

1.1.3 –The barrier-lagoon system in Po Coastal Plain (Italy)

The *Pó* Coastal Plain or Padana Plain, where the Ravenna coastal zone is located (Figure 4), is the other study area of this Thesis. Different than the PCRS in Brazil, this zone presents important territorial elements that were created by man in past centuries. However, from a coastal system point of view, these two zones have several similarities, which differ mainly by the spatial scale, being the PCRS bigger than the Padana Plain.

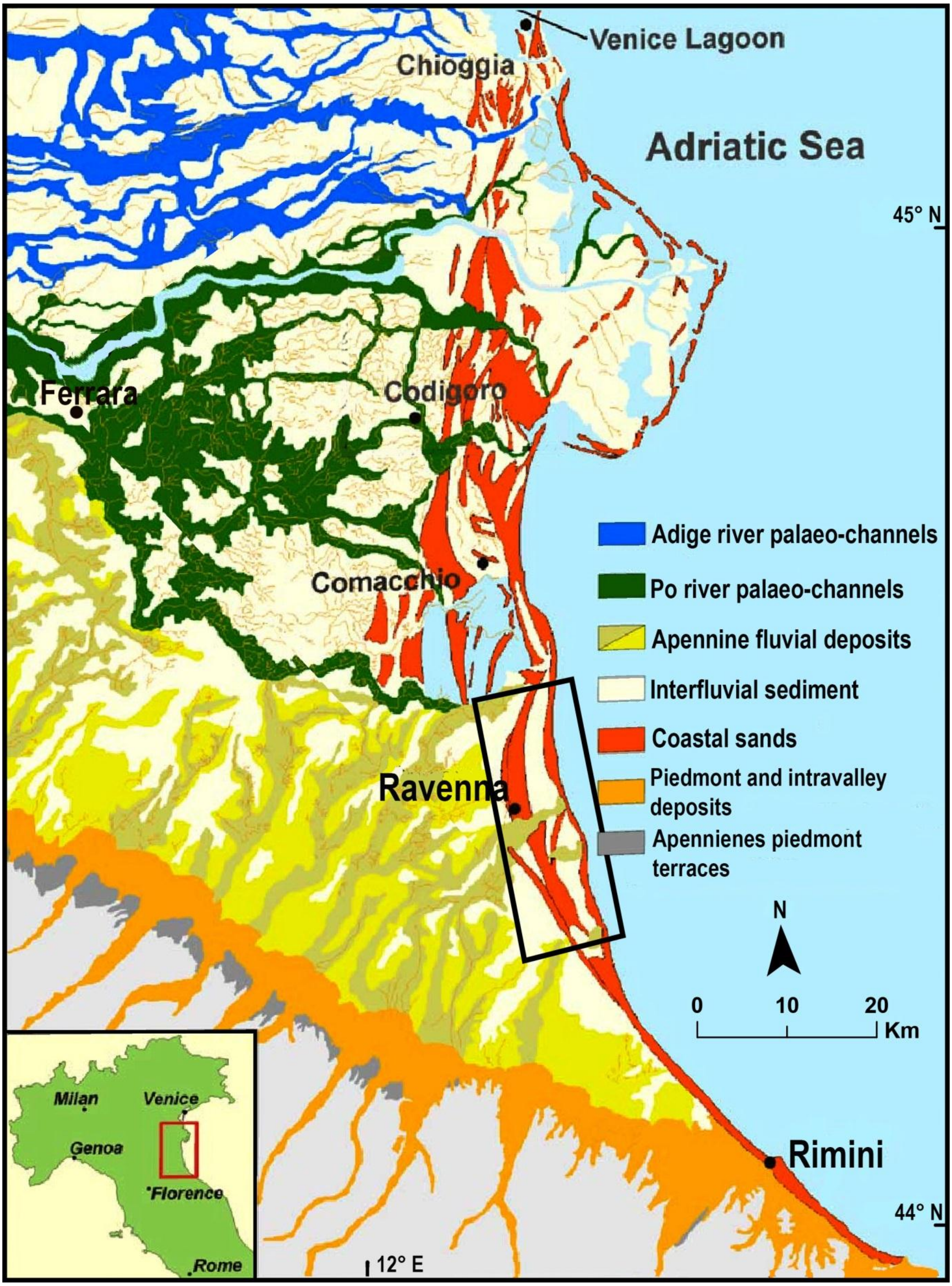

Figure 4: Padana Plain geological map in a 1:250.000 scale; in evidence, the coastal plain of Ravenna (from Regione Emilia Romagna, 1999; modified from Stefani & Vincenzi, 2005).

The first works in a basin scale were supported mainly by the AGIP (Azienda Generale Italiana Petroli), to research the potential oil and gas reservoirs. These studies had a an objective to characterize the basin structures in the 1980s, using reflection seismic data, which allow the identification of the thickness of the Quaternary deposits between 1000 to 1500 m depth (AQUATER, 1978; Amorosi, 1999; Cibin & Severi, 2005; Dalla *et al.*, 1992; Ori, 1993; Pieri & Groppi, 1981).

The studies about the coastal evolution and the geological definitions in the *Pó* Plain began with a synthetic characterization of the quaternary continental deposits in terms of terrace, Holocene terrace and medium/high Pleistocene terraces, where simple lithological differentiations between sand and clay were done (Lipparini, 1969).

The first works using a stratigraphic sequence approach have been proposed by Ricci Lucchi *et al.* (1982), who recognize a succession with two different sedimentary deposits during the Quaternary (Figure 5): i) *Qm,* marine deposits; ii) *Qc,* continental deposits. Moreover, a regressive evolution trend in the Quaternary, was identified when the marine deposit became shallower until they reached the continental deposits.

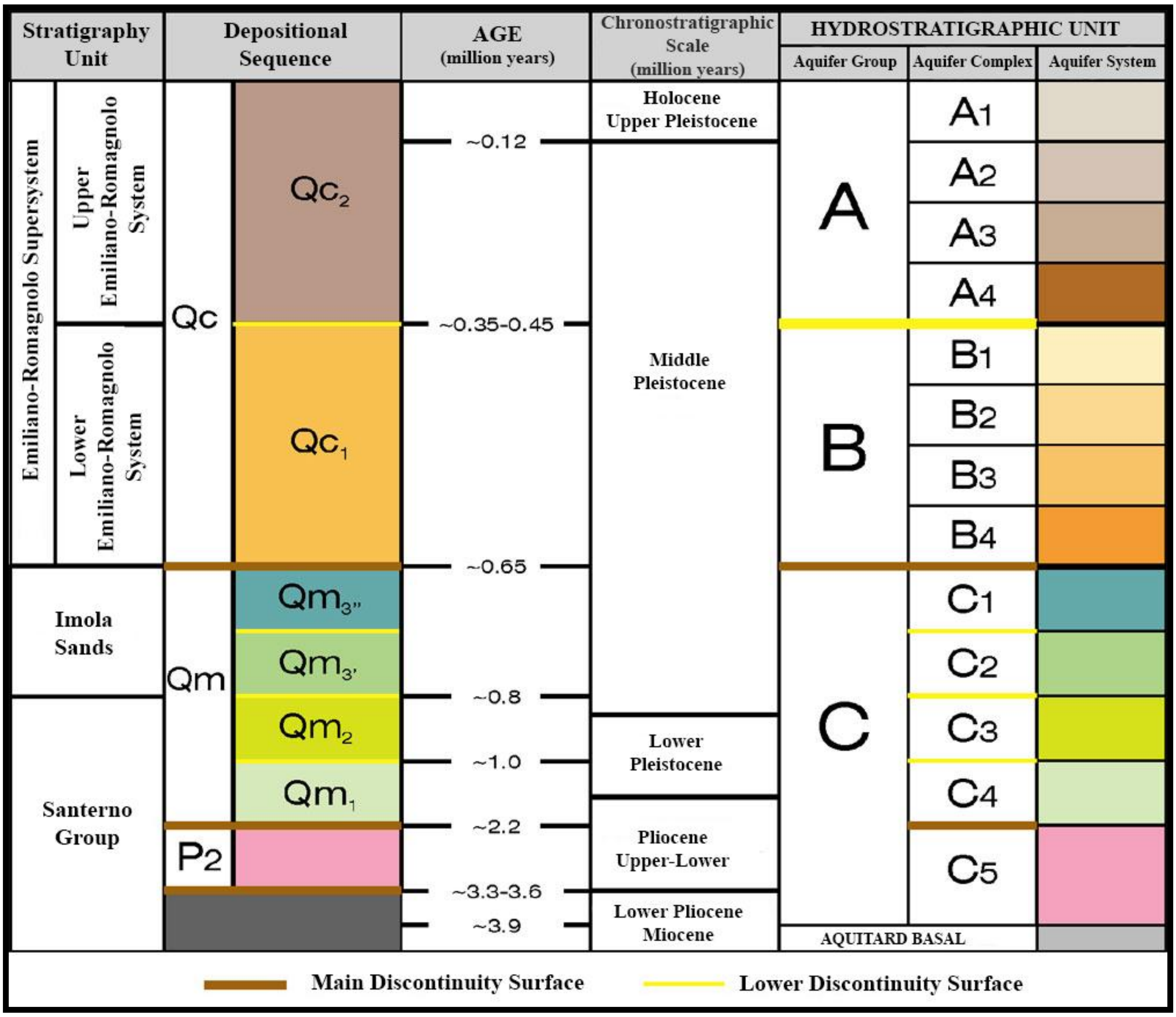

Figure 5: Plio-quaternary deposits stratigraphical scheme for the Padana basin (modified from Regione Emilia-Romagna & ENI-AGIP, 1998).

After Ricci Lucchi *et al*. (1982), other studies have been done using this succession, recognizing smaller boundaries inside Qm and Qc, increasing the depositional sequence details in the *Pó* Plain and including the hydrostratigraphy units (Amorosi & Farina, 1995; Amorosi *et al.*, 1998a, 1998b; Di Dio *et al.*, 1997; Marabini *et al.*,1987, 1995; Regione Emilia-Romagna & ENI-AGIP, 1998). These studies promoted a regional framework (Figure 4) for the geological researches, including the works developed in the coastal zone (Stefani & Vincenzi, 2005).

The studies in the *Pó* Plain coastal zones began with a geomorphological approach (Bondesan, 1985; Castiglioni, 1999; Castiglioni *et al.*, 1990; Ciabatti, 1966; Nelson, 1970; Veggi & Roncuzzi, 1973; Veggiani, 1974), aiming to understand mainly the man-made changes on the territory, which are important elements that influenced the local coastal evolution.

In previous works, beach ridges have also been identified using photointerpretation. In other works, the objective was to reconstruct the drainage network evolution through the historical cartography charts, which shows the territory morphology and the changes, allowing a qualitative assessment of the changes in the territory (Gabbianelli *et al.,* 2000).

The works using the subsurface data began with the analyses of the shallow boreholes, from 6 to 30 m deep (Bondesan *et al.*, 1995; Brunetti *et al.*, 1998; Colantoni *et al.*, 1990; Rizzini, 1974; Veggianni, 1973). These works allowed the study of the Holocene deposits, identifying the transgressive-regressive cycle.

Currently, the studies in the coastal zone are based mainly on the penetrometric data combined with ^{14}C and with data from mollusc association, to construct a high resolution model of the *Pó* Plain subsurface (Amorosi & Marchi, 1999; Amorosi *et al.*, 2003; Scarponi & Angeletti, 2007; Wittmer *et al.*, 2014). These will be presented with more details in this Thesis, focusing on the works about the Ravenna coastal plain subsurface.

Unlike the PCRS studies, which use the GPR method, the methods used in *Pó* plain are in a 1D view. This makes it impossible to visualize the depositional geometry, which would be corroborated with the boreholes and penetrometric data.

The first studies, integrated with the recent works, allow for the creation of a rich database to construct the mainly geological maps in the *Pó* Plain, which involve the Ravenna Coastal plain (Carta Geologica d'Italia in scala 1:50.000, 1999, 2005; Castiglioni *et al.*, 1999). They also allow the creation of an important web GIS database to subsidize the surface and subsurface geological studies and works involving the *Pó* Plain (Regione Emilia-Romagna, 2015).

Moreover, several climatic anomalies modified the climate in Europe; the Little Ice Age (LIA) (Figure 6) was the last significant climatic anomaly (Brázdil *et al.*, 2005). The LIA lasted approximately from 1550 to 1850, influencing the progradation rates during the Holocene and acting on the geological and geomorphological evolution on the northern Adriatic coast (Carbognin & Tosi, 2002; Marabini & Veggiani, 1992; Simeoni & Cobau, 2009). The LIA was a determinant factor that conditioned the current Ravenna coast morphology, by creating a young beach system, formed in the last five centuries.

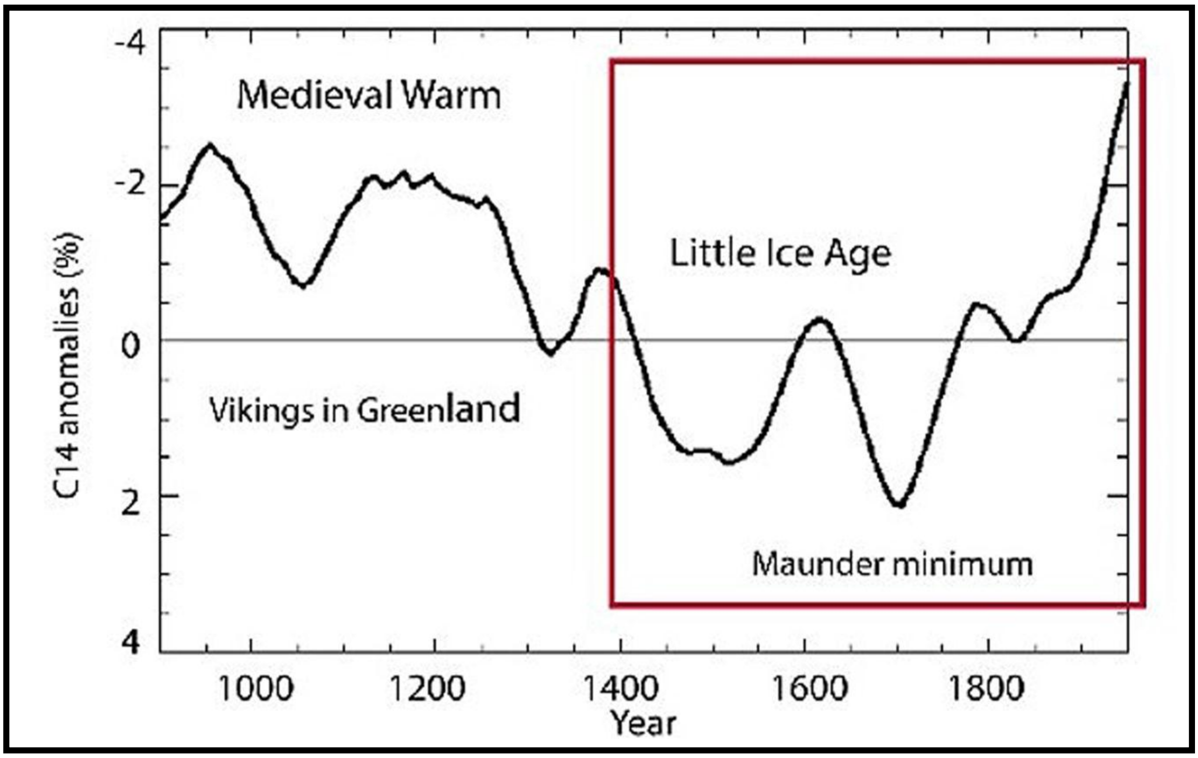

Figure 6: The variations in ^{14}C concentrations in the last 1000 years due solar activity; in evidence in the red rectangle, the variations during the LIA (modified from Svensmarck, 2000).

The Ravenna coastal plain, as the whole *Pó* Plain, is subject to subsidence due to natural (plio-quaternary sediment compaction) and anthropic factors (subsoil fluids exploration, mainly methane and water) (Bondesan, 1989; Brunetti *et al.*, 1998; Carminati & Martinelli, 2002; Teatini *et al.*, 2006). The subsidence rates (anthropogenic plus natural) vary between 10 and 12.5 mm/y according to geodetic surveys done by ARPA (Regional Agency for the Environment Protection) (Taramelli *et al.*, 2014).

According to Armaroli *et al.* (2012), the Ravenna coast is characterized by sandy beaches, with low elevation above medium sea level, and low angle and dissipative beaches,, with microtidal regimes. The longshore is dominated by waves from offshore and the sediment size varies from fine to medium sand (Gambolati *et al.*, 1998).

In terms of the management, the Ravenna Coastal Plain is subject to many factors, natural and anthropic. Thus it is important to understand their influence to obtain a good management plan. This is an important condition that leads local authorities to invest on coastal studies to assist their management actions.

After the World War II, human actions in this coastal area have increased, and presently the Ravenna coast has an erosive trend mainly cause by human influence (Gambolati *et al.*, 1998; Harley & Ciavola, 2013; Martinelli *et al.*, 2011). Human interventions on the rivers that reach the Ravenna coast, through dam constructions, also interfered with the sediment transport rates. These actions changed the sediment supply on the beaches (Martinelli *et al.*, 2011) and affected the natural beach nourishment.

The strong urbanization is supported mainly by the coastal towns' expansion, with summer houses, fixed structures installed on the beach and tourism activities (Cencini, 1998). From 1892 until 2006, more than 50% of the continuous foredunes existing in the Ravenna coast have been destroyed; nowadays, these, foredunes are fragmented (Antonellini *et al.*, 2008).

Since the beginning of 1980 until the present, several actions have been taken in order to reduce the beach erosion. Some of the main methods were the beach nourishment and the construction of breakwaters in the critical areas of the coastal zones. Breakwaters were installed in 60 km of the 130 km of the coast extension, including emerged, submerged, parallel and transverse breakwaters (Perini *et al.*, 2008), which changed the coastal system dynamics.

Due to the high vulnerability of the structures and houses in the Ravenna coast and the high susceptibility of the local beach and dune system, this zone follows many guidelines proposed by European Union and Emilia-Romagna Region and based on scientific research. As an example, we can cite research programs such as: BEACHMED-e; COATANCE; MICORE; and EUROSION (Regione Emilia-Romagna, 2011, 2011a). Moreover, these programs lead to new research to understand the environmental behaviour, and, in many cases, facilitated the implementation of new strategies for the ICZM.

1.2 –Objectives

The objectives of this thesis were to investigate and integrate the knowledge about the behavior of the coastal zones characterized by a barrier-lagoon system in different temporal scales. The territory evolution in the Holocene and the current state of these coastal zones were considered, associated with natural and anthropic factors.

Although each coastal system has their own dynamic system controlled by local variables, this work focuses on two different barrier-lagoon systems: the north coast of the PCRS in Brazil and the Ravenna Coastal Plain in Italy. This study promotes a knowledge exchange about the ICZM in each coastal zone between the researchers

These two barrier-lagoon systems have common and uncommon points, which will be described in this Thesis. Even though the spatial scale of these two systems are different, they are exposed to strong anthropization and the natural events may have cause damage to the territory. Because of that, these localities need a specific management plan, to decrease the local coastal vulnerability and to elaborate the future actions, based on the probable system changes that can be predicted.

The specific objective of this research was to acquire a clear knowledge of the temporal discontinues in the evolutionary processes, and morphological, physical-geometrical and environmental parameters that drive these coastal systems. This was done by investigating the local evolution during the Holocene, and the foredunes and beaches’ behavior towards the main variables that act on the zones, in order to apply the knowledge obtained in the current local ICZM programs.

Due to a lack of knowledge and inadequate management of these variables that control the system, the coastal system may go into crises (Figure 7). This may cause damages to the activities that explore the coastal system resources, increase the vulnerability and susceptibility of the system, and cause immeasurable social, environmental and economic losses.

Figure 7: Interaction between man and the environment in the coastal system. A) Foredunes moving into the side walk in the north coast of RS; B) the human-changes on the coastal system in the Ravenna coast.

1.3 –Premise and Hypothesis

The premises to elaborate the thesis's hypothesis are based on the fact that, to do an efficient ICZM, it is fundamental to know in the best way the interaction between the variables that control the coastal system, analyzing their influences in different spatial and temporal scales (Figure 8). Also, when possible, it is necessary to integrate the analyzed scales (Orford & Carter, 1995; Stive *et al.*, 2002).

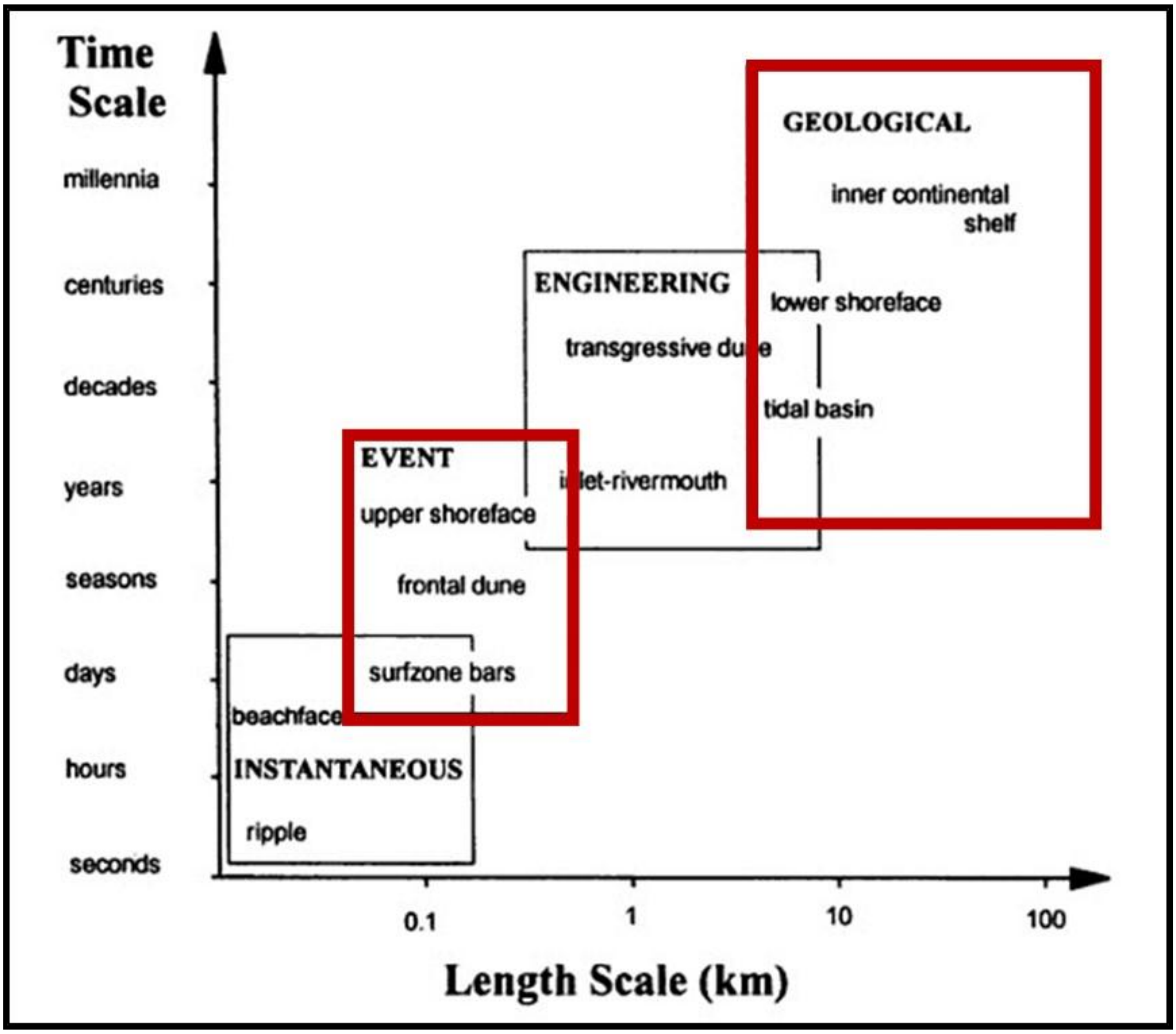

Figure 8: Definition of spatial and temporal scales in the coastal evolution. In the red squares, the scales treated in this work (modified from: Cowell & Thom, 1994).

Due to anthropization, the pressures on the coastal systems have intensified, as can be seen in Ravenna Coast example. In Figure 9A is possible to observe the pressure on the beach/dune system caused by anthropogenic elements; in Figure 9B, 1 km southernmost, without anthropic elements, the foredunes are continuous and more preserved.

Figure 9: Two adjacent foredune systems, the red circles are distant 1 km: A) foredunes under pressure by urbanization; B) preserved foredunes without anthropic elements pressures.

This situation, with anthropogenic pressures on the coastal system, may be observed in many coasts around the world. Other example is in the north coast of RS (Figure 10), where the urbanization was responsible for the dune field's extinction, due to the disordered territorial occupation and the blockade of the sediment supply from the beach to the dune fields (Tomazelli *et al.,* 2008). One of the consequences of these high impacts on the beach/dune system is the reduction of the system resilience and the increase of the coastal towns' vulnerability (Woodroffe, 2007).

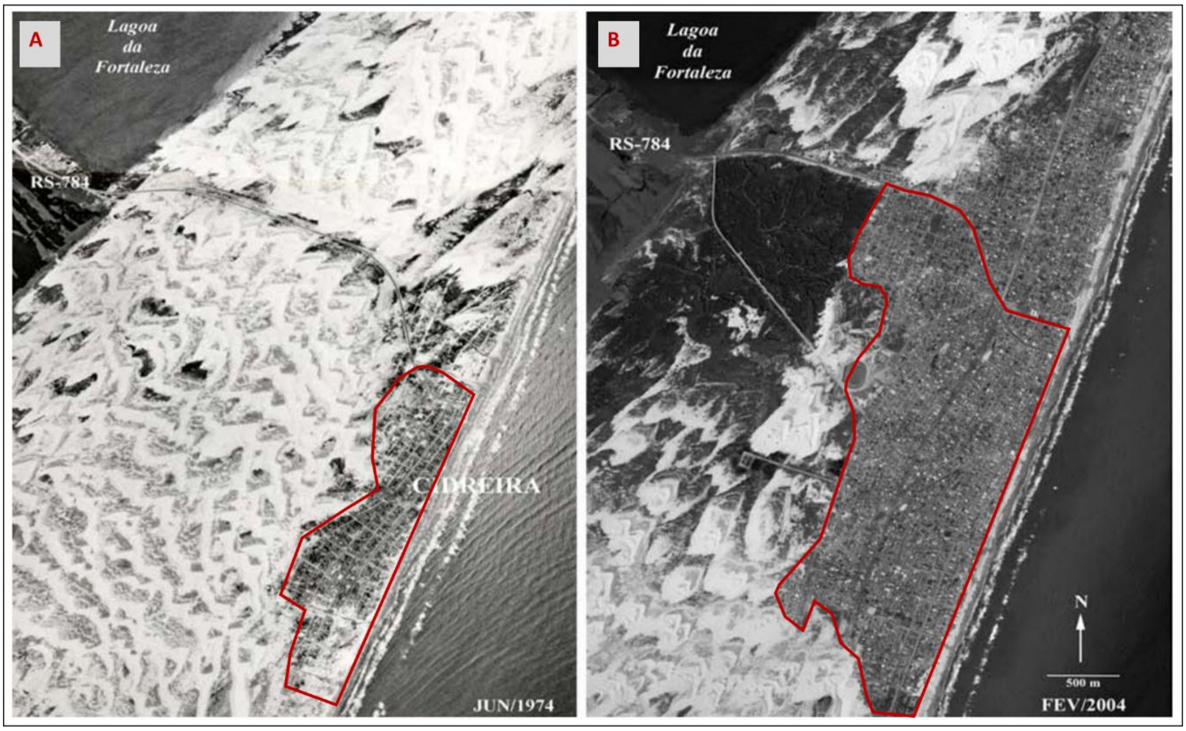

Figure 10: Urbanization in the Northern Littoral of RS. A) Aerial photo from 1974 with the dunes field; B) urbanization in the same place thirty years after, showing the extinction of the dunes field (modified from Tomazelli *et al.*, 2008).

For a good application of the ICZM actions, it is necessary to research the system, knowing the current coastal system behavior due to the mainly local factors that determine the local vulnerability, such as the storms or the facilities constructed on the dune/beach system. It is also necessary to know the long term behavior of the system through the coastal evolution studies, and to integrate the knowledge from two different temporal scales, helping the decision-makers choose the best manner to apply the ICZM (Rosa, *et al.,* 2011).

Assuming that "the past is the key to understand the future" (Lyell, 1830), to understand the actual coastal system dynamic and how your current morphology was determined, it is necessary study the coastal evolution.

The present morphology in the inner shelf is an expression of the antecedent topography, and also of the oceanography processes that have acted on the oceanic floor during Post-Glacial Marine Transgression. Since this affirmation is valid for the autochthone shelf that does not receive modern sediments Dillenburg *et al.*, 2000, 2009; Schwab *et al.*, 2000). This is the case of the Ravenna Coastal Plain and north coast of RS, which were influenced by climate anomalies with different orders, such as the glaciation cycles, that determined the morphology of PCRS, and the LIA, that had a high influence on the current morphology formation of the Ravenna Coastal Plain.

Furthermore, when humankind began to use the coastal zones as a resource, we started to influence the behavior of coastal system, directly and indirectly. This had impact mainly on the system of sediment balance, which has a crucial and complex rule on the coastal system evolution (Carter & Woodroffe, 1994). Because of this, and knowing the processes that occurred in the Holocene, it is possible to integrate them with the present processes, governed by natural dynamic and anthropic influence, allowing us to learn about the past and to predict future trends.

From the considerations done about the coastal evolution and the current state in the coastal zones under study, and considering the premise that a specific management plan is essential for these coastal systems, with a high knowledge about all the variables that act on them in their most complex forms was considered. From this affirmation, the following hypothesis were elaborated:

"The anthropization in the coastal zones under study in this research changed the coastal morphology and dynamic, reflecting in their resilience, susceptibility and vulnerability, if compared with natural coastal systems"

"For effective coastal zone management, the integration of the knowledge about the recent territorial evolution with the knowledge about the current state is fundamental in the ICZM of barrier-lagoon depositional systems".

To test this hypothesis, it is necessary to study the costal system with a high level of detail, in different spatial and temporal scales. For this, new technologies were used to acquire the data that allows the study of the behavior of the coastal system in natural and anthropic zones. This hypothesis was tested in the Ravenna Coastal Plain and in the northern coast of RS, studying the Holocene coastal evolution and the events with annual and seasonal time scales, such as the foredunes erosive processes or the changes done by man on the beaches and dunes.

1.4 –Methods

To achieve the objectives and test the hypothesis, in this work, validated scientific methods were used to be applied in the coastal zone studies. These methods can also be used outside of the academic scope by managers and planners, governmental agencies, local authorities and private companies, in order to increase the objectivity of their decisions. This provides for a better use of the coastal zones resources and exports the scientific research to other fields and disciplines, outside of the exclusivity of the scientific community. Therefore, it is essential that the methods are efficient and have a cost-effective to be used by private companies and government agencies.

Following this purpose, the methods used in this work and that will be explained with more details in each paper, were used to create a database with the information acquired from the previous works in both study areas and were integrated with: i) historical aerial photos; ii) historical charts (geodetics and pre-geodetics); iii) data and information from the Emilia-Romagna Region geological, seismic and soil survey database that allows the download of the 1:50.000 scale soil chart and the geological and geomorphological territorial elements in shapefile format (Regione Emilia-Romagna, 2015); iv) satellite images; v) topographic surveys to elaborate the digital surface model (DSM) and digital terrain model (DTM) from LIDAR (courtesy provide by ENI-IT); vi) topographic surveys using GNSS (Global Navigation Satellite System) in RTK (Real Time Kinematics) mode to obtain a topographic data with high resolution in the horizontal and vertical components.

The newness of this work, which contributed to the know-how exchange between the two research groups cited, was the application of noninvasive geophysical methods through the GPR (Neal, 2004) in the Ravenna coastal plain, to increase the knowledge about the subsurface in the area and construct a high-resolution model about the local coastal evolution. This method is based on the identification of the sedimentary structures and is widely used in studies about the coastal evolution in the PCRS (Barboza *et al.*, 2009, 2011; Rosa *et al.*, 2011) and in others coastal systems around the world (Botha *et al.*, 2003; Bristow *et al.*, 2007; FitzGerald *et al.*, 2007; Johnston, *et al.*, 2007; Moller & Anthony, 2003). The GPR provides excellent results, and the method can be useful in useful in scientific research or other works outside of the academic scope, contributing to expand the research on the coastal systems where it has been used, while also having a good coast-benefit and easy data survey logistic.

For this work, the GPR surveys were done using a COBRA PLUG-IN GPR (with a Control Unit and a SUBECHO Antenna model SE-70) (Figure 11) data collector by Radarteam Sweden AB. Using a transmitting and receiving antenna with a 80 MHz center frequency in Common Off-set arrangement, for localization of the profiles acquired, the GPR has an integrated GNSS.

Figure 11: The GPR antenna used to acquire the subsurface data in the Ravenna Coastal Plain.

For the data processing, two softwares: RADAN^{TM} 7 and Prism 2$^{®}$ were used. The data interpretation was based on the seismostratigraphic methods adapted for GPR data (Neal, 2004), though the identification of the terminations that are: *onlap, downlap, toplap* and *truncations*, the pattern of the reflectors and the geometry (Mitchum Jr. *et al.*, 1977; Vail, 1987). The data interpreted were integrated with the subsurface stratigraphy data from the bibliography and previous works done in the Ravenna Coastal Plain.

For the PCRS was used a new instrument and method which has been applied in the Ravenna coastal plain for monitoring the coastal environment. The method is based on the photogrammetry, with the acquisition of aerial photos done by UAVs, which allow to elaborate the DSM and orthophotos (Brown & Arbogast, 1999; Casella *et al.*, 2014; Gonçalvez & Henriques, 2015; Mancini *et al.*, 2013). This method allows the acquisition of high-resolution data in coastal environments with a low cost when compared with other survey methods as the LIDAR or the Terrestrial Laser Scanner, for example, that are used to acquire data with the same quality as the data acquired using UAVs (Mancini *et al.,* 2013).

In Ravenna, two surveys were realized (commissioned by SAL-Engineering), the first one was done in September 2014, at the end of the summer season, and the second one was done at the end of the winter season in April 2015 (SAL Engineering, 2015). These two surveys enabled the comparison of the changes that occurred on the emerged beach and the dunes during the winter season, evaluating the impacts of the winter storms and the human changes on this coastal zone.

In addition, during this research, a new method to acquire aerial photos using a commercial UAV, a DJI Phantom 2 (Figure 12), was developed. It is a good cost-benefit method to be used by research groups, government agencies or private companies. Moreover, the data obtained may be used in different work fields, such as engineering, urban planning and management, biology, geology, archeology and others areas of the knowledge, depending on the requirements of each research.

Figure 12: The DJI Phantom 2 with the eTrex®30-Garmin GNSS attached to the UAV to increase the georeferencing accuracy.

The DJI Phantom 2 used is a quadcopter with a 3-Axis Camera Stabilization; a 14 Megapixel HD camera, which has a FOV (field of view) of 140° f/2.8 focus at ∞, with real-time Camera Preview on IOS and Android devices. It is necessary to have a smartphone integrated with the UAV Remote Controller to control the camera and the UAV configuration, besides helping the operator to control the acquisition speed (about 1.5 m/s), the terrain photos cover, and the flight elevation.

For the geotagging of the aerial photos, the UAV is integrated with a GPS (Global Position System)where the horizontal and vertical accuracy are ±1 m and ±2.5 m respectively. To increase the accuracy of the aerial photos geotagging, a GNSS (Global Navigation Satellite System) eTrex®30-Garmin with barometric altimeter (Figure 12) calibrated with the local topographic chart was linked, and the geotagging was done using the BaseCamp™ software.

Due to the FOV of the DJI Phantom 2 camera, which has a fisheye type, it was necessary to correct the photo surface, flattening the photos surface (Figure 13) for the photogrammetry reconstruction. This correction was done using the calibration profile for the DJI Phantom 2 in the Agisoft Photoscan software (Agisoft, 2013), and the photos were corrected using a toll in the Adobe Photoshop CS5 software.

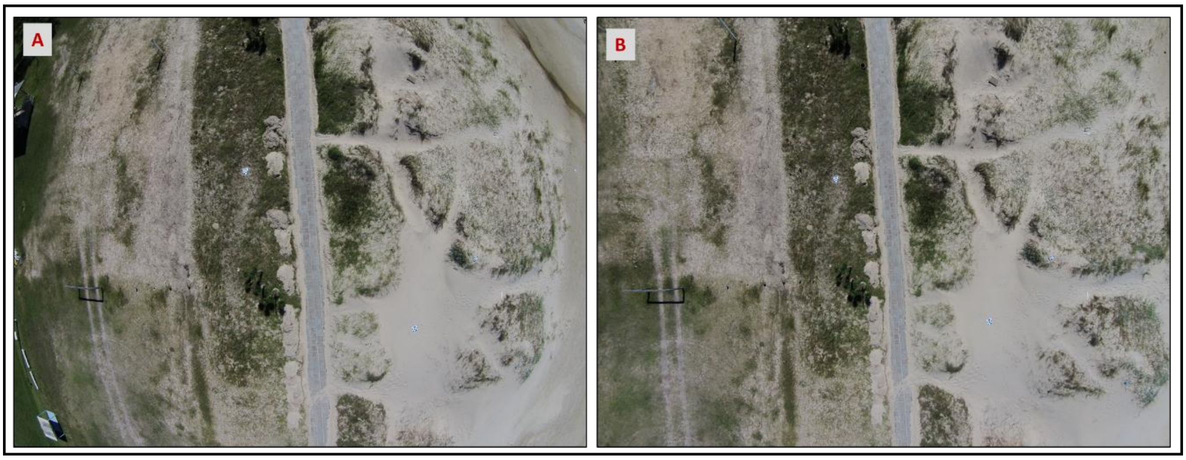

Figure 13: Aerial photos from DJI Phantom 2. A) The aerial photo before correction; B) the aerial photo after the profile correction.

After the correction of the photos, the Agisoft Photoscan software was used to do the photogrammetry reconstruction, based on the Structure from Motion (SfM) method (Snavely *et al.,* 2007). The results obtained were a DSM with 0.3 m cell resolution and an orthophoto with 0.05 m pixels. In addition, to increase the accuracy of the model, Ground Control Points (GCP), which were georeferenced using a Trimble® GNSS device to acquire the points location using the DGNSS system were used.

The low coast UAV survey methodology described was used in the north coast of RS in Capão Novo, to elaborate the DSM and the orthophotos, allowing the comparison between the adjacent natural and anthropic zones.

Following the purpose of organizing the data base with past and current works in the studied areas and to process and operate the spatial data obtained, the Geographical Information System (GIS) was used. The software used were: Esri ArcGIS® 10.1, Blue Marble Geographics – Global Mapper™ 15, Fledermaus-v7. These softwares allow the management and analysis of the data set informing their spatial localization (Andrews *et al.,* 2002). The data set were operated with their appropriate coordinate system: for the Italian study area data set, the DATUM UTM-ETRF 2000 was used; for the Brazilian data set the DATUM UTM-WGS84-22S was used. Thus, it was possible to manage the data set with high accuracy to restore the elaborated and interpreted data with a spatial reference. The. GIS software was also used as a tool to produce the final product, represented mainly as illustrative maps.

Chapter 2

SURFACE AND SUBSURFACE DATA INTEGRATION, USING NEW DATA TO REBUILD THE SURFACE GEOLOGICAL MODEL, FROM THE LITTLE ICE AGE TO THE PRESENT, IN THE RAVENNA COASTAL PLAIN, NORTHWEST ADRIATIC SEA (EMILIA-ROMAGNA, ITALY)

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Surface and subsurface data integration, using new data to rebuild the surface geological model, from the Little Ice Age to the present, in the Ravenna coastal plain, northwest Adriatic Sea (Emilia-Romagna, Italy)

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ABSTRACT

New analyses of the geological surface in the Ravenna coastal plain provide an increase in the knowledge of this coastal system, updating the information about the geology in the area and rebuilding the coastal model without the man-made changes on the territory in the last four centuries, when the Little Ice Age had a large influence on the coastal dynamics. This natural factor, combining with the territory anthropization defined the actual coastal morphology, canceling most territorial indicators needed to create an accurate coastal evolution model, as the beach ridges morphology in the territory. Because of the lack of territorial indicators, it is not possible to use the morphology of the territory to construct a local coastal evolution model. Because of this, to rebuild the local coastal evolution model and to understand how the coastal evolution would be without human influence, this work proposes an integration of data using: actual data from the surface, such as the high-resolution digital surface model (DSM) and digital terrain model (DTM); the actual database from Emilia-Romagna Region Geological Survey, as the shapefile with the regional soil chart and with the geological elements present in the territory; the knowledge from previous work done in the area; and

the subsurface data from GPR, this is the first work using a GPR survey in the coastal plain of the northwest Adriatic. In addition, the work follows a successful case study done in the south Brazilian coastal plain, which integrated previous work done in the coastal plain with new methods such as GPR data acquisition. The GPR data allow corroboration of the interpretation of the coastal model constructed using the surface data. Finally, the surface geological model proposed in this work may aid the bases to: i) a new horizon for the local coastal geology scientific research; ii) a methodology to apply in other barrier-lagoon systems around the world to update knowledge about these systems; and iii) powerful information to support coastal managers and decision makers to construct a long-term master plan for effective Integrated Coastal Zone Management.

Highlights

- Multi-disciplinary approach to build a coastal evolution model to aid the new researches and the management in the coastal zone.
- Identification of the territory changes and the barrier-lagoon coastal system using different data source.
- Integrations of the surface and subsurface data to increase the resolution of the model
- Proposal of a new costal evolution model without man-made changes in the area to identify the real geomorphology of the coastal zone

Keywords: Coastal geology; Coast evolution; Barrier-lagoon; GPR; Soil association

1. Introduction

Coastal evolution researches are fundamental to improve our knowledge of the coastal territory and to understand the future evolution trend of coastal systems (Bonaldo and Di Silvio, 2013; Soons et al., 1997), knowing the behavior of the coastal territory due to the natural and anthropic pressure on this system (Zecchin et al., 2009). Considering the barrier-lagoon coastal system, according to the nomenclature proposed by Hesp and Short (1999), it is mainly based on their morphological settings. This system has a quick response due to: littoral dynamic changes, such as winter storms (Masselink and Van Heteren, 2014); changes in the fluvial sediments' discharge rate; coastal anthropization, such as coastal protection constructions (Armaroli et al., 2012; Corregiari et al., 2005); or relative sea level (RSL) changes, which are the primary controller in the barrier-lagoon system dynamics (Carter et al., 1989; Cowell and Thom, 1994; Dillenburg and Hesp, 2009; Duffy et al., 1989*;* Lorenzo-Trueba and Ashton, 2014; Stanley and Warne, 1994). Understanding the system response due to the cited factors, it is possible to decrease the vulnerability of the coastal system, mainly in the coastal zones under intense urbanization, which is verifiable in some coastal systems in the world. In addition, actually, the awareness of how barrier-lagoons evolve is an important topic to consider inside the Integrated Coastal Zone Management (ICZM) (Ceia et al., 2010; Oost et al., 2012), for territory management and to decrease coastal vulnerability (Davis, 1994) that is summed up in an economic advantage (Dezileau et al., 2011; Sebatier et al., 2012).

In most coastal environments that are characterized by a barrier-lagoon system, as in the US (FitzGerald et al., 1994; Hayes, 1994; Simms et al., 2006), Australia (Bird, 1965; Short and Hesp, 1984), Europe, in which the Po Plain is an example (Amorosi and Farina, 1995; Amorosi et al., 2005, 2008; Brunetti et al., 1998; Corregiari et al., 2005) or in the south Brazilian coast (Dillenburg et al., 2009; Sawakuchi et al., 2008; Tomazelli and Villwock, 1996, 2005). These coastal zones have been the subjects of research for decades, the main interest is to understand how the coastal dynamics are driven by the cycle of high- and low-frequency climate changes or by man-made changes, and how the climate changes guided the coastal evolution. Moreover, these researches are important for an efficacious economic resource exploration on barrier-lagoon systems in terms of minerals resources exploration and territory occupation (Roy et al., 1992).

Much work has been done to improve the knowledge integrating previous research with new tools to study coastal evolution, and in many cases the results obtained were used to assist ICZM programs (Rosa et al., 2011). An example is the Rio Grande do Sul coastal plain (PCRS) in southern Brazil, which is formed by four barrier-lagoon sedimentary deposits, which were shaped during the last four sea level highs in the Late Quaternary period (Dillenburg et al., 2009). The morphology of these four sedimentary deposits is preserved and may be observed on the territory. The Holocene barrier known as the Barrier IV (Villwock and Tomazelli, 1995) system is more studied and has been characterized to understand the actual coastal system behavior and to understand the process on the other older systems (Rosa et al., 2011) using a hierarchical method (Neil and Abreu, 2009). To study the PCRS, the Ground Penetrating Radar (GPR) method was used, which allows obtaining high-resolution data in the subsurface of the coastal deposits (Barboza et al., 2009, 2011, 2013, 2014; Biancini et al., 2014). The GPR data in PCRS were used in conjunction with stratigraphy correlation and dating from drill hole surveys to validate the coastal evolution model and to corroborate the GPR data interpretation (Barboza et al., 2009; Dillenburg and Barboza, 2014).

In the PCRS study case, this integration allowed identification of the Holocene coastal depositional system behavior with very high resolution (Barboza et al., 2011). Moreover, it was possible to recognize, through the reflectors' geometry from the GPR data, the type of coastal environment present in the subsurface, which is represented in the radar facies as beach ridges, backshore/foreshore, upper and lower shoreface (Barboza et al. 2014; Neal, 2004; Rosa, 2012). The scientific knowledge of Holocene coastal evolution may support territorial planning and management, and to identify the system trend on the Holocene time scale. In addition, it is possible to recognize the nature of the pressures on the system with more accuracy, aiding the local research groups and local authorities in the ICZM decision actions (Rosa et al., 2011; Zular et al., 2013).

Climate cycles on smaller scales than the Last Glacial Maximum (LGM) are unable to cause significant changes in coastal morphology, such as by the Little Ice Age (LIA), which occurred during the Holocene (Fig. 1). The LIA was a climatic anomaly during 1550 to 1850 (Barlow, 2001; Brázdil et al., 2005; Grove, 2001; Jones and Briffa, 2001; Svensmark, 2000) that changed the climatic conditions in Europe, influencing the geological and geomorphological evolution in the northern Adriatic coast

(Carbognin and Tosi, 2002; Marabini and Veggiani, 1992; Simeoni and Cobau, 2009) comprising the Ravenna coastal plain evolution.

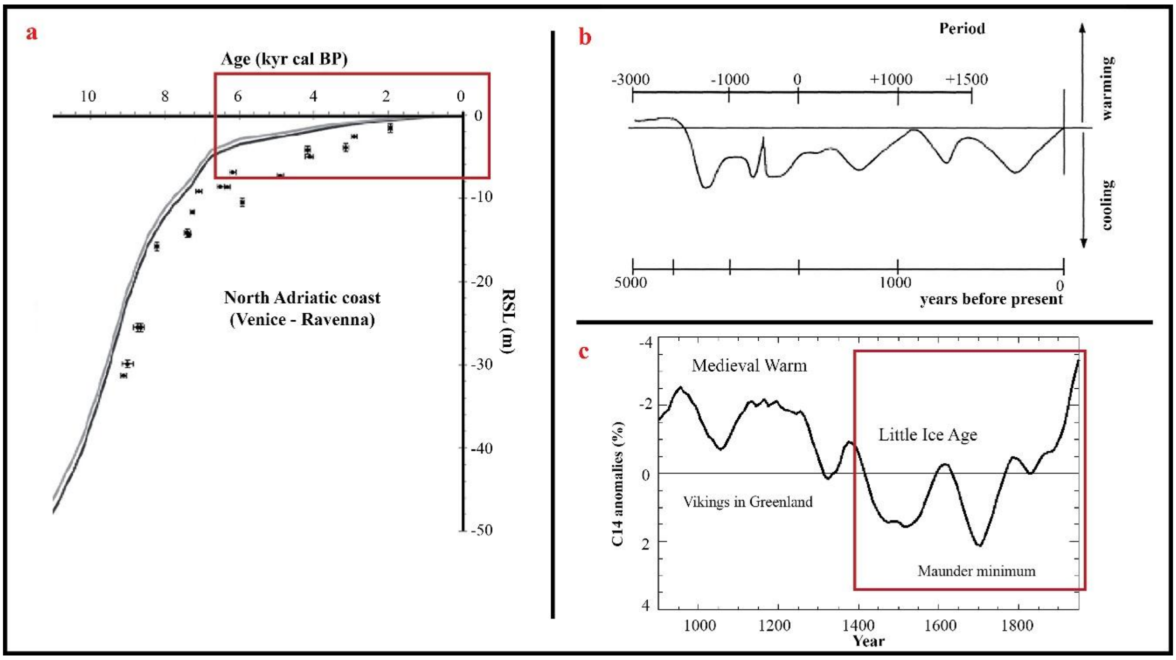

Fig. 1. a) Holocene Sea Level Curve for the North Adriatic (modified from Lambeck et al., 2011). b) Climate variations in Europe in the past 5 ky BP (modified from Betti and Morelli, 1998). c) Changes in ^{14}C concentration in the past 1 ky BP due to solar activity (modified from Svensmark, 2000).

The purpose of this work is to increase knowledge about morphological changes in the Ravenna coastal plain during the LIA period to the present. It was performed by investigating the coastal plain surface using different data sources and the subsurface data using the GPR tool, as was done to study the Holocene evolution in the PCRS, integrating the results obtained with the data from previous work done in the Ravenna coastal plain.

The final aims of this paper are: i) integrate the past work on coastal evolution of the zone with new tools, to investigate the subsurface, increasing the knowledge of the recent coastal evolution in the Ravenna coastal plain, during the last four centuries; ii) investigate the interaction between the natural forces by short to medium time scale climatic changes with the anthropic influence on territory; iii) characterize the subsurface coastal environments, based on the geometry of sediment depositions identified through GPR data; iv) update and increase the local geological skills; v) integrate the territory elements with surface and subsurface geology to reconstruct a potential model about the local coastal evolution without the man-made changes on the territory, providing a frame on the recent coastal evolution, to increase the knowledge about how the territory evolved, to show the importance of this knowledge for the ICZM work in all barrier-lagoon systems, to aid the decision makers with decreasing coastal vulnerability and lost economics.

2. Previous work

The Ravenna coastal plain has been well studied and documented in the literature, the Po Plain evolution has been studied and reconstructed in different temporal–spatial scales, providing an indispensable framework for this paper. The sedimentary evolution was identified with a regressive trend where two main cycles are present, marine (Qm) and continental (Qc) (Ricci Lucchi et al., 1982). Lower discontinuities were identified as inner Qm and Qc, which allowed recognition of the depositional sequence with inferior order as they are organized in different hierarchy orders (Amorosi and Farina 1995; Amorosi et al., 1998, 1998a, 2001; Farabegoli et al., 1997; Marabini et al., 1987).

In the Ravenna coastal plain, the first subsurface studies were done using drill hole data, which have allowed identification and building, with accurate data, the Holocene transgressive–regressive cycle and recognition of the coastal environments, characterizing the barrier-lagoon local system (Bondesan et al., 1995; Rizzini, 1974; Veggi and Roncuzzi, 1973; Veggiani, 1973). These works were complemented with recent works, through the drill hole data in the area, allowing increasing the resolution of coastal evolution, which were used to elaborate the Geological Chart in the Ravenna coast on a scale of 1:50,000 and others' work (Amorosi et al., 1996, 1999, 1999a, 2005).

The first works on the Ravenna coastal plain were mainly to investigate the geomorphology in the zone, starting in 1960 until the present (Amorosi, 1999), and to correlate the climatic changes with the regional coastal evolution (Stefani and Vincenzi, 2005). These papers characterized the geomorphological evolution due to natural forces and man-made changes, and due to the interaction between them, which were intense after World War II (WW II) (Bondesan, 1985; Castiglioni et al., 1990; Ciabatti, 1966, 1990; Colantoni et al., 1990; Nelson, 1970; Veggi and Roncuzzi, 1973; Veggiani, 1974). All of these works were done using data in one dimension, and represent an important database for local workers to understand the local barrier-lagoon system behavior.

3. Study area

The study area is in the Ravenna coastal plain (Fig. 2) located in the Po Plain, northwest of the Adriatic Sea in a passive margin and in an epicontinental basin (Ridente and Trincardi, 2005). The north part of the Adriatic Sea extends about 300 km, has a continental shelf with low gradient of about 0.002° (Storms et al., 2008), and is very shallow (<50 m) (Bever et al., 2009). The actual coastal system is characterized by sand beaches, with average 70 m width and low slope, about 0.03°. The dunes' height, when they are present, is between 1.5 m and 3 m and the entire territory in the study area has a low elevation above RSL; the mean maximum topographic height is about 1.5 m above the RSL (Armaroli et al., 2012).

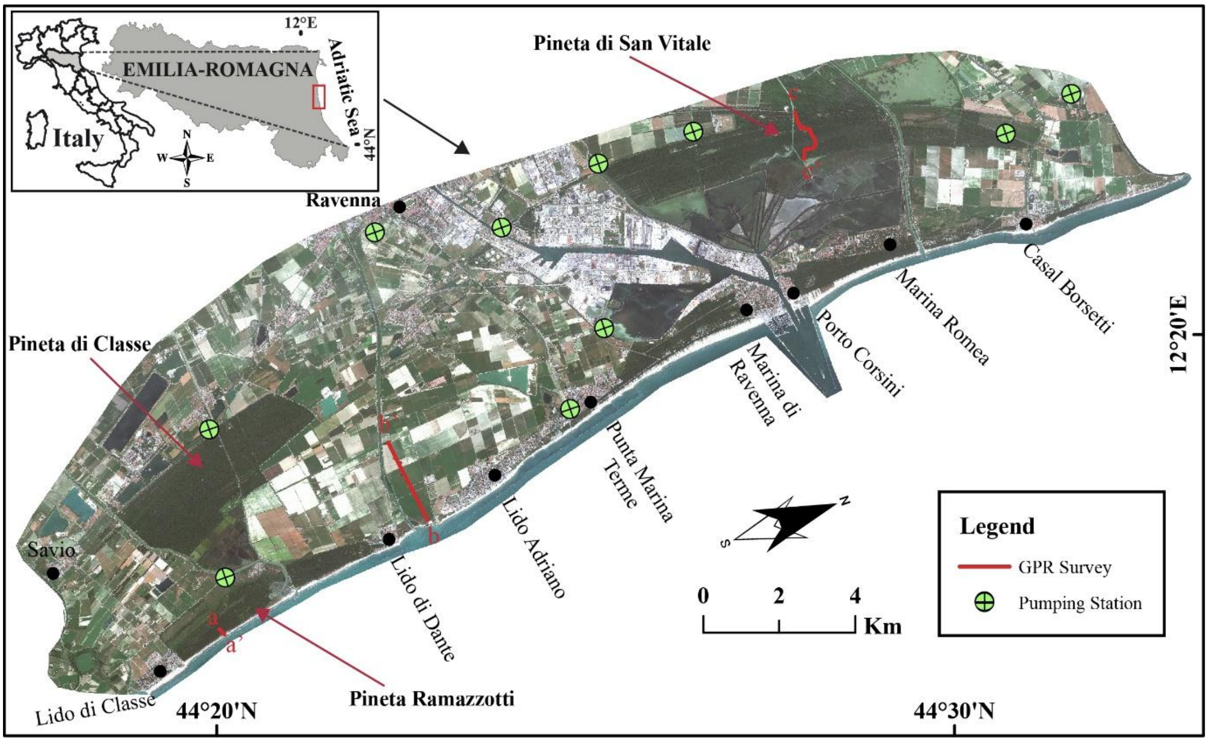

Fig. 2. Study area showing the Pinewoods (*Pineta*), the location of the drainage pumping station, and the GPR survey location in the Ravenna coastal plain.

According to Amorosi et al. (1999, 2008) at the end of the LGM, 18 ky BP, the continental shelf emerged, with Alps and Apennines rivers that formed the Po river drainage basin; during the Transgression System Tract (TST) from 14.5 to 5.5 ky BP the continental shelf was submerged. When the High Stand Tract (HST) started 5.5 ky BP, the shoreline was about 20 km inland from the present location. In the last 6 ky, when the sea level rise rate started to decrease (Fig. 1a) (Betti and Morelli, 1998; Lambeck et al., 2011), the normal regression began, with river mouths and beach ridges (beach ridges definition used according to Otvos (2000)) having had a significant progradation, creating the actual deposition structure of the Po Plain.

During the Holocene, the LIA was responsible for changing the deposition trend (Brázdil et al., 2005) conditioning the actual Ravenna coast morphology, through an increase of Apennines river solid transport where their deltas have had a high progradation rate, tens of meters per year (Grove, 2001). Because of climatic improvement at the beginning of the 19th century (Fig. 1b) the coastal dynamics were changed and the river deltas began to erode, going from river-dominated deltas to wave-dominated deltas *sensus* Galloway (1975) (Corregiari et al., 2005a). The existing local morphology is the result of a delicate balance between natural coastal dynamics and anthropic changes in the last few centuries; also, the man-made changes were fundamental to drive the coastal evolution in this area (Stefani and Vincenzi, 2005).

The Ravenna coastal plain and the whole Po Plain are subject to subsidence due to natural factors, by the Plio-Quaternary sediment compaction and due to anthropic factors by subsoil fluids exploration (Bondesan, 1989; Brunetti et al., 1998; Carminati and Martinelli, 2002; Gambolatti et al., 1999; Teatini et al., 2006). Today, the subsidence rate (anthropogenic plus natural) in the study zone is about 10 to 12.5 mm/y according to the ARPA (Regional Environment Protect Agency) Geodetic leveling survey, with an 18.5 mm/y rate peak in Lido di Dante coastal town (Taramelli et al., 2014).

Together with high progradation on the zone in the 19th century, man-made changes on territory for their own use began. The main changes were lagoon and swamp reclamations for agricultural exploitation with drainage channels being built; for harbors and sighting towers to be built (Cencini, 1998; Piastra, 2011); and adjusting and driving the river flow since Roman times (Petrini et al., 2014). To maintain the land reclamation in the Ravenna coastal zone, a complex drainage system is present that is linked with channels and a pumping station system (Fig. 2), where are present 10 pumping stations maintain the territory reclamation (Mollema et al., 2013). The human interventions during several centuries have eliminated the real morphology above the territory (Cencini, 1998), making it difficult to characterize the old natural morphology. Even so, sets of foredune ridges covered by man-made pine groves are present in some parts of the territory in the Pineta zone. Today, the coastline is mainly characterized by sandbanks and littoral bars, in many case connected with littoral spits growth, which create a barrier-lagoon system that was reclaimed, reducing the lagoon area extension (Bondesan, 1990).

After WW II, human action in the Ravenna coastal plain was intensified. These actions were responsible for increasing the exploration of potential coastal economics, resulting in high urbanization on the entire territory (Martinelli et al., 2011). Actually, the Ravenna coastal plain has an erosional trend (Bondesan et al., 1989; Gambolati et al., 1998; Harley and Ciavola, 2013; Martinelli et al., 2011). Because of this local erosion trend, the local authorities built groins and breakwaters along the coast to contain this erosional trend, changing the coastal system dynamics (Armaroli et al., 2012). Moreover, human interventions on the rivers that reach the Ravenna coast, through dam construction, have interfered with the rivers' rates of sediment transport, affecting the natural coast erosion–deposition equilibrium (Antonellini et al., 2008; Martinelli et al. 2011; Piastra, 2011).

Actually, the coastal sediments' transport in the zone is dominated by waves generated in the open sea; the prevalent wave direction is from the NE, being responsible for the littoral drift dominance from south to north (Gambolati et al., 1998). However, in the north part of the study area, the littoral drift is from north to south, creating a "zero point" that coincides with Ravenna's port (Gambolati et al., 1998; Preti et al., 2009). The tidal regime is microtidal, where the neap mean range is about 30–40 cm and the spring mean range is about 80–90 cm (Armaroli et al., 2012); the currents generated by the tide are insignificant for the littoral drift (Gambolati et al., 1998).

4. Material and methods

To investigate the recent coastal evolution in the Ravenna coastal plain, different source data on the Geographic Information System (GIS) environment were integrated to increase the knowledge about the zone from the 16th century to the present day. In the GIS environment, it has been possible to integrate the different data sources and represent the results and the satellite imagery WordView-2 2011 was used as the base image. Combining the surface data obtained in this work with the subsurface data from GPR has allowed an increase in the knowledge and obtaining of a valid coastal evolution model for the study area.

4.1. Surface data

The surface analyses were done using different data sources. The historical cartography from 1690, 1713, 1757, and 1868 provide important territorial information about the geomorphology history and the man-made changes on the territory, on a century time scale. The historical data were used to gain a valid qualitative representation of the local coastal and morphology evolution (Bishop et al., 2012; Piastra, 2011).

In addition, a high-resolution digital surface model (DSM) from 2005 and a digital terrain model (DTM) from 2014 in .ascii format (generously provide by ENI–It) georeferenced using the DATUM UTM Zone 33N (ETRF00) were used as well as all data elaborated in the GIS environment, the vertical values were referred to the mean sea level. These data were obtained from a LIDAR survey with 1 m × 1 m cell size, which were used for the morphology investigation. The DSM from 2005 was reclassified in ESRI-ArcGIS® software in four altimetry classes to associate with the other data used in this work. The four classes were: i) terrain **Under RSL**, using the values below 0 m; ii) **RSL** terrain level from 0 to 0.5 m; iii) **Above RSL**, from 0.5 to 7 m; iv) the altimetry **Above 7 m**. The DTM from 2014 allows identification of the crest and cave morphology to map the beach ridges, where pinewoods exist above the beach ridges. In these data, the Pinewoods have been filtered to show the terrain. To aid the digitization of the beach ridges identified in the DTM data, seven topographic classes were defined to give a better visualization of the beach ridges on the DTM data. This definition was done in the GIS environment, and these classes have been chosen from the topographic profile following the methodology in Fig. 3 to identify the crest and caves that characterize the beach ridges. The values above 1.4 m represent the beach ridge crests and the values below 1.4 m between the crest represent the cave. The high resolution of the DTM data allows use of the decimal centimeter to represent the classes. After that, the beach ridges have been digitized in ArcGIS® and were called **DTM Beach Ridges**.

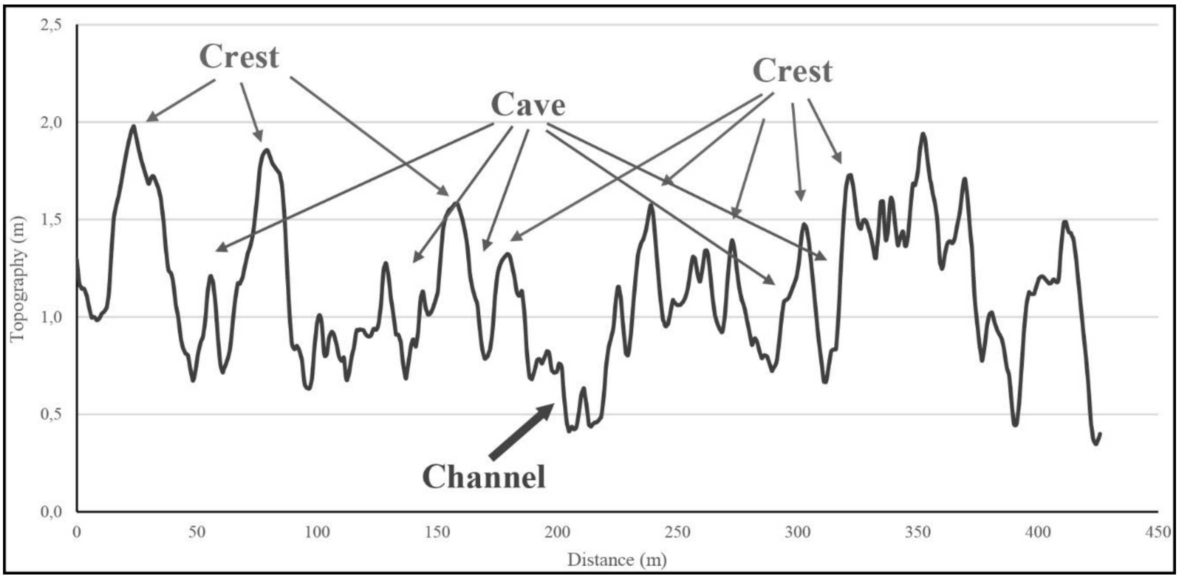

Fig. 3. An across profile from DTM 2014 showing the topographic differences that allow identification and digitization of the beach ridges.

The surface shapefiles of the geology elements from the 1:50,000 geological chart, soil units chart at 1:50,000, and soil-type catalogue were downloaded from the Emilia-Romagna Region WEBGIS Portal (I suoli dell'Emilia-Romagna, 2015; Regione Emilia-Romagna, 2015). The elements from the shapefile were overlapped between them and between DSM and DTM, to confirm the territorial information.

A new soil association was done using the soil-type catalogue, using all soil associations present in the Ravenna coastal plain. This association was done in the GIS environment to facilitate the visualization of the presence of the sand soil and mud soil in the Ravenna coastal plain, and to aid the territory interpretation. In this work, the soil association done by the Emilia-Romagna Region has been reclassified into three new soil association classes based on the sand, mud, and clay concentration (Table 1). The three classes proposed are: i) **Sand Soil**, where sand soils, named by Geology, seismic, and Emilia-Romagna Survey as Cerba fine sand (CER1); Cerba fine sand with superficial organic horizon (CER3); Cerba loam sandy with high contents of carbonate (CER4); San Vitale fine sand (SAV1); San Vitale loam sandy with high contents of carbonate (SAV3); and Pirottolo fine loam sandy (PIR1) were present; ii) **Mud Soil**, with Galisano loam clayey silt (GLS2); Galisano clayey silt to silt and sandy substrate, in coastal plain (GLS3), Marcabò loam silt (MCB1), Savio loam silt (SVO1), Roncole Verdi loam clayey silt (RNV1), Sant'Omobono loan silt (SMB1), Villalta loam sand very fine (VIL1), soils composed mainly by mud and clay on the upper horizon; and iii) **Mud and Sand Soil**, where in the soil association done by Emilia-Romagna Region soils with sand and mud (the supplementary material presents a representative soil-type profile for each soil type cited above to show the pedogenesis) are present.

This new association allows comparison of the pedogenesis with the morphological elements present on the charts to corroborate the coastal model proposed without the man-made changes. Table 1 shows the percentage of sand, silt, and clay extract from a representative soil profile for each soil type in Emilia-Romagna obtained from Geology, seismic, and soil Emilia-Romagna Survey data catalogue (I suoli dell'Emilia-Romagna, 2015).

Table 1

Proposed soil association, divided into Sand Soil and Mud Soil. The table shows the horizons' depth and the percentage of sand, silt, and clay obtained from a representative soil profile.

Soil association	Soil Acronym	Depth - cm (from - to)		Sand (%)	Silt (%)	Clay (%)
SAND SOIL	CER 1	0	60	96	3	1
		60	80	98	2	0
		80	110	99	1	0
		110	120	99	1	0
	CER 3	0	3	93	5.5	1.5
		5	10	91.3	6.9	1.8
		15	30	94.5	4.8	.7
		40	80	98.2	1.3	.5
		90	115	99.5	.3	.2
	CER 4	0	40	76.6	12.6	10.8
		40	50	79	13.5	7.5
		50	80	82	9	9
		80	110	88.4	7.1	4.5
	SAV 1	3	17	91	6	3
		17	60	95	5	0
		60	100	95	5	0
	SAV 3	10	35	97.8	1.2	1
		40	70	97.5	.7	1.8
		90	120	98	.3	1.7
		130	160	97	2.2	.8
	PIR 1	0	20	81	9	10
		20	60	93	1	6
		60	70	94	1	5
MUD SOIL	GLS 2	0	50	2	60.2	37.8
		50	90	.5	55.5	44
		90	140	1.3	58.7	40
		140	160	4.6	75.4	20
	GLS 3	10	40	3.3	49.9	46.8
		70	100	1	45.2	53.8
	MCB 1	0	50	20	52	28
		50	70	17	54	29
		70	90	7	62	31
		90	110	6	68	26
		110	140	9	70	21
	SVO 1	10	35	17.5	61.5	21
		55	65	22.2	64.1	13.7
		75	85	86	8	6
		110	130	93	5.5	1.5
		140	145	11.7	73.5	14.8
	RNV 1	0	65	14	49	37
		65	85	14	39	47
		85	100	12	45	43
		100	130	16	55	29
	SMB 1	0	50	6	72	22
		50	75	3	71	26
		75	105	5	73	22
		105	150	7	79	14
	VIL 1	0	50	58.3	28.9	12.8
		50	80	60.5	27.8	11.7
		80	120	89.3	7.5	3.2
		120	150	12.5	71	16.5

To validate and confirm the correspondence between bibliography data integration and the results from data elaboration about the beach ridges, a field visit was undertaken. The field trip allowed obtaining real information about the territory, investigating the morphology that is present in the Pineta zone, and the pedogenesis of the terrain to compare with the obtained data. This information allows linking the beach ridges/foredune ridges with the zone where it is present in the sand soil and the lagoon environment with the zone where it is present as mud soil. This was done to investigate the morphology that is present in the Pineta zone and based on the pedogenesis of the terrain.

4.2. Subsurface data–GPR

The GPR data were acquired along profiles (Fig. 2) using a COBRA PLUG-IN GPR (with UNIT, Control Unit, and SUBECHO Antenna model SE-70) data acquisition by Radarteam Sweden AB, using a transmitter and receiver antennae with 80 MHz center frequency in Common Off-set arrangement; and a COBRA Wi-Fi two channel (250–500 MHz) produced by Radarteam Sweden AB. To locate the profiles, the GPR had an integrated Global Navigation Satellite System (GNSS). The dielectric constant for sand (6), that represents a velocity of 0.15 m/ns (Daniels et al., 1995) as was validated by lithological data obtained from existing drill holes on the Ravenna coastal plain. The GPR data obtained were elaborated using two software programs, RADAN™ 7 and Prism® 2.6. The interpretation of the data was based on the seismostratigraphic method adapted for GPR data (Neal, 2004), identifying the radar facies and the termination pattern of reflectors and geometry (Mitchum Jr. et al., 1977; Vail, 1987).

5. Results

The results from the surface data are represented mainly using illustrated maps, which allow overlap of different data sources and elaborate the geological surface model without man-made changes in the Ravenna coastal plain. The reclassified DSM (Fig. 4A) shows the low topographic in the zone and the beach ridges digitized from the geological chart. The zones inside the class Under RSL and RSL actually are occupied mainly by agricultural fields, the class Above 7 m is due to the presence of the pinewood zone, river embankments, and constructions in the coastal towns. The geological elements were overlapped showing the paleobeach ridges. Using the classification in this work that subdivides the beach ridges from the geological chart and were called Sand beach ridges (the beach ridges identified above the sand soil) and Mud beach ridges (the beach ridges identified above the mud soils), also their localization was correlated with the DSM classes. The DTM (Fig. 4B) allows identification of the beach ridges that are not mapped in the geological chart due to the nonappearance of territorial elements in the DTM data, such as settlements, pinewoods, and constructions. These beach ridges have been digitized to complement the information about the surface geological elements in the Ravenna Coastal Zone.

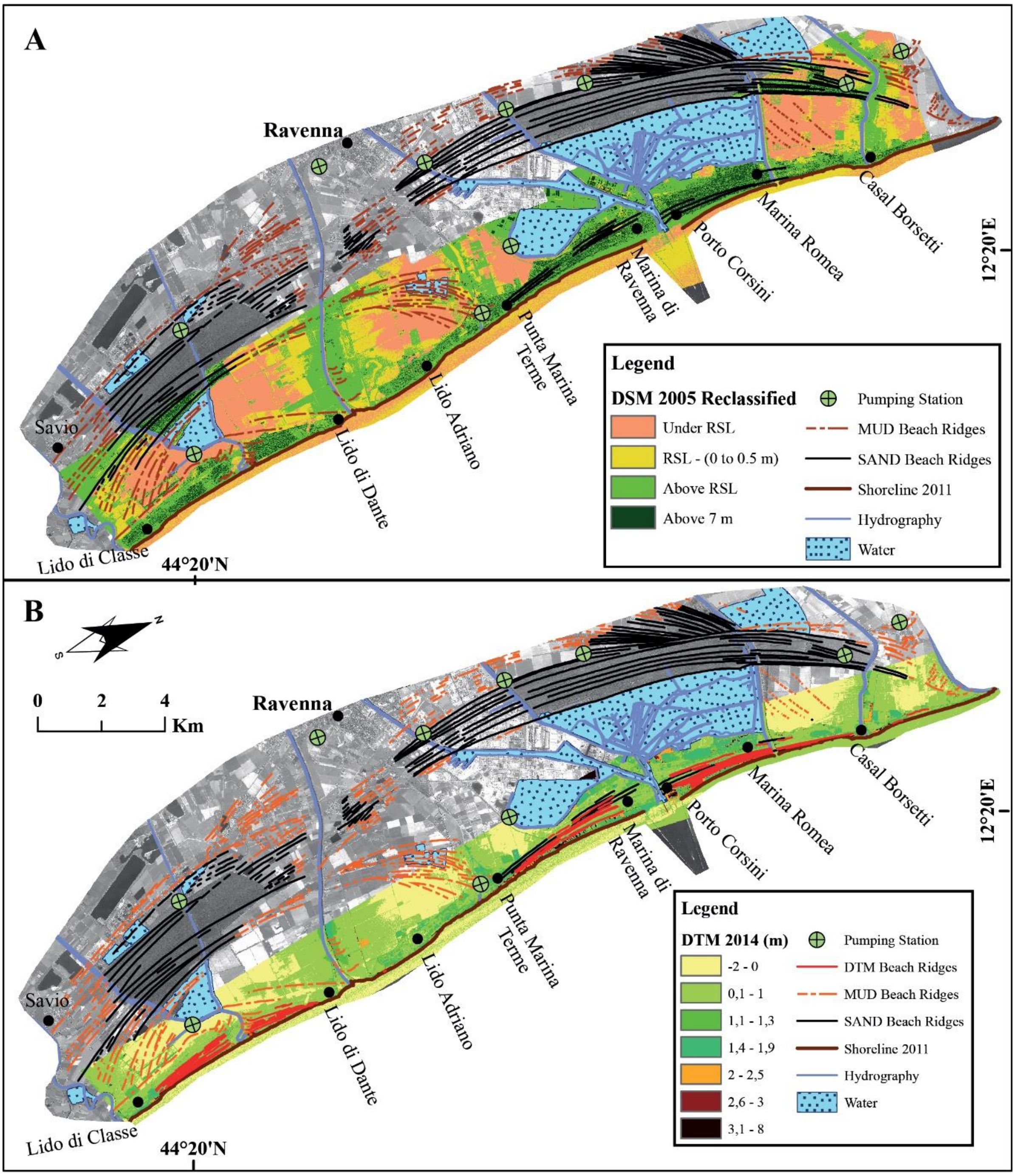

Fig. 4. A) The DSM 2005 reclassified with the beach ridges above the sand soil and above the mud soil. B) The DTM 2014 reclassified with the beach ridges above the sand soil and above the mud soil, plus the beach ridges identified and digitized from the DTM data.

The new soil association proposal that was derived from the Emilia-Romagna Region soil chart (Fig. 5A) and where 14 soil associations and 13 different soil types are present. In Table 1, the two classes subdivided in sand soil and mud soil are presented; this classification has been done based on the percentage of the content of sand, mud, and clay in each soil type. The 14 soil associations were grouped in a class with sand soil (CER1, CER3, CER4, SAV1, SAV3, and PIR1) called Sand Soil; and in a class with mud and clay soil (GLS2, GLS3, MCB1, RNV1, SMB1, SVO1, and VIL1) called Mud Soil, the waterbodies are represented as CA. This allows subdivision in the three cited classes in the Methods section and they are represented in Fig. 5B. A class that is called Mud and Sand Soil has been created to incorporate a soil association that contains the present SVO1, MCB1, and CER1 soil types.

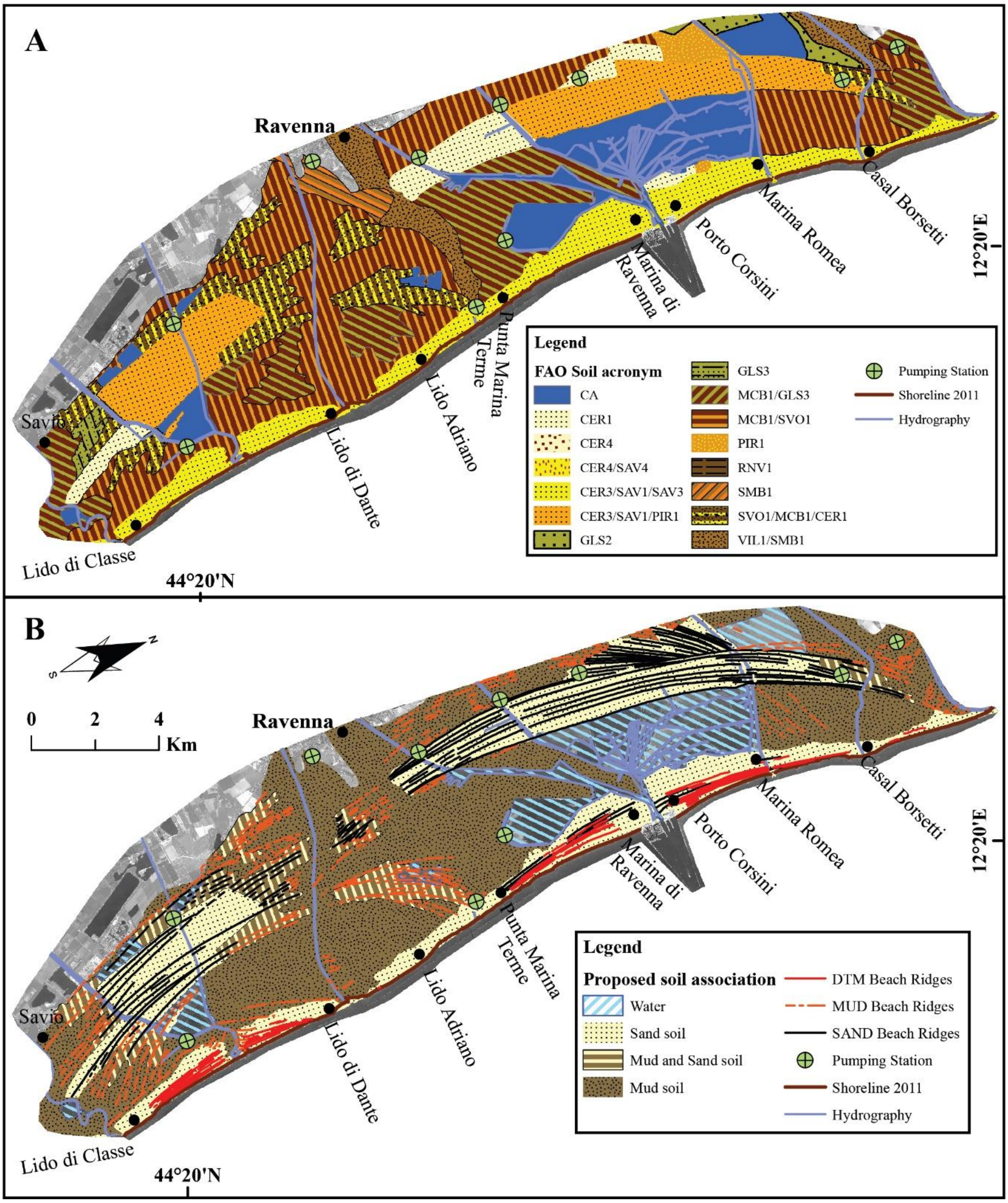

Fig. 5. A) The soil association from Regione Emilia-Romagna with the 14 soil associations. B) The reclassification of the soil association with the three classes proposed in this work.

For the subsurface, analysis was done using a GPR profile (Fig. 2) across the Ravenna coastal plain, to find the depositional geometry and to corroborate with the surface model proposed in this work. This is the first attempt to acquire the two-dimensional subsurface data in the study area. The profiles are concentrated in the Pineta Ramazzotti (profile a–a′), Pineta di San Vitale (profile c–c′), and in the agricultural fields between Lido di Dante and Lido Adriano (profile b–b′). The results are represented in the radargram obtained during the survey. For the Pineta Ramazzotti, the profile acquisition was done using the COBRA Wi-Fi 2 channel (250–500 MHz) with a close acquisition window to investigate the low deep deposition (max. 6 m). This radargram allows identification of two radar facies that are interesting for this work (Fig. 6): the radar facies A that represents the backshore/foreshore facies from 0 to –2.5 m, where the depositional geometry are continuous and with low-angle reflectors; the radar facies B the upper shoreface facies, from –2.5 to –5 m, where it is possible to see a depositional geometry with subparallel, low-angle, continuous, and undulate reflectors (Barboza et al., 2011; Dillenburg et al., 2011; Rosa, 2012). The arrows in Fig. 6 show the progradation in the ocean direction, which represents a coastline regression. This profile has been done where the Sand Soil association is present.

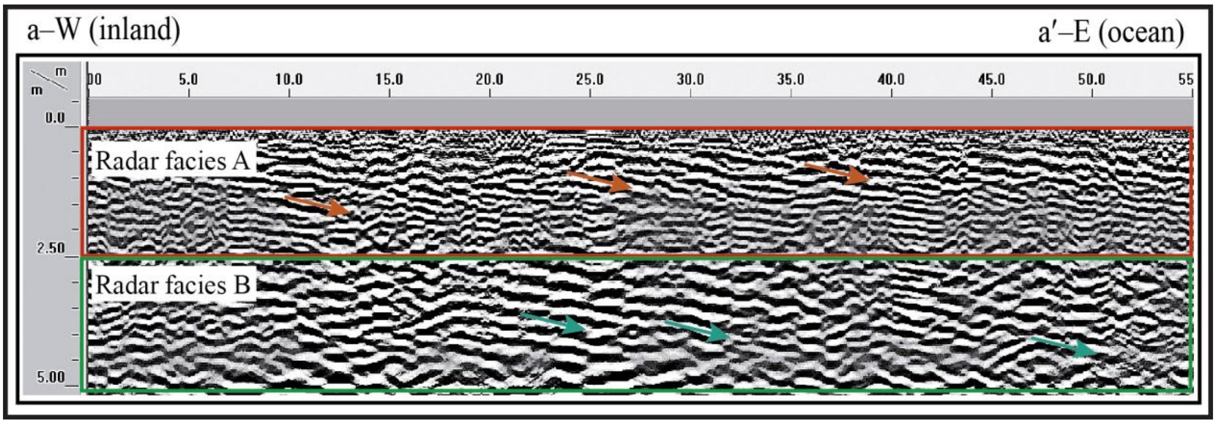

Fig. 6. A sample of the GPR profile done in Pineta Ramazzotti showing two radar facies identified as backshore/foreshore (radar facies A) and upper shoreface (radar facies B).

The profiles b–b′ and c–c′ were done using the COBRA PLUG-IN GPR with 124 MHz central frequency to gain more signal penetration. The radargram sample for the profile b–b′ (Fig. 7), acquired in the agricultural fields, where the Mud Soil association is present, does not show depositional geometry, and the surface signal is dissipated. The GPR signal is attenuated, and this attenuation is due to the mud, clay, or silt present in the terrain, which are impermeable to the GPR signal (Neal, 2004; Rosa, 2012). This radar facies is typical of the lagoon depositional environment (Rosa, 2012).

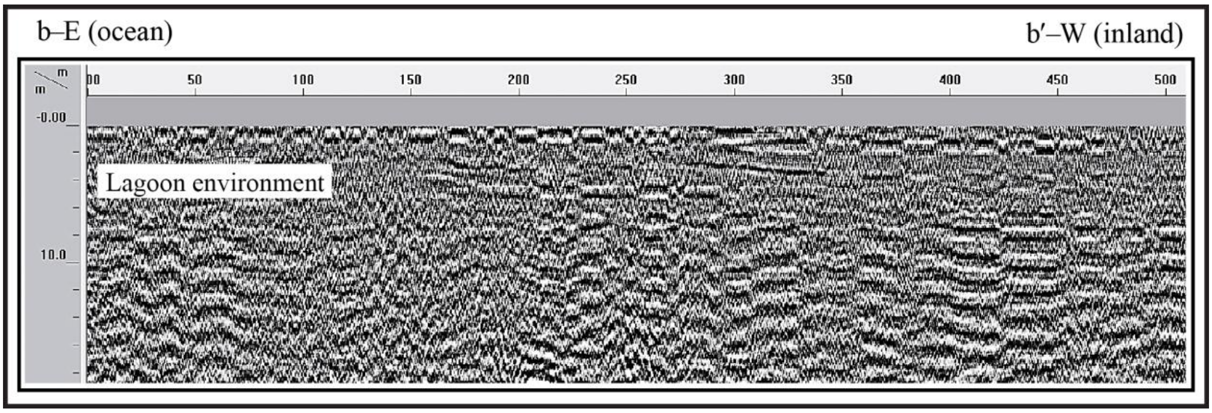

Fig. 7. A sample of the GPR profile done in the agriculture fields between Lido Adriano and Lido di Dante, showing the signal attenuation without depositional geometry. This radar facies was interpreted as a lagoon environment.

The profile c–c′ was done in the Pineta di San Vitale (Fig. 8) where the Sand Soil association is present and the beach ridges are mapped from the geological chart. This profile has in the shallow subsurface a radar facies (A), from 0 m to –4 m that represents the backshore/foreshore with continuous and subparallel reflectors, which represent a backshore/foreshore facies, with a progradation in the ocean direction.

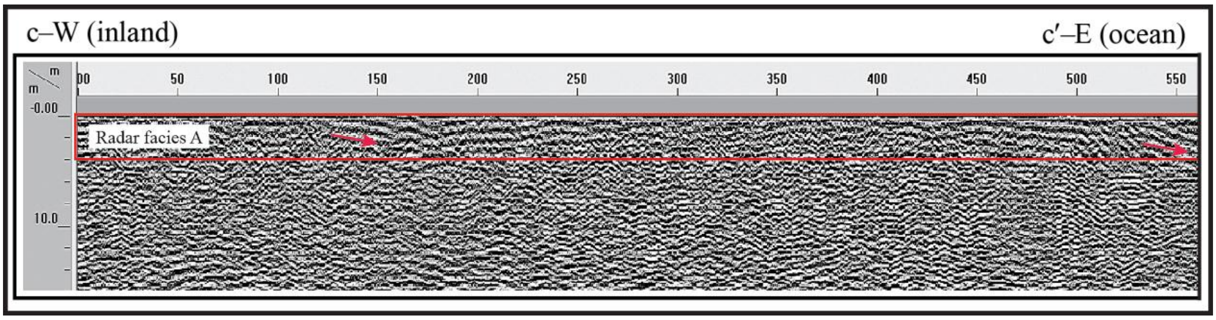

Fig. 8. A sample of the GPR profile done in Pineta di San Vitale, the radar facies A shows the progradation in the ocean direction.

6. Discussion

6.1. Surface data

The results from the DSM 2005 (Fig. 4A) show the importance of maintenance due mainly to the drainage pumping system in this territory (Mollema et al., 2013). Without this maintenance, the

Ravenna coastal plain zone probably would be flooded. These data show the high susceptibly and vulnerability of the territory, because the major part of the zone is below the RSL.

To investigate the geological elements, the DSM data were overlapped to allow identification of the morphological divergence between the data from DSM and the data from the geological chart. The presence of beach ridges (in the legend as MUD Beach Ridges) in the zones classified as Under RSL, and where reclamations have been done, which were identified using the photo interpretation to construct the geological chart (Amorosi, 1999; Cibin and Severi, 2005). The presence of beach ridges below the RSL may be explained by the local subsidence, but in the north part, between Marina Romea and Casal Borsetti, the zone was reclaimed between the years 1912–1935 and 1961–1965 (PRG, 2003) and actually, the soil association is similar to the soil association existing behind Lido di Dante and Lido Adriano. Before the reclamation, the north zone was flooded; due to the similarity of the soil associations, it is possible to consider the genesis of the zone between Marina Romea and Casal Borsetti to be similar to the zone behind Lido Adriano and Lido di Dante, where the Mud Soil class is present. Moreover, the succession of beach ridges that may be observed in the geological chart may be interpreted as a progradating strand plain and this is not true.

Near the actual coastal zone, beach ridges are present and easily identified on the field or using aerial photos; they have not been altered by human activity and they were not mapped on the geological chart. The beach ridges morphology near the shoreline are present in the terrain and they are below the pinewoods forest. These beach ridges are similar to the beach ridges identified in the Pineta di San Vitale and Pineta di Classe that were represented as SAND beach ridges in the maps (Fig. 4A, 4B, and 5B). The DTM 2014, which filtered the pinewoods to build the DTM 2014 allow identification and mapping of these beach ridges near the coast (Fig. 4B), increasing the detail of the morphological elements mapped in the Ravenna coastal plain.

The field visits along the Po and Ravenna coastal plain aided building these hypotheses. Observing the soil pedogenesis, in the zone behind the Pineta Ramazzotti, the soil is greatly altered by agriculture but is constituted mainly by agglomerates of mud and clay (Fig. 9A). They are different if compared with other beach ridges also mapped in the geological chart inside an agricultural zone, which does not have a beach ridge morphology preserved, but the pedogenesis of this reworked soil is mainly constituted by sand, confirming the presence of the beach ridges (Fig. 9B).

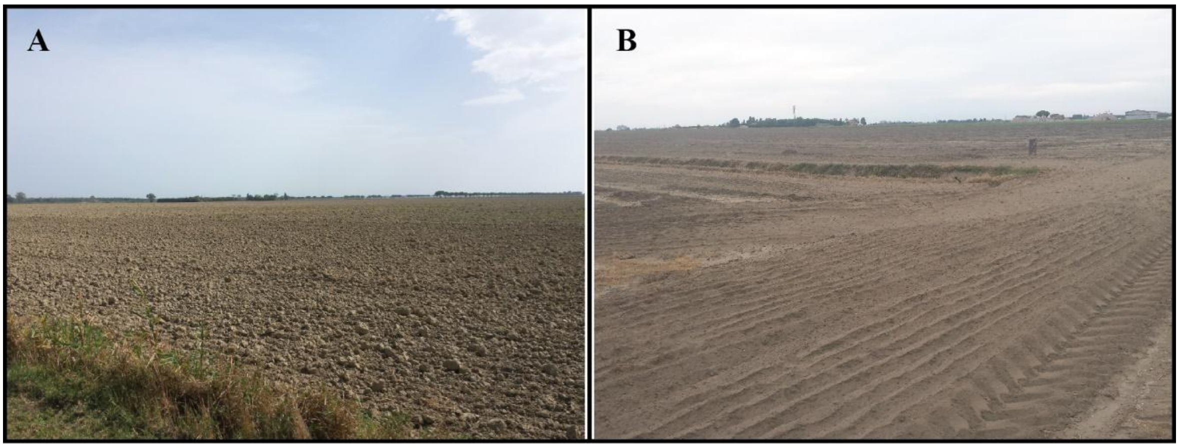

Fig. 9. Photos of the soil, which was mapped as beach ridges in the geological chart. A) The agglomerates of mud and clay in the agricultural field that were mapped as beach ridge in the geological chart not corresponding with the beach ridge pedogenesis. B) A sand soil in an agriculture field corresponding to what was mapped as beach ridges in the geological chart.

Because of these field observations, the classification of the soil chart in sand and mud classes (Fig. 5B) was done to associate with the geological elements from the geological charts. This association allows linking the pedogenesis of the territory with the beach ridges, corroborating the purpose in this work, which does not consider the beach ridges that are present in the zone where the Mud Soil or Mud and Sand Soil classes are present. Where the class Mud and Sand Soil is present, it was considered a spit, which may be the exit of a beach system but without the beach ridges because this is not clear on the territory. The soil association done in this work was associated with the DSM 2005, overlapping the data (Fig. 10). This data combination shows the Mud Soil corresponding with the classes Under RSL and RSL level; the Sand soil near the coast corresponds with the terrains where the topography is Above RSL.

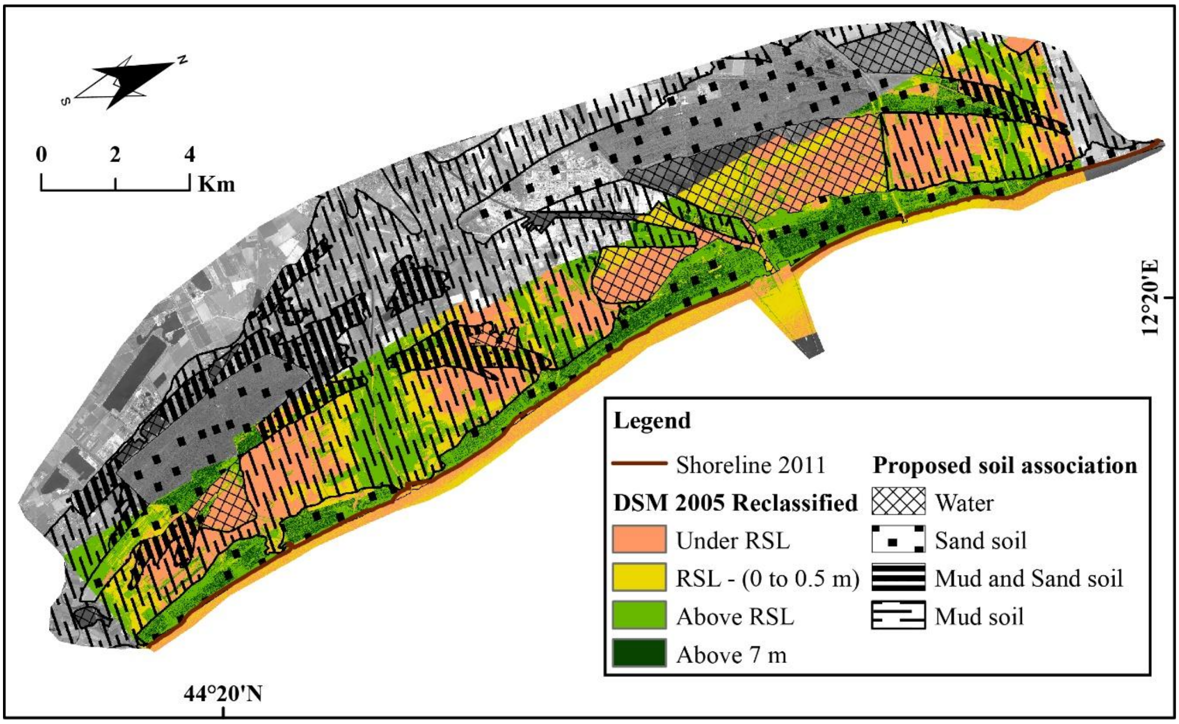

Fig. 10. The three soil association classes overlapped on the reclassified DSM from 2005.

In addition, historical charts were used to corroborate the conclusions about LIA changes in the study area. The charts show the river delta's dominance and the shoreline behavior during the 17th and 18th centuries, passing to a wave-dominance delta according to Galloway (1975) (Fig. 11). The historical charts indicate that this zone is not a progradating strand plain, and a water body's presence behind the coastline may be observed. Moreover, the historical charts show the man-made changes on the territory with the pinewoods and the lagoons that were reclaimed.

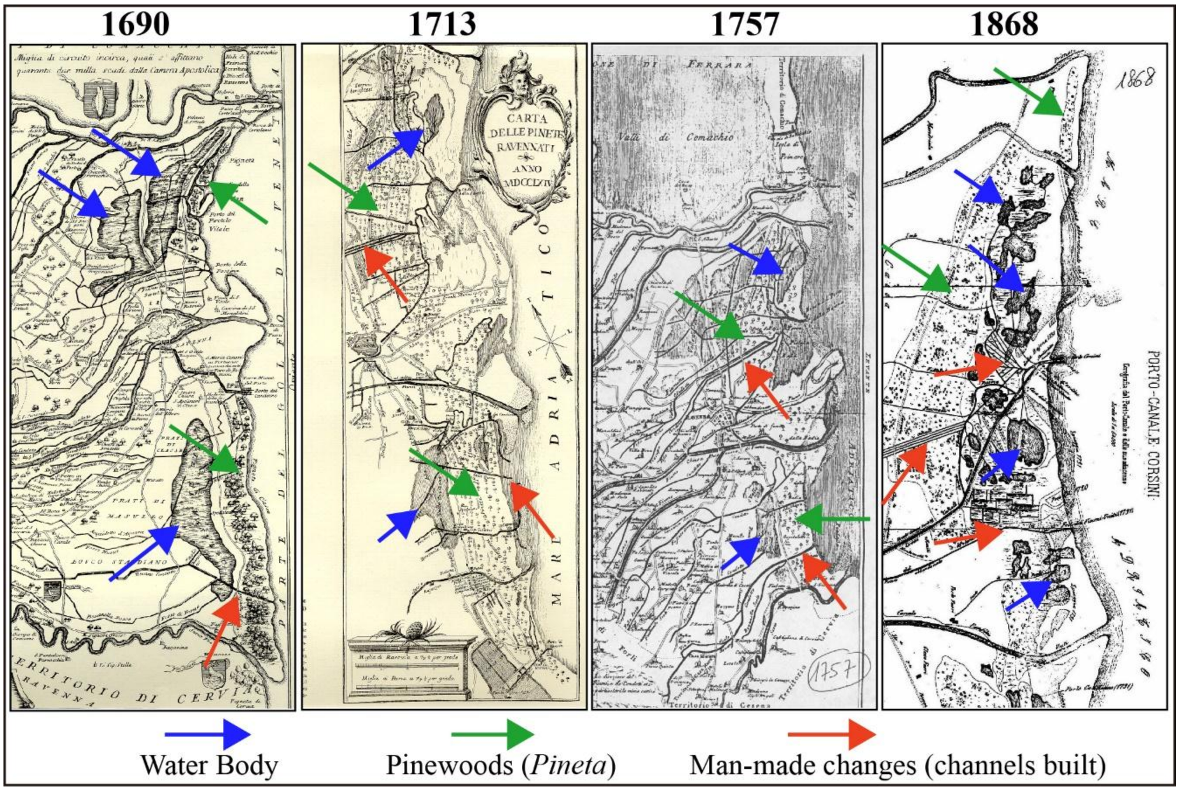

Fig. 11. Historical charts from 1690, 1713, 1757, and 1868. The colored arrows indicate the presence of water bodies, pinewoods, and channels built by man in the last four centuries.

6.2. Subsurface data

The result from the GPR profiles shown in the Results section gives an important basis to build the recent coastal evolution model in the Ravenna plain, and to understand how the territory was without the man-made changes. The profiles done in Pineta Ramazzotti (a–a′) and Pineta di San Vitale (c–c′) correspond with the sand soils association. These two profiles (Fig. 6 and 8) have the backshore/foreshore radar facies, and in the profile it is possible to identify the upper shoreface radar facies that represent a system progradation in the ocean direction. This progradation indicates a normal regression, if correlated with the RSL, which actually is rising. The system progradation is responsible for the beach ridges formation near the shoreline (the Sand beach ridges mapped from the geological chart and the DTM beach ridges mapped from DTM 2014).

The results obtained in the profile b–b′ (Fig. 7), which was done where the mud soils are present (Fig. 9) was interpreted as a lagoon or swamp environment. The GPR response and the data obtained are the data expected for this zone, and in the coastal environments, this GPR response may be correlated with the zones where a mud and clay deposition are present that is the typical deposition of lagoon environments (Rosa, 2012).

In the Pineta di San Vitale (profile c–c′), the geometry of the reflectors in the radar facies (A) (Fig. 8), indicates a coastal barrier depositional system with low energy. The GPR data of the Pineta di San Vitale indicate the presence of another coastal barrier depositional system in the Ravenna coastal plain.

Combining these GPR profiles, it is possible to corroborate the hypothesis about the local coastal evolution model using the surface data in the Ravenna coastal plain. The subsurface data show a progradating barrier, where the Pineta Ramazzotti and the coastal towns are located; a reclaimed lagoon environment where the agricultural fields in the Ravenna coastal plain are present; and an older progradating barrier that is located in the Pineta di Classe and Pineta di San Vitale, characterizing this coastal plain as a typical barrier-lagoon system.

6.3. Data integration

Integrating the results and interpretation of the surface data obtained in this work with the subsurface data from GPR, it was possible construct a surface coastal model for the Ravenna coastal plain without the man-made changes above the territory (Fig. 12A and B). This model demonstrates that the Ravenna coastal plain depositional system is characterized by a barrier-lagoon system with a lagoon environment between two sand barriers. In addition, the inland sand barrier was called the Old Barrier; the sand barrier near the shoreline, where the coastal towns are present was called the Actual Barrier.

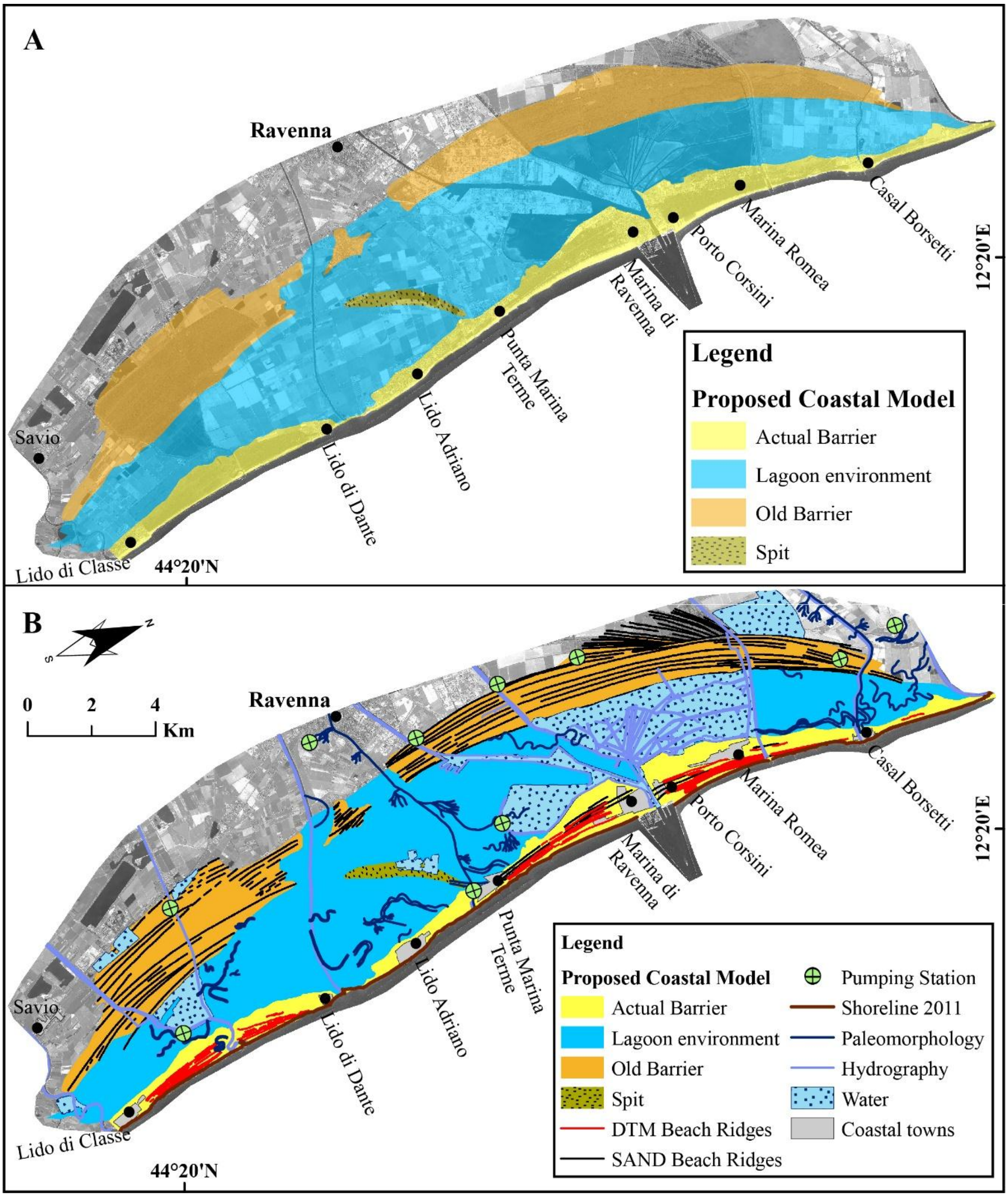

Fig. 12. A) The geological coastal model without man-made changes, with two sand barriers, the Old Barrier and the Actual Barrier, that are separated by a lagoon environment. B) The proposed coastal model with the geological surface elements and only with the beach ridges that are above the sand barriers, and the beach ridges digitized from the DTM 2014.

The Actual Barrier is a sand barrier that was formed when the depositional system came to be wave dominated, after the LIA. The delta's erosion closed the lagoon environment, which was contemporarily modified by man. Moreover, the sediments reworked by the waves were responsible for creating the beach ridges mapped from DTM 2014. This deduction may be corroborated with the GPR profile in Pineta Ramazzotti (Fig. 6), where the high gentle deposition angle, in the backshore/foreshore indicate a low energy for sedimentation, which is due to the wave action. The soil association proposed shows that this actual barrier is in the Sand Soil class, in accordance with the genesis of the beach ridges.

The Lagoon Environment between the sand barriers was formed during the LIA. Actually, this zone emerged due to terrain reclamations (PRG, 2003) that were drained by the drainage system and is occupied by agricultural fields. The DSM 2005 shows that the main area in this zone is below the RSL, the zone above the RSL are the rivers that are elevated to create a gradient for the water flow and to protect the territory against flooding. The soil association in the zone shows that a soil composed mainly by silt and clay is present. The mud and clay agglomerates observed in the field show the local pedogenesis, corroborating this result. The response of the GPR and the radargram in the shallow subsurface is characteristic of lagoon environments. Inside the lagoon environment, which has a Mud and Sand soil association that was interpreted as a spit, may be formed due to a dynamic system change linked with the sediment supply. Because of the extensive man-made changes above the entire zone, it is very difficult to construct the territory elements on a large scale.

The Old Barrier is a sand barrier, and represents the inland lagoon environment margin. The Old Barrier was formed before the LIA. The beach ridges mapped in the zone correspond with the real situation; also combining the mapped beach ridges with the soil association, where the Sand Soil is present, may correlate the beach ridges with the pedogenesis. Moreover, in Pineta di Classe and Pineta di San Vitale the beach ridges’ morphology is preserved below the pinewoods. The two inlets present in the Old Barrier, between Pineta di Classe and Pineta di San Vitale may be explained by the actual hydrology and by the paleomorphology elements from the geological chart 1:50,000. The two inlets were formed by the Ronco and Montone rivers. Actually, these two rivers have a confluence in a river called Fiumi Uniti that arrives between Lido di Dante and Lido Adriano. In this case also, the subsurface data may corroborate the interpretation, due to the presence of the two radar facies that represent the backshore/foreshore depositional system.

The integration of the data used in this work allows review of the geological surface data from the Emilia-Romagna geological chart, and updates the data relative to the beach ridges mapped and to construct the surface coastal evolution model presented in Fig. 12A and 12B.

7. Conclusion

Integration of the surface and subsurface data, obtained using different sources and new technologies increases the knowledge and updates the territorial information about the Ravenna coastal plain. Moreover, this work was the first work that used two-dimensional data, from GPR, to investigate the emerged portion of the Ravenna coastal plain. In this work, the subsurface data contribute to increasing the scientific bases to support the surface geology model without man-made changes proposed for this coastal zone. The GPR data were used following the successful application of this method in other barrier-lagoon systems in the world, such as the PCRS studies. The method contributes to developing more work following this methodology, which is an actual and validated method used by several research groups across the world. In the Emilia-Romagna Region, the applicability of this method may be very interesting due to the high expertise on the geology of this coastal plain and these data may be integrated with the previous work done in the emerged and submerged portions of the northwest Adriatic basin. In addition, this paper may contribute to advancing the two-dimensional subsurface investigation in other barrier-lagoon system studies around the world, updating the knowledge on these systems and contributing to new research in the coastal geology field.

To conclude, the surface data have been used to build the geology surface model proposed in this work, showing the territory modifications after the climatic changes by the LIA, and the extensive man-made changes done in the Ravenna coastal plain. The coastal model gives the basis to do a high-resolution construction of the recent coastal evolution in the Ravenna coastal plain. Moreover, the model is important to aid the local authorities in defining the guidelines for future ICZM applications, indicating the susceptibility and vulnerability, based on the genesis of the area and aiding to plan future territorial occupation. This geology model shows that all coastal towns were built above the Actual Barrier, which is a new barrier formed in the last four centuries, being a more vulnerable environment than other barrier-lagoon systems. In the future, there is a need to integrate more data about the subsurface, to reconstruct a high-resolution stratigraphy model with the beach ridges dating, using accurate methods such as optically stimulated luminescence (OSL). This will be provide a complete model about the Ravenna coastal evolution and will help to improve even more coastal evolution studies in the northwest Adriatic.

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Chapter 3

SEASONAL DUNE AND BEACH MONITORING USING PHOTOGRAMMETRY FROM UAV SURVEYS IN RAVENNA COAST (EMILIA-ROMAGNA, ITALY)

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SEASONAL DUNE AND BEACH MONITORING USING PHOTOGRAMMETRY FROM UAV SURVEYS IN RAVENNA COAST (EMILIA-ROMAGNA, ITALY).

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ABSTRACT

Coastal monitoring is fundamental for studying the behavior of dunes and beaches due to natural and anthropogenic factors. Different tools have been used for these investigations, including LIDAR, satellite images, terrestrial laser scanning, and photogrammetry, allowing both qualitative and quantitative analyses. Particular tools are applied based on the interesting spatial and temporal scales of the coast being studied. In this paper, seasonal coastal change monitoring is conducted using high-accuracy and high-quality photogrammetry acquired via two unmanned aerial vehicle (UAV) surveys, in addition was added data on the strongest winter storm of the 2014-2015 season. The results of these two surveys are compared to identify the changes that occurred on beaches and dunes due to i) man-made changes, such as tourist facilities and winter storm defense construction; and ii) the winter storm, from dune erosion, looking at the magnitude of impact across all coastal zones under study. Moreover, this work shows the efficacy and applicability of photogrammetry from UAVs for coastal work, whether it is a useful technique for scientific studies and authorities to use due to its greater cost/benefit, and whether it contributes to the application of local Integrated Coastal Zone Management.

Keywords: ICZM; dune morphology; beach and dune changes; coastal environment monitoring.

1. INTRODUCTION

Beach and dune monitoring is very important in understanding morphological changes to coastal environments (Ruggiero et al., 2005; Richter et al., 2013), which are in a complex link with natural dynamics and anthropogenic factors (Psuty, 1988; Sherman and Bauer, 1993; Hesp, 2002; Carrasco et al., 2012). In addition, knowledge about morphological changes to the coastal environment has an important application in Integrated Coastal Zone Management (ICZM) (Andrews et al., 2002; Lambert and Zanuttigh, 2005; Davidson et al., 2006; Archetti and Zanuttigh, 2010; Taborda and Silva, 2012; Tătui et al., 2013, Buono et al., 2015), in understanding the causes and driving the actions of stakeholders and decision-makers.

In the beach system, erosion and deposition are the natural responses of sediment dynamics and represent the coastal system's resilience (Woodroffe, 2007; Houser et al., 2015). Major anthropogenic changes occurred on beaches and dunes occur when men began to economically explore this environment by, for example, building harbors for commercial purposes or facilities and settlements adjacent to the coast for recreational and touristic purposes (Gormsen, 1997; Catto, 2002; Helsenfeld et al., 2008).

This coastal anthropization is reflected directly in the sediment dynamics, changing the system's resilience (Woodroffe, 2007). Furthermore, erosion and marine storms have become an economic issue, due mainly to structural damages and loss of land, both of which increase the system's vulnerability (Klein and Nicholls, 1999; Kindermann and Gormally, 2013), as the dunes are a natural source of protection against flooding and erosion (Dissanayake et al., 2014) and may hold back the saltwater intrusion as a point of freshwater table recharge (Saye et al., 2005; Antonellini et al., 2008).

This work uses of photogrammetry from unmanned aerial vehicle (UAV) surveys to monitor coastal zones with high resolution data (Mancini et al., 2013; Casella et al., 2014; Gonçalvez and Henriques, 2015) during the 2014-2015 winter season. As such, this study determines the applicability of using this recent technology for coastal monitoring on a seasonal temporal scale to integrate the results with the data from works that study small and large scale (Sherman, 1995; Larson and Kraus, 1995). The study site is highly influenced by man-made changes due to economics interests as well as by natural factors such as winter storms and relative sea level changes.

Photogrammetry from UAVs allows the generation of a high resolution digital surface model (DSM) and ortho-rectified images to support the scientific monitoring of coastal morphology changes and understand the environment's behavior (Gares et al., 2006). It is a relatively low cost survey method for spatial and temporal monitoring compared to LIDAR survey and satellite images (Casella et al., 2014), which are methods that give high-resolution DSM and orthophoto respectively as the data obtained in this work. However, LIDAR surveys and satellite images are more expansive, thus decreasing the cost-benefit when using a spatial scale of hundreds of meters to kilometers and for a seasonal temporal scale, hampering the survey's repeatability (Gonaçalvez and Henriques, 2015). Repeatability is an indispensable element in effective environment monitoring, whether for scientific studies or ICZM programs (World Bank, 1993; UNEP, 1995; Klein et al., 1999; USAID, 2009).

The main aims of this paper are i) to test and expand the photogrammetry from UAV surveys for the monitoring of coastal environmental behavior in a seasonal scale; ii) to examine both natural and man-made forces on dune and beach morphology; iii) to identify the role of different factors to integrate with other coastal environmental knowledge, such as biology, economics and engineering; iv) to show the importance of maintaining the beach and dune system's natural resilience and decreasing the system's vulnerability; and iv) to provide validated, high-resolution data to support ICZM decision-making.

2. STUDY AREA

The beach-dune system monitoring was conducted in the Ravenna Province Coastal area (Fig. 1) (Emilia-Romagna Region, Italy) on the NW Adriatic Sea, which has 50 km of sandy beaches and a low gradient coast, and is under pressure from natural and anthropogenic factors (Bondesan et al., 1995; Gambolati et al., 1998; Perini et al., 2007; Vicinanza et al., 2009; Armaroli et al., 2013; Taramelli et al., 2014b). After World War II, a heavy anthropization began in the zone, with a tourism economy boom as a main factor, along with simultaneous heavy urbanization behind the shorelines, with new settlements constructed as holiday homes (Cencini, 1998). Along the coastal territory, dune ridges were fragmented and flattened in order to build fixed beach establishments called "*bagni*" (Martinelli *et al.*, 2011). From 1892 until 2006, 50% of foredune ridges were damaged (Antonellini et al., 2008).

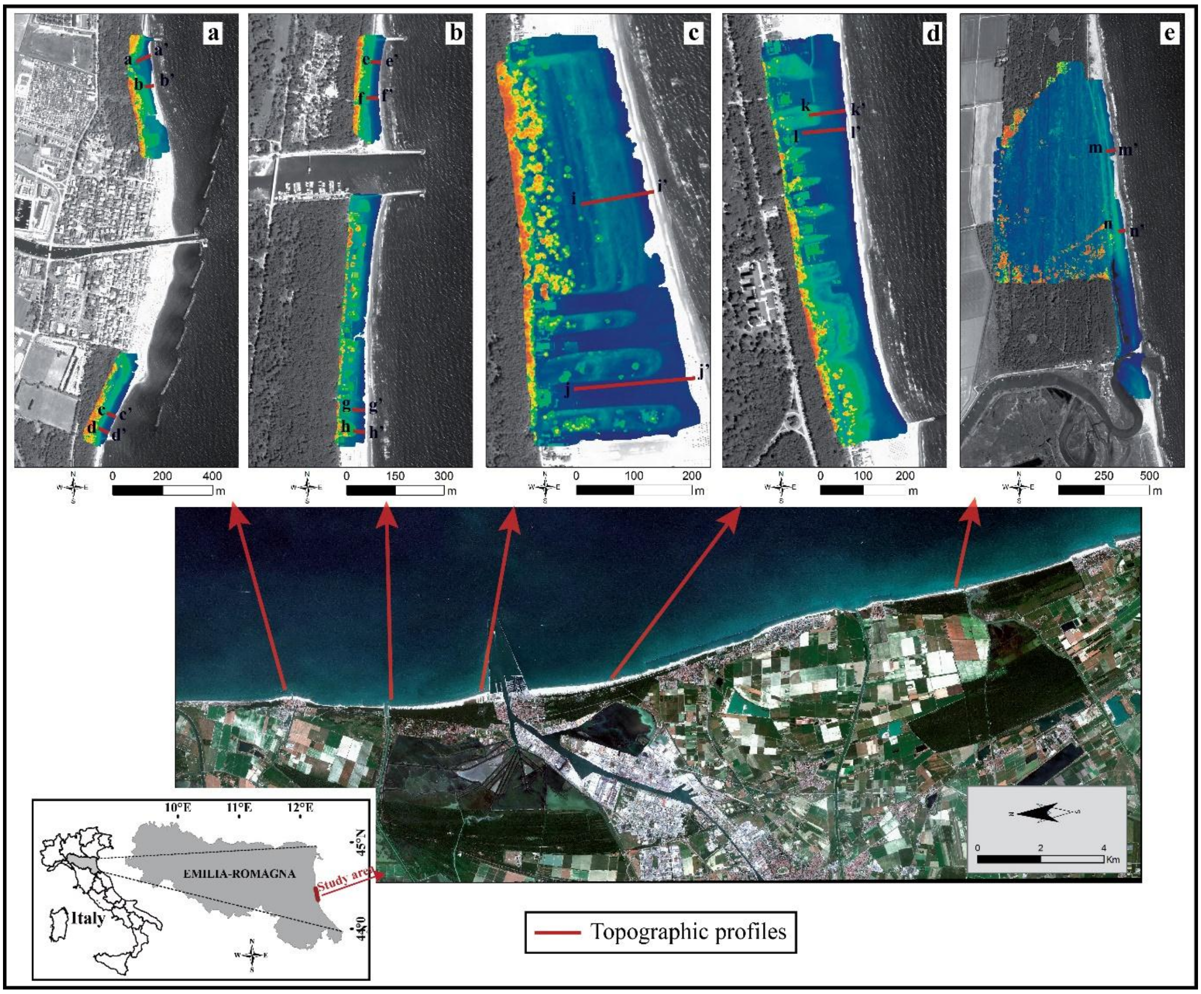

Figure 1: Study area and UAV surveys in a) Casal Borsetti, with two surveys—one in north of the town and the other in the south; b) Marina Romea, with one study north of Lamone river mouth and the other on the south; c) Porto Corsini; d) Marina di Ravenna; and e) Pineta Ramazzotti.

The study area includes a non-urbanized zone (Fig. 1e) that is under the protection of several international and national constraints (VV. AA., 2009). Here, in 2006, the Bevano River mouth was deflected 500 m south (Gardelli et al., 2007) to prevent erosion. In the same area, dune reconstruction and re-vegetation has been carried out (Taramelli et al., 2014b), with the body of water behind the dune reconstruction preserved to create a natural environment (VV. AA., 2009). It is a stretch of about 5 km that retains the natural costal dynamic and without a direct anthropogenic influence on the coastal system, and the zone shelters the unique continuous foredune ridges of the Ravenna coast (Taramelli et al., 2014a).

During winter season, in front of the *bagni* exist the "winter dunes." According Armaroli et al. (2012), these are built using foreshore and upper shoreface accumulated sand, which is reworked using bulldozers as a storm surge and inundation damage protection measure (Fig. 2). They are called artificial dunes by Harley and Ciavola (2013), who studied the importance of these anthropogenic dunes in decreasing the impacts of the winter storms. Due the missing natural dynamics between vegetation, storms, and wave or wind action in these dune formations, which are completely man-made dune, in this work these type of dunes will be called "bulldozer dunes" (Fig. 2). The term bulldozer dunes may be the most apt name for an anthropogenic dune, as it describes the dunes' genesis. During the summer season in the study area, the sand from bulldozer dunes are used to increase the beach's width (Figs. 2a and 2b), providing more space in front of establishments (Armaroli et al., 2012).

Figure 2: Bulldozer dunes; anthropogenic dunes built using a bulldozer on the Ravenna coast; a) bulldozer reworking the sand to prepare the beach for the summer season; b) bulldozer increasing the beach's width for the summer season; c) behind a bulldozer dune in Marina di Ravenna during the winter season; d) above the bulldozer dune to protect the *bagni*.

Ravenna's coastal plain has a low elevation above medium sea level (MSL), with dune crest elevations between 1.5 to 3 m above MSL (REGIONE EMILIA-ROMAGNA, 2010), an average sediment size of between fine and medium sand (Armaroli and Ciavola, 2011), and a microtidal regime, with a neap mean range of 30 – 40 cm and a spring mean neap of 80 – 90 cm. The beaches have a slow gradient of 0.03°, the mean backshore/foreshore width is 70 m, and the beaches are classified as being very dissipative (surfing scaling parameters ($-\xi_0$) < 0.3) (Armaroli et al., 2012).

The waves are of low height, below 1.95 m for 91% of waves measured by the Ravenna port tide gauge, Dominant wave comes from the east and storms are caused by the "Bora wind" from the ENE and the "Scirocco wind" from the SE (Armaroli et al., 2012). The Bora wind has an important influence on wave climate and circulation patterns in the Adriatic Sea. It is turbulent, powerful, and cold, and it can last from 12 h to several days and may occur several days during winter (Signell et al., 2010). Thus, it is an important factor to monitor in order to understand its effects on the coastal system and how it behaves.

The studied zone has an erosive trend induced by man's influence (Bondesan et al., 1995; Gambolati et al., 1998; Martinelli et al., 2011; Harley and Ciavola, 2013), principally due the construction of inland dams, which decrease the river sediment rates for natural beach nourishment (Martinelli et al., 2011). The zone is affected by natural subsidence (sediments compaction) and anthropogenic subsidence (gas and groundwater extraction) (Taramelli et al., 2014a), both of which increase the erosionary trend and the pressures on this coastal system (Gambolati et al., 1999). To fight erosion and preserve the urban zone, breakwaters were built alongshore at the beginning of the 1980s, changing the alongshore sediment transport dynamic (Armaroli et al., 2012). After 1990, beach nourishment have been done at critical points. Because of that, this coastal zone is under intense pressure, increasing the coastal susceptibility. Thus, appropriate ICZM actions are essential to decrease the system's susceptibility and to integrate the stakeholders' interests.

3. MATERIALS AND METHODS

To monitor the beach dune system during the 2014/2015 winter season, two high-resolution DSMs were generated from dense point clouds, which were elaborated using a structure from motion (SfM) approach with data from two UAV surveys to create a high-accuracy analysis (Mancini *et al.* 2013). Using the photogrammetry method, it was possible to measure the coastal system's response to environmental changes, analyzing the effects and the impacts induced by coastal dynamics during the season and human actions taken in this particular zone from a sedimentary depositional-erosion point of view (Brown and Arbogast, 1999). Moreover, between these two surveys, a large storm occurred over the NW Adriatic coast, damaging many structures in that area. This method allowed a qualitative and quantitative evaluation of the beach dune changes. This analysis included principal storm data from during the season that showed the importance of local action.

3.1- UAVs surveys

In this work, two UAV surveys were done in the study area: the first in September 2014, corresponding with the end of the summer season, and the second in March 2015, at the end of the winter season. The flights covered only the beaches and dune systems, and not any strictly urban zones, due an ENAC (Ente Nazionale Per l'Aviazione Civile - Italiana) regulation prohibiting UAV flights near settlements (ENAC, 2013). The monitoring campaign was commissioned by SAL Engineering and the UAV included a technical report system (SAL Engineering, 2015), a vertical take off and landing (VTOL) hexacopter, and a calibrated Canon EOS model 550D digital camera (resolution 5184x3456, focal length 25 mm, pixel size 4.4036x4.4036 µm).

Photo acquisition was automatic, set at one shot per second, flying at about 60 m height, with appropriate overlap between aerial photos. The images were then were processed to generate the DSM and converted into ortho-rectified images (orthophoto) by Agisoft Phothoscan's workflow algorithms (Agisoft, 2013) using an SfM approach (Snavely et al., 2007). For a precise georeferencing, and to minimize horizontal and vertical error, a GNSS-NRTK was used to acquire the coordinates of ground control points (GCP) with UTM Zone 33N (ETRF00) for horizontal coordinates and the geoid model ITALGEO2005 provided by the IGMI (Istituto Geografico Militare Italiano) for vertical values compared to the mean sea level. The GCPs were subjected to a PhotoScan process for better photogrammetric reconstruction.

The data were consigned in ortho-rectified images with 0.5 m pixel size and in dense point cloud with .LAS format. Using Global Mapper, the DSMs were generated in ASCII format with 0.5 m cell size. This resolution allowed the determination of the sediments' spatial distribution on the coast (Andrews et al., 2002). The surveys were segmented into seven areas: i) *Casal Borsetti North* (Fig. 1a); ii) *Casal Borsetti South* (Fig. 1a); iii) *Marina Romea Nord* (Fig. 1b); iv) *Marina Romea Sud* (Fig. 1b); v) *Porto Corsini* (Fig. 1c); vi) *Marina di Ravenna* (Fig. 1d); and vii) *Pineta Ramazzotti – Bevano Mouth* (Fig. 1e). The surveys in the Casal Borsetti and Marina Romea coastal towns were each divided into two parts north and south of the river mouth. All elaborations, results and discussion use this subdivision.

3.2- Surface changes

The surveys were used to evaluate the surfaces changes of beaches and dunes, due principally to storm events during the period analyzed. For the surface analysis, Fledermaus software was used; this software is a validated analysis tool for interactive 3D geo-spatial processing (Varela-Gonzales et al., 2013), allowing a surface comparison between surveys based on volumetric difference and providing information about spatial variations (Brown and Arbogast, 1999). In the software, is possible to drape the DSMs with orthophoto, improving the analysis and integrating the 3D assessment from DSMs with 2D data to identify the beach land use or vegetation cover (Gonçalvez and Henriques, 2015).

Two types of analysis were executed: the first was focused on the surface differences between surveys, using 2014 survey data as the *base surface* and the 2015 survey data as *interest surface* as well as request by the Fledermaus tool called surface difference tool; this process was done for each segment. The tool subtracts the cell center value and the result is represented in another DSM as an elevation difference, where positive values represent areas with deposition and negative values represent erosion.

For the pine forest and vegetation, and others elements that were not of interest for analysis, the orthophoto imagery helped to identify changes, although the aim was to evaluate the spatial variations. The high resolution allowed the representation of sedimentary beach and dune spatial changes using a 0.5 m color scale within the ranges of > + 4 m to < - 4 m. In the second analysis, the beach dune profile from the 2014 and 2015 UAVs surveys was extracted for the critical and representative zone and exported in .xyz format to analyze the local environmental changes in each segment.

3.3- Meteo-Marine Data

In order to evaluate the beach-dune system's susceptibility, meteo-marine conditions were used to identify the strongest storm over the set period. This analysis was conducted using data from the Angelina platform (courteously provided by ENI-IT) and the storm events were identified according to MICORE project criteria, which consider a storm as being indicated by wave height >1.5 m for six consecutive hours (Arpa-Emilia Romagna, 2011). The event of interest was identified as an intense storm that occurred on 5 and 6 February 2015, lasting about 43 hours with strong winds from the ENE. During the storm, the mean wave height was 2.40 m and the highest wave was 4.85 m. Moreover, a storm surge occurred, with a mean sea level of 0.73 m and a highest sea level of 1.21 m.

To estimate the maximum flood level (MFL) during the storm, the wave runup (R_2) elevation was calculated according to Stockdon et al. (2006) using a dissipative-specific formula. Maximum flood level occurred in association with the highest wave (4.85 m), with a R_2 = 0.73 m (± 0.21 m root mean square error) and a concurrent sea level of 1.02 m. The sum of these two components determined a MFL of 1.75 m (±0.21 m root mean square error), which was overlapped the extracted profiles from 2014 and 2015 UAV surveys, to demonstrate the susceptibility of zones without dunes.

4. RESULTS AND DISCUSSION

The two surveys allowed the monitoring of changes induced by humans and by winter storms on this coastal zone. The results will be discussed for each segment. The results also allow a discussion of the advantages of and the precautions to use with the UAV surveys for coastal monitoring in order to obtain an enhanced result. Photogrammetry by UAVs may have limitations in the coastal zone, which can be addressed by integrating the survey with other information and knowledge about the site under study. In this work, the presence of man-made changes may confuse the interpretation of beach and dune behavior during the winter season but with due caution, these elements will not interfere with the aim of this work.

On Ravenna's coast, man-made changes done to prepare the beach for summer's tourist season are significant, modifying the natural morphology after winter season (Armaroli et al., 2012). In the locations where the foredunes have been reworked, the high resolution DSM and orthophotos from UAV survey enable the investigation of these changes (Figs. 3a and 3b). The presence of vegetation on foredunes without any man-made changes is evident in the 2014 survey (Fig. 3a), while in the 2015 survey, man-made changes to foredune are visible, with a sign leave by the bulldozers on the sand to rework the foredune (Fig. 3b), limiting the interpretation of the natural behavior in this zone.

The DSM and orthophotos from the UAV surveys proved a powerful tool for monitoring the beach and coastal dunes. Also, from naturalist point of view, they allow people to inquire and obtain information about vegetation on dunes. The orthophotos provide valid data to observe the natural state of the system, and how it changes on the coast, since the presence of vegetation is clear on the foredune. In these two surveys, it is possible recognize the changes in vegetation density on the foredunes due to the seasonal growth of trees and bushes (Figs. 3c and 3d).

These changes in vegetation generate high negative values in the measurement done by the difference surface tool, which are considered as volume changes (Fig. 4) by the software. In this case, the surface differences are due principally to seasonal changes in vegetation density on the dunes. The negative values may be interpreted as dune erosion but can also be considered as noise when the aim of study is the spatial distribution or sediments. Because of this, the integration of knowledge from the study site, and the DSM and the orthophotos from photogrammetry, can resolve this problem during interpretation of the results.

In addition, the UAV surveys may be used to monitor in detail geomorphological elements and processes, such as dune blowout behavior (Figs. 3e, 3f and 3g) (Andrews et al., 2002) or washover processes, providing an accurate result with a high spatial resolution (Mancini et al., 2013). This analysis requires attention to the noise source during data elaboration and principally during data interpretation. Other instruments, however, such as the terrestrial laser scanner, may give better results for detailed morphological elements and small spatial scales in terms of survey time and the ability to clean noise like vegetation and others elements not of interest.

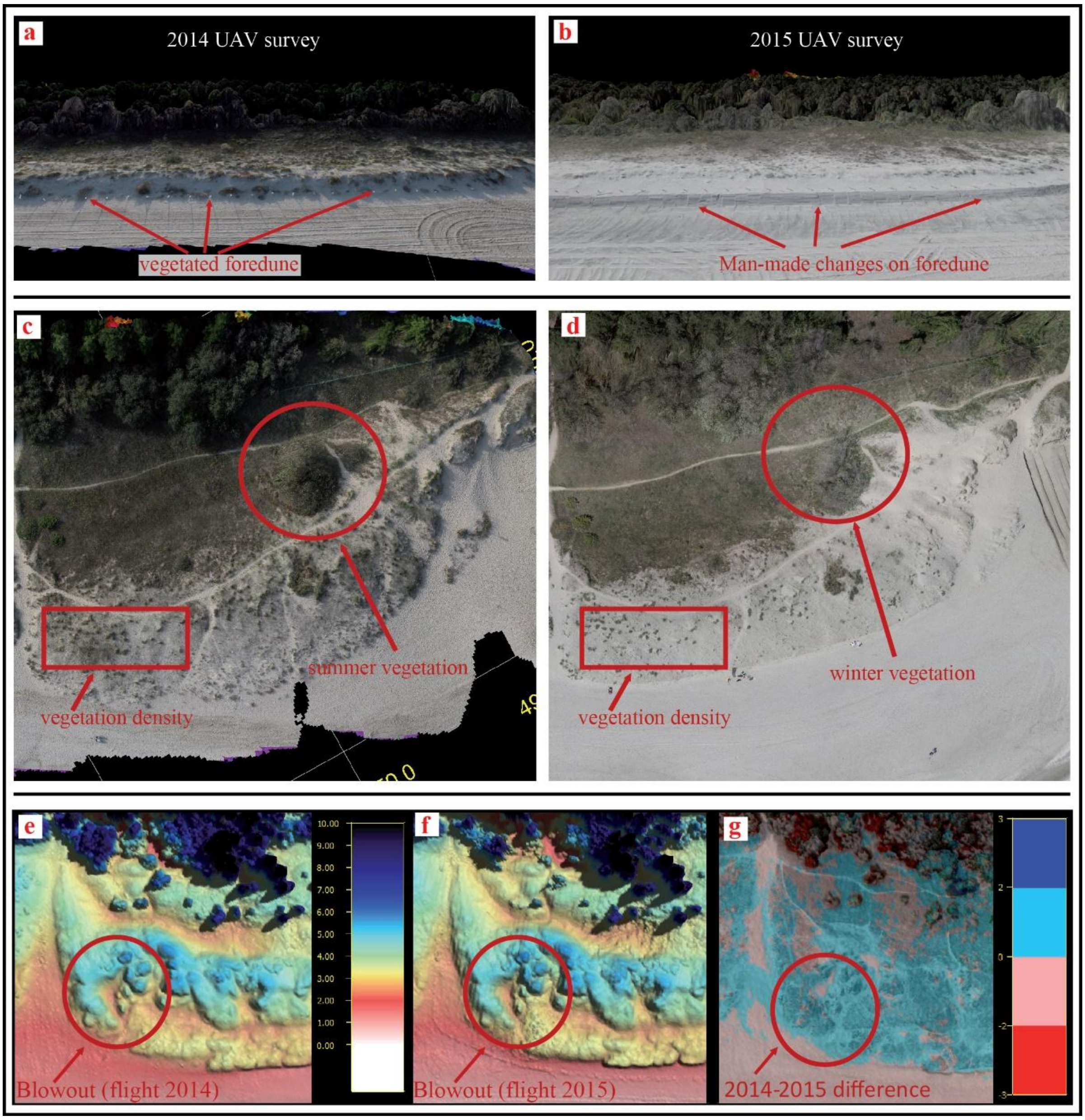

Figure 3: The potential of UAV surveys for coastal monitoring; a) and b) a natural foredune with vegetation from the 2014 UAV survey and the man-made changes to the foredune observable in the 2015 UAV survey; c) and d) the vegetation difference between the 2014 and 2015 UAV surveys; c) after the 2014 summer season, there exists a higher vegetation density on the foredune; d) after 2015 winter season, less vegetation is seen on the foredune; e), f) and g) a detailed scale dune monitoring, blowout detail on the DSM obtained from UAV survey (e and f); g) high resolution data on deposition and erosion on blowout, obtained using surface difference tool.

For a land use and spatial occupation analysis on the coast, it was possible to acquire data with high resolution (Fig. 4a and 4b). Observing and comparing the surveys, is was possible clearly verify the changes on land for both images. These changes occur every year in the most anthropogenic parts of the Ravenna coast when the bulldozer dunes are built (Fig. 4a and 4b) the beach profile is flattened in summer to build tourist facilities (Armaroli, et al. 2012; Harley and Ciavola, 2013). The surface difference (Fig. 4c) shows these changes on the territory, and moreover, is possible identify coastal system changes due to anthropization such as the bulldozer dunes and changes due to natural dynamics such as dune erosion by storms. These qualitative and quantitative analyses provide important information by which local authorities can follow changes to the coastal system.

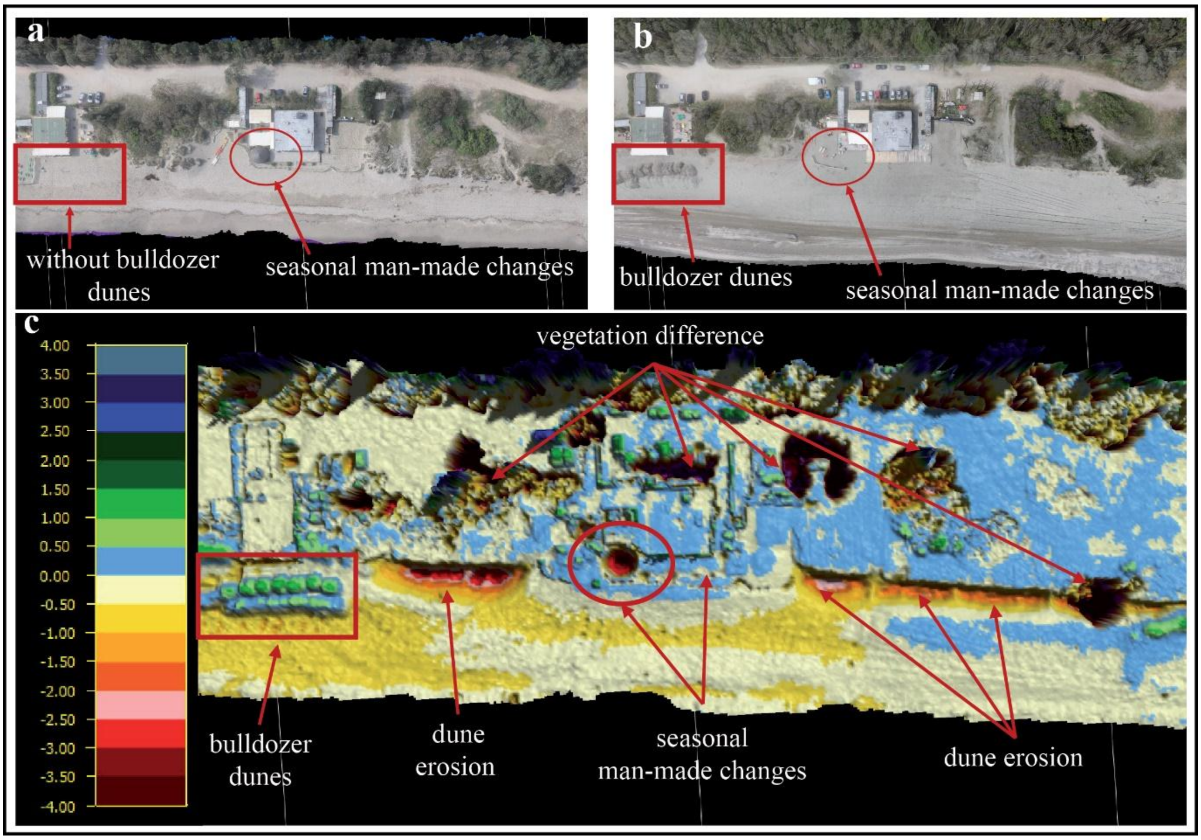

Figure 4: Individualized elements on the beach; a) imagery from the 2014 UAV survey; b) imagery from the 2015 UAV survey; c) surface difference between the 2014 and 2015 UAV surveys.

For each segment, two representative profiles were done using the same positions in the 2014 and 2015 UAV surveys (Fig. 5). Figure 1 shows the topographic profiles location. Profiles were extracted using fledermaus-v7 software overlapped with MFL to show the changes that occurred during the 2014-2015 winter season, the susceptibility of this beach/dune system, and the territorial vulnerability. A discussion of each segment is presented below.

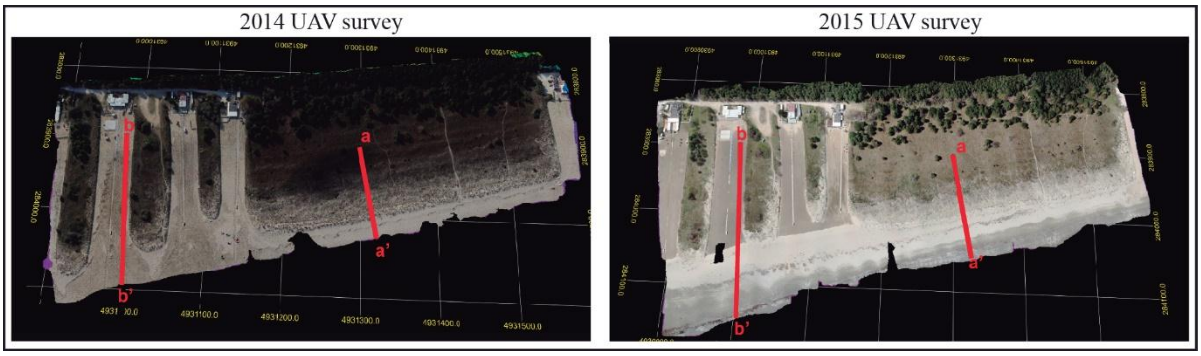

Figure 5: Example of profiles extracted from the 2014 and 2015 UAV surveys. This method was used to extract and calculate the profiles along each segment.

4.1 - Casal Borsetti North: In front of the Casal Borsetti settlement, severe erosion process led to parallel and transversal groins construction aided in protecting the foredune during winter storm. Figure 6 shows the surface difference between the surveys. In this segment, the majority of the area shows a positive value due man-made changes on the system, where the dunes had been reworked and bulldozer dunes had been constructed. Adjacent to the bulldozer dune is a small zone with a negative value, showing dune erosion. Behind the coast exists a pinewood forest and due to the difference in vegetation density between the two surveys, the surface difference behind the dune shows high variation.

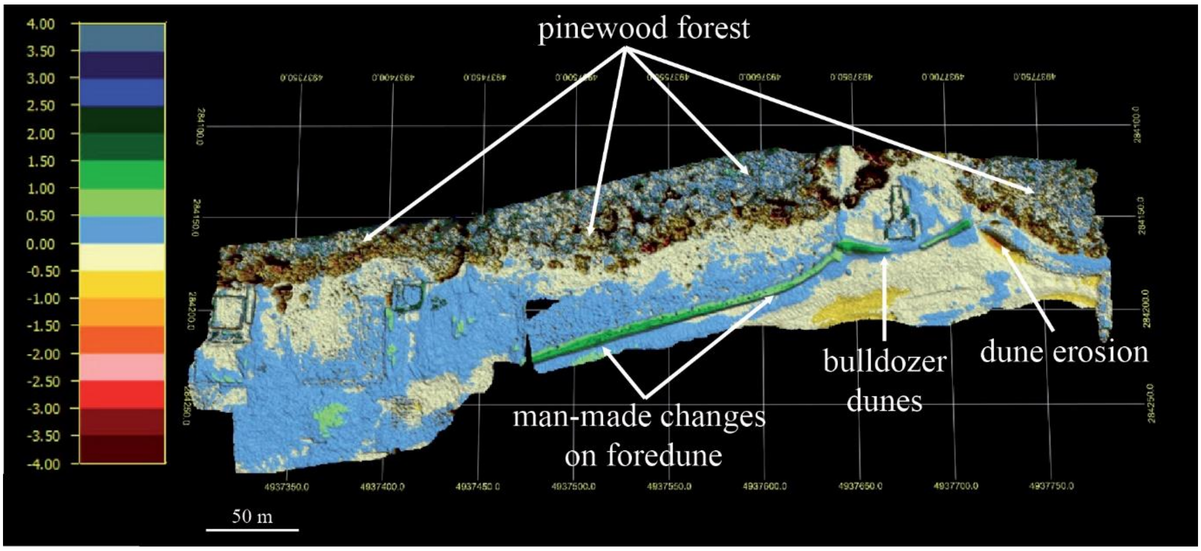

Figure 6: Surface difference between the 2014 and 2015 UAV surveys at the north of the Casal Borsetti settlement.

Analyzing across dune and beach profiles, (Fig. 14) profile a-a’ shows the bulldozer dune constructed in front of a *bagno* and the vulnerability of this structure due to the winter storm. In profile b-b’, the increase in the foredune is due to sand rework by humans (Fig.2a). It is possible to see the bulldozer signs in the sand. The groins protected this zone, decreasing damage from the winter storm surge.

4.2 - Casal Borsetti South: the segment at the south of the Casal Borsetti settlement is more natural than the northern one. A fixed structure is present in the right part of the segment, where values are positive, between 1 m and 1.5 m (Fig.7), due to bulldozer dune building. Behind it is a pinewood forest and the higher positive and negative values above the dune are due to vegetation density. A part of the foredune in the center of the segment has been eroded, as detailed in Fig. 14, profile c-c’. The sedimentary spatial distribution has a positive value in the left part of the segment, where a transversal breakwater is present that contributes to trapping the sediment (Armaroli et al., 2012). The profile d-d’ (Fig.14), which was extracted close to the breakwaters, shows that the foredune changes are between 0.5 m and -0.5 m. These values are too small to be considered a change between seasons.

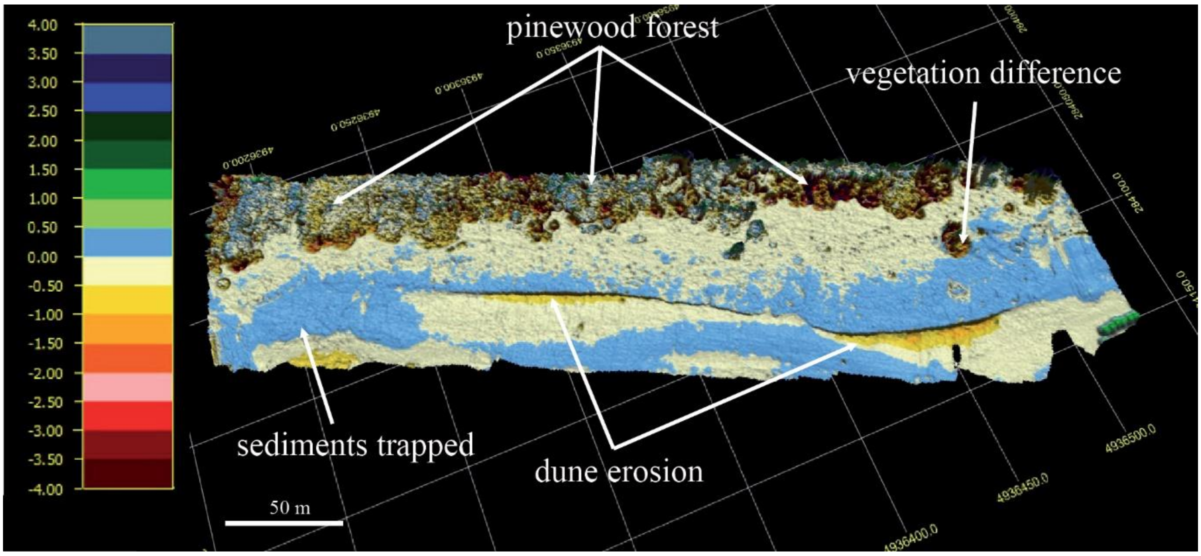

Figure 7: Surface difference between the 2014 and 2015 UAV surveys at the south of the Casal Borsetti settlement.

4.3 - Marina Romea North: This segment is between a transversal breakwater and the north jetty of the Lamone River Mouth. The impact of the storm in this zone was strong. The foredune had been eroded and the erosion values are between -0.5 m to -1 m (Fig. 8) in main foredune zone. The profiles e-e' and f-f' in Fig. 14 show the erosion in this segment that occurred during the 2014-2015 winter season.

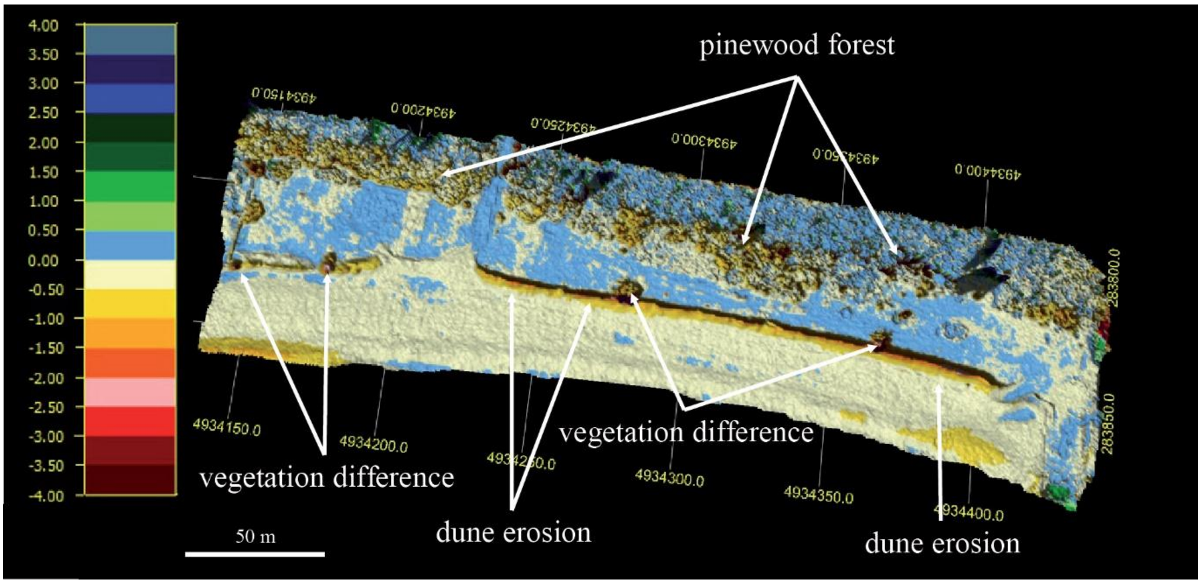

Figure 8: Surface difference between the 2014 and 2015 UAV surveys at the north of the Marina Romea settlement.

The segment of Marina Romea North is a more natural beach than Marina Romea South. Although the impact of the storm in this zone was strong, the vulnerability of this part lower due the nonexistence of fixed structures on the beach. Moreover, in this zone, the vacations houses are behind the pinewood forest, contributing decreased local vulnerability.

4.4 - Marina Romea South: Together with Marina di Ravenna, this segment is highly anthropized, with many fixed structures on the beach. In addition bulldozer dunes are present in front of all the fixed structures, where the surface difference values are positive, ranging from 0 to 3 m (Fig. 9). This segment shows the importance of bulldozer dunes in protecting the *bagni* from storm damage. All of the dune fragments still present in this zone show erosion, with values of about -1.5 m. The profile g-g' (Fig. 14), in front of a fixed structure, shows exposure to the storm and the protection created by the bulldozer dune. In profile h-h' (Fig. 14), erosion is seen in a dune adjacent the fixed structure.

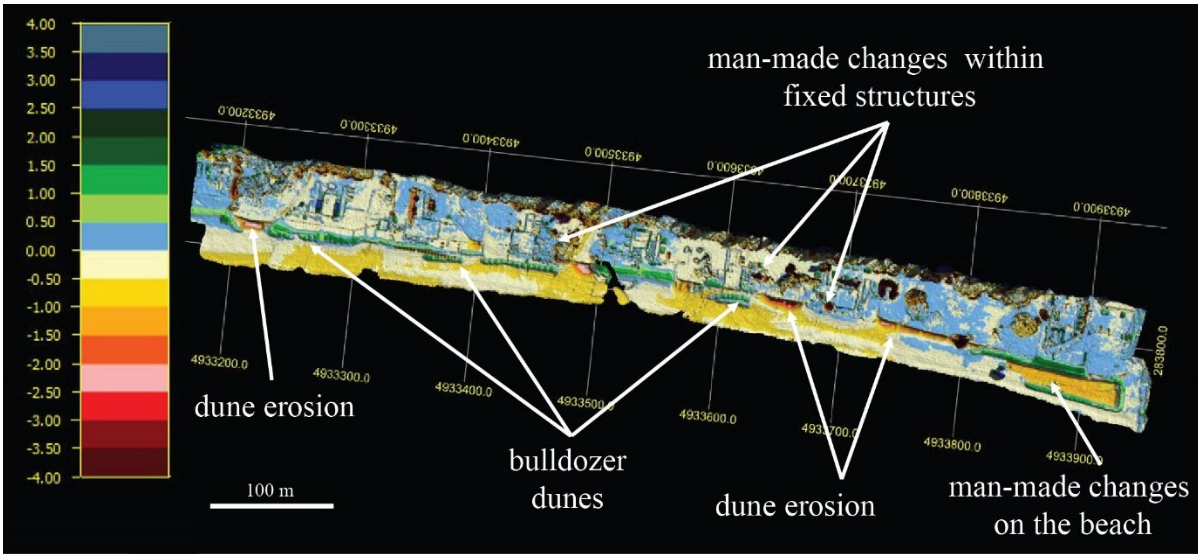

Figure 9: Surface difference between the 2014 and 2015 UAV surveys at the south of the Marina Romea settlement.

During the summer season, this zone receives many tourist and the beach is modified to create more space and change the land use. The clearest changes are concentrated near the *bagni*, where recreational areas have been built. It is possible to identify these new construction by the surface difference (Fig. 4c).

4.5 - Porto Corsini: This segment is located at the north of Ravenna's port, where there is a 3 km length jetty that traps the sediments. In this zone, the morphological changes due to the winter storms are very light. The surface difference values vary between -0.5 m and +0.5 m (Fig. 10) for the majority of the beach and dunes in this segment. The anomalies are due to bulldozer dunes in front of the three fixed structures in this segment. On the dunes, it is possible to observe the presence of vegetation, and the black area of the figure is due to no data for the 2015 survey.

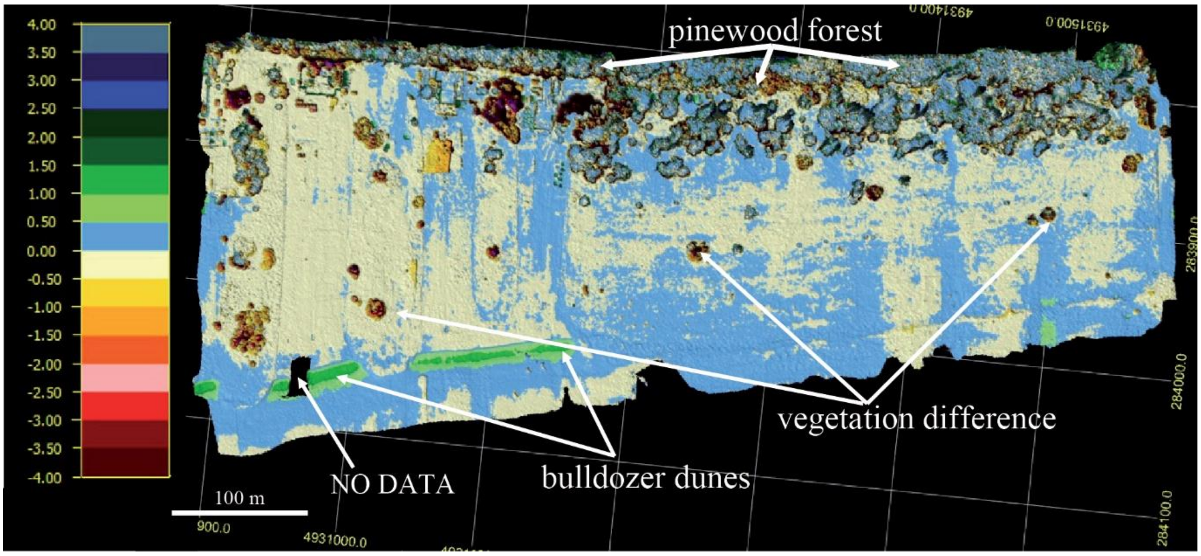

Figure 10: Surface difference between the 2014 and 2015 UAV surveys at the Porto Corsini settlement.

The profile i-i' (Fig. 15) shows the equilibrium of the foredune during the winter season. Regarding profile j-j' (Fig. 15), many fixed structures are clearly exposed to winter storms, showing the bulldozer dunes' role in front of these structures along the coast.

4.6 - Marina di Ravenna: In this part, at the south of Ravenna's port, half of the segment, on the left, shows natural dynamics with dunes. Here, the surface difference values for the beach are negative, at about -0.5 m, and behind the dune the values are positive, at about 0.5 m, representing a small sediment deposition (Fig. 11). These dunes are under control of monitoring for blowout behavior because these dunes represent a natural element adjacent to a dense anthropized coastal system (Fabbri, 2015). As such, the UAV surveys are important for understanding the environmental behavior adjacent to these dunes. The other part of the segment shows fixed structures built between dune fragments, where bulldozer dunes have been built to protect the facilities and the fixed structures.

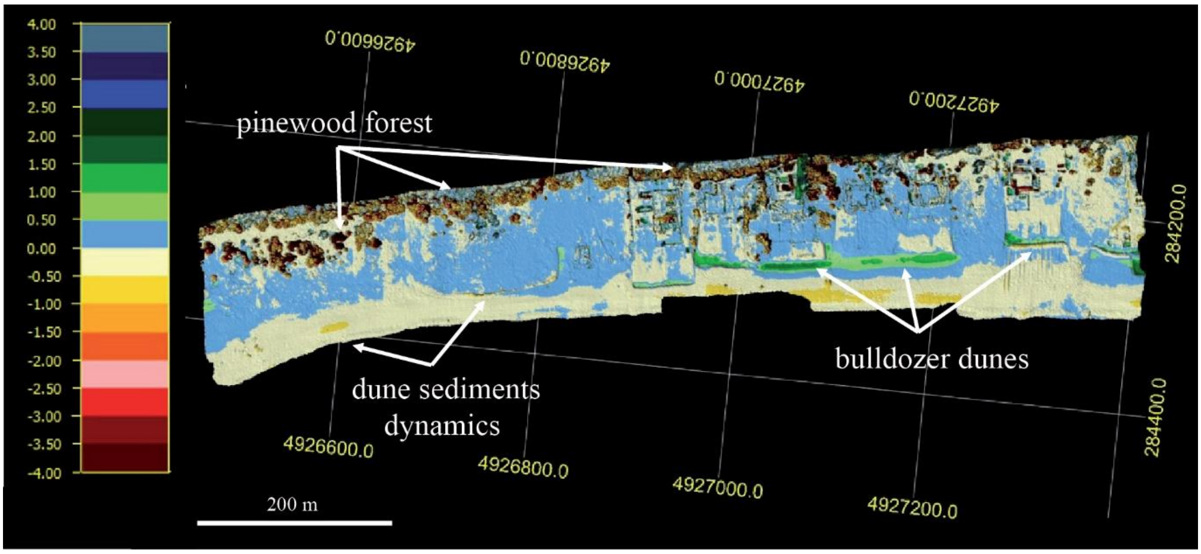

Figure 11: Surface difference between the 2014 and 2015 UAV surveys at the Marina di Ravenna settlement.

Marina di Ravenna has the widest beach of the entire study area. At about 70 m, it dissipates the wave energy and consequently decreases the impact of storms. This can explain the low susceptibility of this beach and dune system and the lower vulnerability to winter storms. Profile k-k' (Fig. 15) shows no erosion on the dunes. Where the *bagni* are present in profile l-l' shows the bulldozer dunes' topography and the exposure these structures would face without bulldozerd dunes.

4.7 - Pineta Ramazzotti: This segment is inside the natural reserve on the Ravenna coast. Without residences, fixed structures, or tourists, it was also severely affected by the storm in March 2015. The aerial beach in this segment is smaller than the other segments, decreasing wave dissipation and increasing the energy of the wave on the beach and on the foredune (Richter et al., 2013). To understand the natural dynamic changes on the Ravenna coast, it is important to investigate and monitor this zone in particular. In the right part of the segment, near the coastal town of Lido di Dante, the erosion values see through surface difference (Fig. 12) are around -2.5 m, with a deposition behind the dunes.

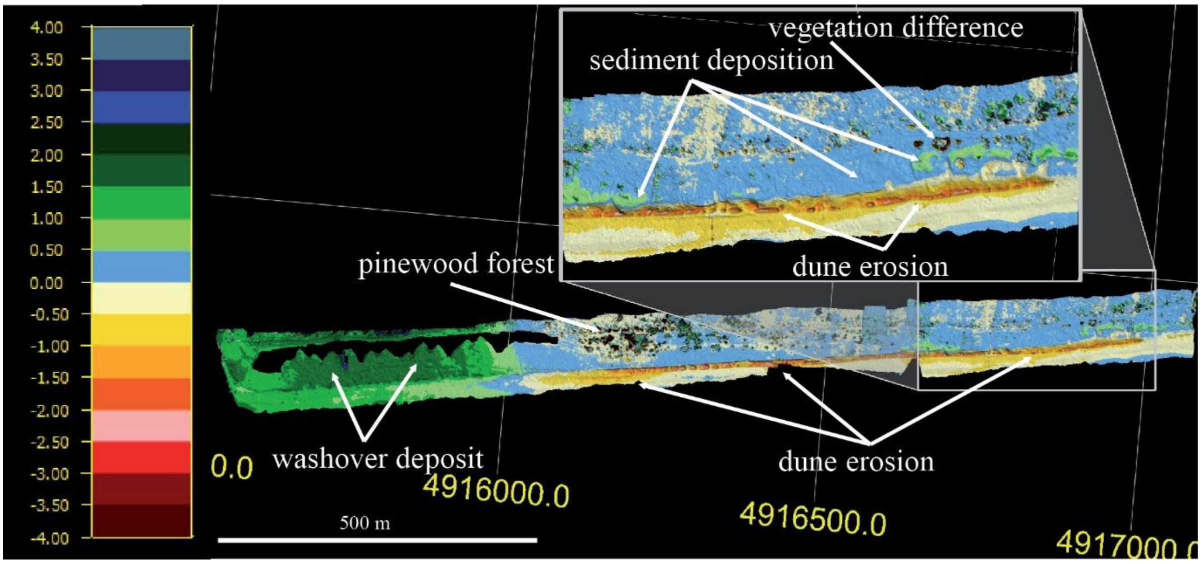

Figure 12: Surface difference between the 2014 and 2015 UAV surveys at Pineta Ramazzotti.

Profile m-m' (Fig. 15) shows the dune flattened and the foredune ridge completely damaged after the storm. A more detailed surface difference in this part demonstrates the impact on the foredune profile a-a' (Fig. 13A). At several points, strong erosion can be seen, where the foredune retracted almost 10 m (profile n-n', Fig. 15). The left part of this segment shows heavy sediment accumulation, with values of up to +3 m. During the storm, the left part of the segment was subjected to the washover process, increasing the surface at this point. Profile a-a' in Fig. 13B clearly shows the behavior of this part. In the 2014 UAV survey (before the storm), the dune was around 1 m height, while in the 2015 UAV survey (after the storm), the washover process had increased the dune height by 1 m.

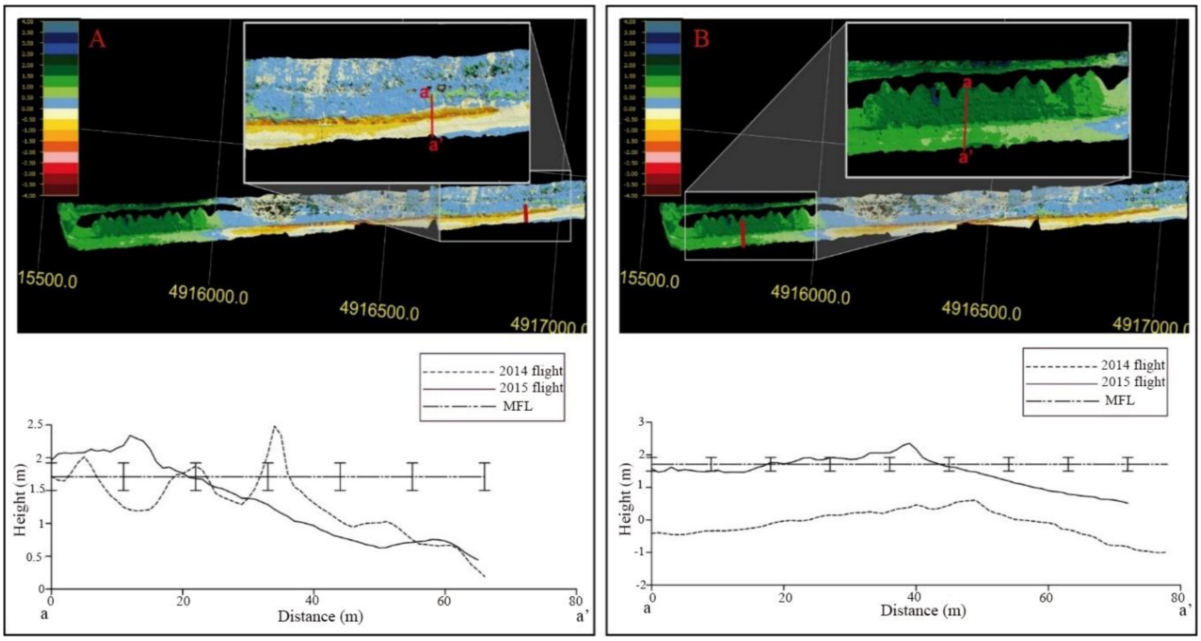

Figure 13: A) zoom and profile at the damage zone of the Pineta Ramazzotti segment, where profile a-a' was extracted; B) Zoom and profile at the south of the Pineta Ramazzotti segment, where profile a-a' was extracted.

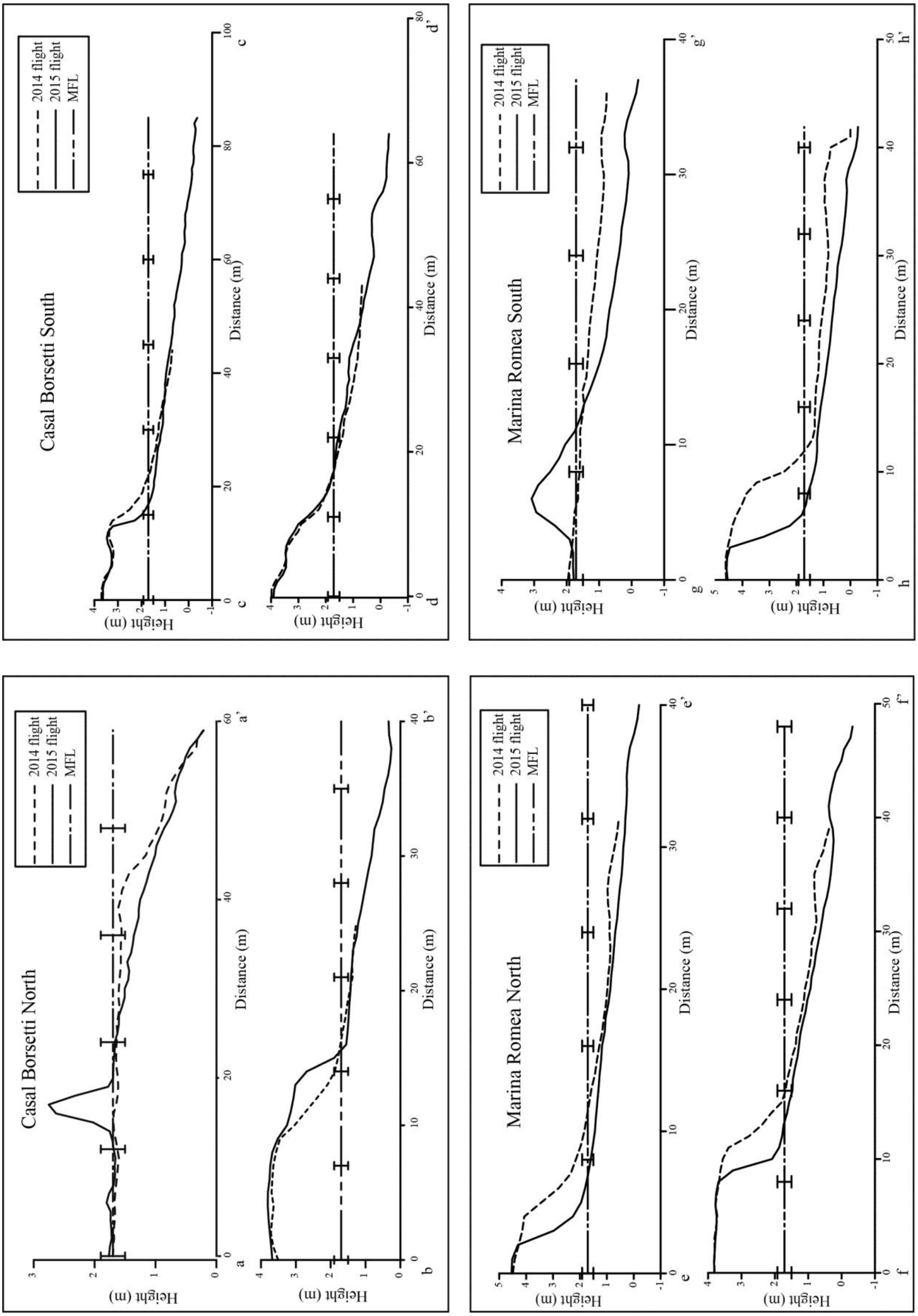

Figure 14: Profiles extracted from the 2014 and 2015 UAV surveys overlapped with WFL; profiles a-a' and b-b' at the Casal Borsetti North segment; profiles c-c' and d-d' at the Casal Borsetti South segment; profiles e-e' and f-f' at the Marina Romea North segment; g-g' and h-h' at the Marina Romea South segment.

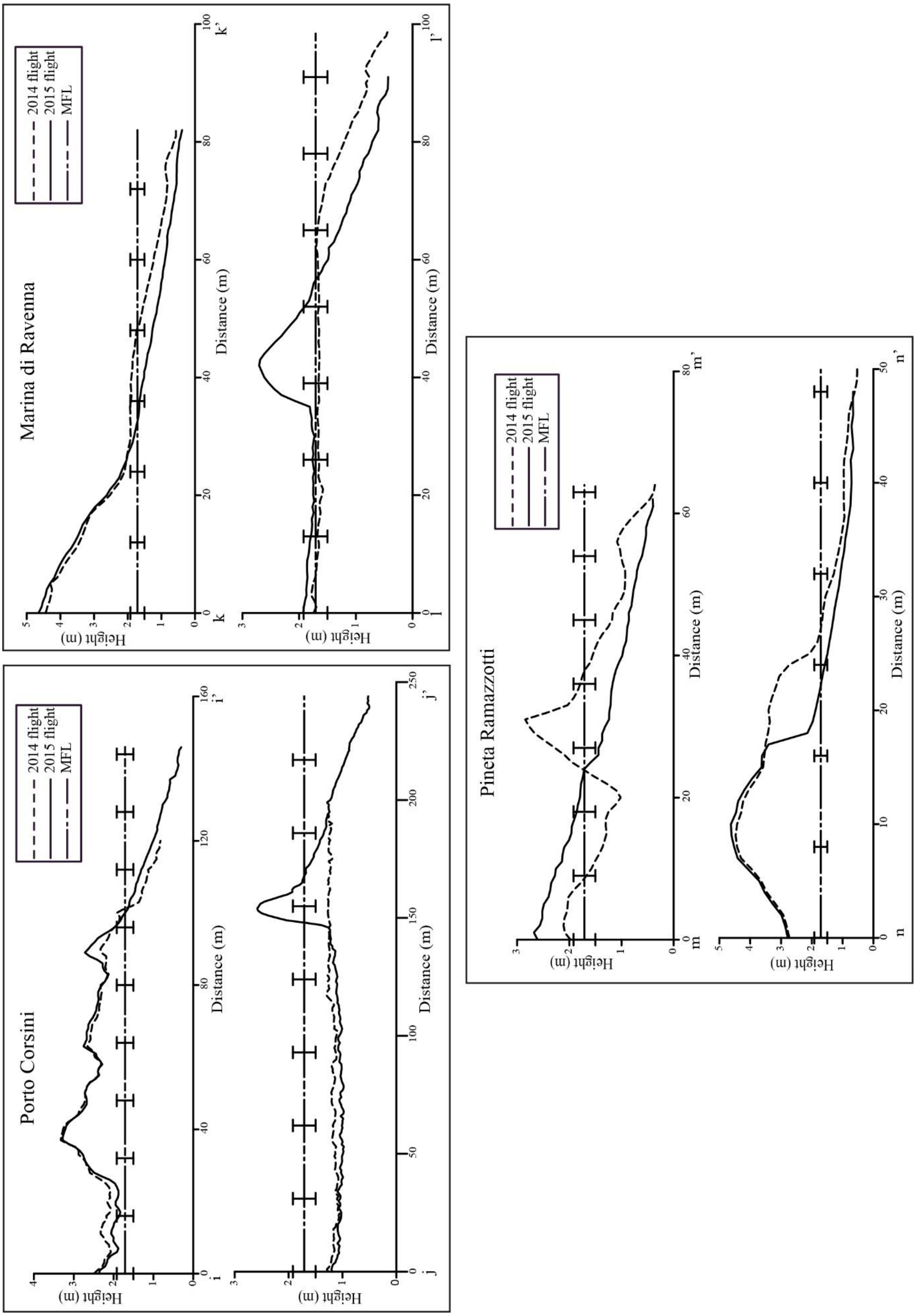

Figure 15: Profiles extracted from the 2014 and 2015 UAV surveys overlapped with WFL; profiles i-i' and j-j' at the Porto Corsini segment; profiles k-k' and l-l' at the Marina di Ravenna segment; profiles m-m' and n-n' at the Pineta Ramazzotti segment.

5. CONCLUSION

The use of UAV surveys has allowed us to monitor the Ravenna coast, understand the mean pressure factors for all segments, and see how the coastal behavior changed during the winter season due to man-made changes and a winter storm. The changes in the Pineta Ramazzotti segment showed the power of the storm, which caused severe erosion of the entire dune, changing the local morphology. A natural foredune present in this zone increases the resilience of the coastal system. Thus, it is important to continue monitoring and to integrate more knowledge about dune and beach behavior to construct a complete framework of behavior in this zone that will aid in maintaining the natural state.

The results from the other segments show the changes that have been made by building fixed structures; the UAV surveys were an important tool in investigating these changes during the 2014-2105 season, and can be used as a new tool to support local studies in geomorphology and ICZM studies. Moreover, this work has determined the man-made changes on the beach and the importance human actions, especially with regard to the fixed structures during winter storms and their vulnerability in the absence of bulldozer dunes. With the assistance of photogrammetry, it is possible identify the critical points of the dune and beach system, thus decreasing local susceptibility by giving authorities an understanding of the natural and anthropogenic factors that induce coastal susceptibility. Coastal geomorphology has been made a theme for local stakeholders' interests and not just a scientific research theme, forcing local authorities to seek out regular, high resolution data acquisition.

Moreover, this study shows the facilities for coastal monitoring, promoted by UAV surveys based on photogrammetry to monitor the environment's behavior and drive ICZM actions. The results obtained from UAV surveying may be use to monitor a particular location or an interesting area in the beach and dune system. It may also be applied in multidisciplinary scientific studies such as economics and management studies to evaluate environmental changes from a monetary point of view, or in biology to investigate the changes in vegetation and habitats. Or, engineering studies can use the high-resolution data to increase the measurements quality of projects.

The territory DSM and orthophotos obtained by photogrammetry allow the gathering of high accuracy data to identify changes due to natural factors or human actions in the short and long terms (Stive et al., 2002). The cost of these surveys is more advantageous for local authorities, compared with the cost for LIDAR surveys or high quality satellite imagery for regular data acquisition. Another important factor to consider in using UAV surveys for ICZM by local authorities is the relativity low price of UAVs, including a low operating cost and high automatic survey level (Gonçalvez and Henriques, 2015) that can obtain highly accurate data. Thus, this method can become an important tool that allows coastal environmental decision-makers to understand coastal behavior by monitoring the coastal dynamic and using that information to evaluate their decisions.

Acknowledgments

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Chapter 4

NATURAL AND ANTHROPOGENIC COASTAL SYSTEM COMPARISON USING DSM FROM A LOW COST UAV SURVEY (CAPÃO NOVO, RS/BRAZIL)

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ICS2016-Paper ACCEPTANCE-1547

Para Frederico Scarelli

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Dear Frederico,

Thank you for submitting your revised paper. I have now reviewed it and I am pleased to inform you that it is accepted and ready for publication in the Special Issue of the Journal of Coastal Research. If you haven't done so already, please send your copyright transfer agreement to ics2016.secretariat@sydney.edu.au , I have attached a copy of the form to this email. We would like to thank you for your contribution and for complying with formatting and deadlines.

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We are looking forward to seeing you in Sydney in March!

Best wishes,
David

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Natural and Anthropogenic coastal system comparison using DSM from a low cost UAV survey (Capão Novo, RS/Brazil)

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ABSTRACT

Scarelli, F.M.; Cantelli, L.; Barboza, E.G.; Rosa, M.L.C.C.; and Gabbianelli, G., 2016. Natural and Anthropogenic coastal system comparison using DSM from a low cost UAV survey (Capão Novo, RS/Brazil). *In:* Vila-Concejo, A.; Bruce, E.; Kennedy, D.M., and McCarroll, R.J. (eds.), *Proceedings of the 14th International Coastal Symposium* (Sydney, Australia). *Journal of Coastal Research*, Special Issue, No. 75, pp. XX-XX, ISSN 0749-0208.

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In many cases, the unplanned urbanization processes are the main factor that cause the crisis in the coastal environment, decreasing the coastal system resilience. This paper compare the differences between the anthropogenic and natural coastal zone, based on the morphological dune reconstruction, using a low cost UAV (unmanned aerial vehicle) survey and the photogrammetric reconstruction method. The study area is in the Northern Littoral of Rio Grande do Sul State, where are present a dune field with few man-changes, adjacent an anthropogenic zone with high changes on the beach/dune system, which has a contrast in the beach/dune system between these two zones. By photogrammetric reconstruction method, were possible obtain a high-resolution DSM (Digital Surface Model) and a high-resolution othophoto to analyse the morphology differences. The characterization of the natural and the anthropogenic zone and the knowledge obtained from this work are important to understand the local coastal system behaviour. The data acquired are important to aid the coastal managers and decision makers to have a high-resolution data to apply in the local Integrated Coastal Zone Management. Moreover this work propose a low coast method to obtain a high-resolution data in the coastal zones, and a tool for the researches group and local authorities, with good cost-benefit, to acquire more information, increase the local database and to monitor the coastal environment.

ADDITIONAL INDEX WORDS: *ICZM; coastal morphology; coastal zone; photogrammetry.*

INTRODUCTION

To increase knowledge about coastal environmental behavior and to apply integrated coastal zone management (ICZM), it is essential to know about the pressures on the system and the interaction between the anthropogenic and natural factors (Psuty, 1988; Sherman and Bouer, 1993; Hesp, 2002; Carrasco *et al.*, 2012). This knowledge aids coastal managers in improving their choices about coastal actions including better coastal resources management, decreasing the vulnerability and the hazards in the coastal zone and attending to stakeholders interests, which is a fundamental point in ICZM actions (Kindermann, and Gormally, 2013). To acquire more information and to monitor the coastal environment, local authorities need a better cost-benefit tool to obtain data on natural factors as the impact of the storm-surges on the coast, and by anthropogenic pressure factors as the coastal urban zone expands (Andrews *et al.*, 2002; Lambert and Zanuttigh, 2005; Davidson *et al.*, 2006; Tătui *et al.*, 2013).

This work proposes a methodology to acquire high-resolution Digital Surface Models (DSM) and ortho-rectified images (orthophotos) in the coastal environment (Mancini *et al.*, 2013) using a low cost and easy to operate unmanned aerial vehicle (UAV). Moreover, these data may be used in several disciplines, as engineering, urban planning, biological, geological and environmental science, archaeology and others (Gares *et al.*, 2006).

The study aims to investigate the morphology and the interaction between natural and anthropogenic features of a dune/beach system on a Brazilian coastal region, using aerial photos obtained from a UAV survey (Casella *et al.*, 2014; Gonçalvez and Henriques, 2015).

In this work we have done a qualitative analysis since the main aim is to propose the methodology to acquire environmental data at a low cost. In the region where this study was conducted, many features are present that may increase the vulnerability and the risks in the coastal zone such as small creeks, which are washouts through the foredunes and beach named “sangradouros”, according to Figueiredo and Calliari, (2005). These are mainly pluvial water drainage channels that are about 0.8 m deep. These features may be observed along the entire Rio Grande do Sul (RS) coast and are mainly present in the urbanized stretches. These washouts represent a high coastal hazard, because in many cases the beaches are trafficked by cars and the washouts are hidden, causing severe accidents. In addition, due to the foredune fragmentation the sediment transport from dune and beach to the surf zone, mainly during storms, may create a sediment deficit, increasing the coastal erosion. Finally, this work offers a good coast-benefit tool for local authorities to increase the investments in the local ICZM and in the coastal urbanization planning, since many of the coastal settlements grow without an urban plan (Esteves *et al.*, 2003).

Background

The study area is in Capão Novo, a beach settlement in the Northern littoral stretch of Rio Grande Do Sul (RS), the southernmost state of Brazil (Fig. 1). The RS coast is approximately 620 km length, has a gentle undulating barrier coast with a NE-SW orientation, and is characterized by a barrier-lagoon depositional system formed by sea level changes during the Quaternary (Villwock *et al.*, 1986; Dillenburg *et al.*, 2009). The coast is classified as dissipative and intermediate beaches; the beaches area about 60 m in width (Gruber *et al.*, 2006), and have a microtidal regime with a semidiurnal tide with a mean of 0.5 m. It is a wave dominated coast and the sediment supply is by littoral drift that is northward. The barrier deposits are dominated by quartz sand from very fine to medium; the dominant winds are from NE during spring and summer, and from SW during autumn and winter (from April to July). The latter are responsible for the stronger storm surges (Dillenburg and Barboza, 2014). The average significant wave height is 1.5 m, and during storms the sea level may surge up to 1.3 m at the coast (Barletta and Calliari, 2001; Calliari *et al.*, 1998).

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Figure 1: Study area in North Littoral of RS. The red polygon is the UAV survey area.

The study area is located in a mildly concave part of the coast in a regressive stretch of the barrier that was covered by transgressive dunefields during the barrier progradation (Dillenburg *et al.*, 2009; Barboza *et al.*, 2011 and 2013). In this stretch, the reduction and dispersion of wave energy resulted in a positive balance for the sediment budget, however, the anthropogenic activities and an unplanned development (Esteves *et al.*, 2003) increased the vulnerability along the coast. The foredunes have been subject to an urbanization process with sidewalks built directly above the dunes and beachfront propreties and sand mining, that affected the local sand balance (Dillenburg *et al.*, 2004). Capão Novo and near settlements represent the most developed and urbanized beaches in this stretch, principally by holiday houses that are engaged during the summer season. The beaches were classified as developed and mainly eroding beaches by Estves *et al.*, (2003). This study focuses on a 600 m stretch which includes a part of a dune in an urbanized zone and a part of dune in an adjacent non urbanized zone, with a washout in between.

METHODS

To do a high-accuracy analysis of the stretch under study a low coast UAV was used to obtain a high-resolution DSM and orthophoto from a photogrammetric reconstruction method (Mancini et al., 2013). The flight was done in the final part of the summer season (mid-march) when the beach presented a summer profile. To collect the aerial photographs a DJI Phantom quadcopter was utilized, a smaller commercial UAV costing about USD$1,000. The advantages of this UAV are that it has an easy flight system platform allowing a safe control and operability and costs much more less than a professional UAV. The DJI Phantom UAV has an integrated GPS Positioning Module as

±0.8m vertical and ±2.5m horizontal accuracy, a Controlled Automatic Return to Home; an Intelligent Flight Battery; a 3-Axis Camera Stabilization; a 14 Megapixel HD camera, which has a FOV (field of view) 140° f/2.8 focus at ∞, with real-time Camera Preview on IOS and Android Device Application. A smartphone integrated with the the UAV Remote Controller is required to control the camera. The survey took about one hour, and was done in three flights in the entire stretch, flying at three different heights, ~16, ~30, and ~5 m above the washout to increase data resolution. The flight speed was ~1.5 m/s; and 689 photos were acquired, shot perpendicular to the ground, with about 80% overlap between the aerial photos to allow the creation of the DSM in Agisoft Photoscan software. The UAV flight was coupled with a Global Navigation Satellite System (GNSS) eTrex®30-Garmin with barometric altimeter and with the local topographic chart. The flight track acquired was used to insert a geotag in all the photos using BaseCampTM. For high-accuracy that allows one to use the model for a quantitative and future comparative analyses 36 Ground Control Points (GCPs) were used and georeferenced by Differential Global Navegation Satellite System (DGNSS) using a Trimble® ProXRT GNSS in UTM-WGS84-22S. These used in Agisoft as monument points in coded targets. Due to the FOV wide-angle camera on the UAV, a customized calibration profile to recover planarity in the potos was used, and this calibration allow us to obtain a higher accuracy orthophoto.. Using a Structure from Motion (SfM) approach (Snavely et al., 2007) by Agisoft Photoscan Professional Edition algorithms workflow (Agisoft, 2013), after photo alignment and GCPs the following was accomplished: i) point cloud; ii) the dense cloud, where the model was cleaned, deleting the outlyer points and persons or other objects; iii) a mesh was built; and iv) the texture. After this workflow the model has been exported into a DSM in ascii format and an orthophoto in tiff extension, allowing the data to be imported into a Geographic Information System (GIS) software.

RESULTS AND DISCUSSION

This survey allow us to obtain a DSM with a 0.3 m cell resolution and an othophoto with a pixel size of 0.05 m. The orthophoto was draped on the DSM to improve this analysis, allowing us to identify the features in the area, such as the vegetation density. In this model the features without interest were not eliminated such as the people, cars or trees, because these elements may indicate the survey quality. Based on the model results (Fig. 2) it is possible to recognize clear differences between the natural and urbanized areas:

In the urbanized area (Fig. 2E and 2F): the dune is very fragmented, the blowouts are visible, the anthropogenic pressure is very high with a walkway above the dune, and behind the dunefacilities for vacationers are present. In addition, a -controlled washout is present, which removes sediments from the foreshore/backshore and carries them to the surf zone, decreasing the dune resilience. Since according to Tomazelli *et al.* (2008) most of the sediment to the natural system nourishment of the dune system in the Northern Littoral of RS comes from the backshore/foreshore, that are transported by the NE wind.In the natural area (Fig. 2C and 2D), an active dune field is present, with vegetation that increases in density inland. The sediment availability for the system equilibrium due to the seasonal beach profile changes is clearly higher and the washout is bigger than in the urbanized area and without human driven changes. Actually this area present the same morphological characteristic of the zone in 1948 where it is possible to identify the dune fields with a NE orientation but without anthropomorphic pressures.

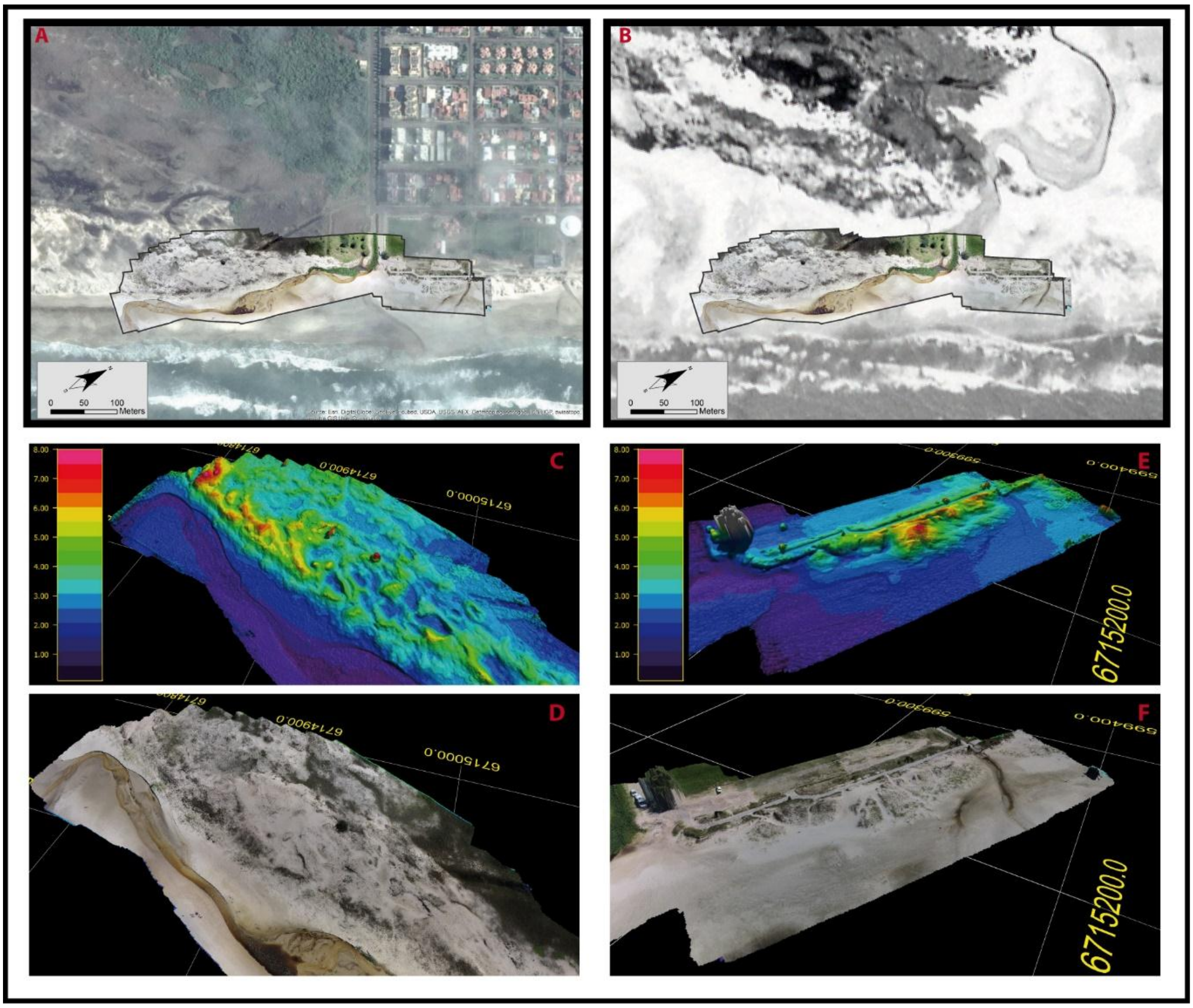

Figure 2: Results from the UAV survey: A) the orthophoto overlapping the World Imagery from ArcGIS Online data; B) the orthophoto overlapping the aerial photo from 1948; C) DSM in the natural area; D) orthophoto draped on the DSM in the natural area; E) DSM in the anthropogenic area; F) orthophoto draped on the DSM in the anthropogenic area

This survey has disadvantages and advantages, which are necessary to discuss to increase the potential of the method in future work. The disadvantages are the time to realize the workflow on Agisoft, mainly to obtain high-resolution data; a powerful computer is necessary; the coast of the GNSS equipment to do the GCPs survey with high accuracy; in the surveys where water and features in movement are present, there may be some gaps because, e.g. the vegetation is moved by wind, and the softwares are unable to do point matching between the photos; for a quantitative analysis of the volumetric changes with high accuracy , the vegetation cover may be a problem because it interfere in producing accurate results; the weather is another limiting factor because the Dji Phanton cannot fly in wind speeds above ~18 km/h winds. The advantages are the price to acquire high-resolution data if compared to the other UAV's or Lidar surveys that may be able to provide the same data accuracy; the facility to operate the UAV with high security; the logistics are simpler allowing a quick organization for the surveys after an interesting event such as a storm appears; easily repeatability of the data to increase the database and to aid coastal monitoring; the data may be used in different disciplines for scientific work as well for management work.

CONCLUSIONS

Using a low coast UAV, it has been possible conduct a first high-accuracy DSM to study the coastal environment in the coast of RS. This has allowed us to investigate the factors that act in this zone and to understand in a detailed scale the environmental response to the urbanized areas. The results obtained from the aerial photographic survey are of great quality, which is ± 0.13 m accuracy, and in accordance with other works (Mancini *et al.*, 2013; Casella *et al.*, 2014; Gonçalves and Henriques, 2015) where the same survey methodology was used using a SfM approach with a professional camera. Actually others surveys are programmed to monitor changes along the RS coast and to continue this study a survey after the winter season (September) will be carried out to monitor and quantify the seasonal changes. Moreover, this work provides a low cost methodology to aid the local authorities acquire high-resolution data in their area of interest and to improve the management and knowledge about the environment responses to natural and human pressures. In many cases, mainly in developing countries such as Brazil, the local authorities do not have funds to create a simple database to aid decision-makers in their actions, and this work and UAV provides a low cost alternative to support bothscientific research or the local authorities.

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LITERATURE CITED

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Chapter 5

5 –FINAL CONSIDERATIONS

5.1 –Scales integration

From the results obtained in this work and discussed in the previous chapters, it was possible to integrate the temporal scales used to study the two areas.

The scale integration was done to provide information about the system dynamic behaviour in the long-term (late Holocene) and in the short-term (seasonal). The information obtained from these studies contribute to the management and planning of coastal zones; they also provide a technical basis to help the decision-makers in the ICZM. The scale integration proposed in this work is a key question for an effective ICZM application (Buono *et al.*, 2015; Montanari *et al.*, 2014).

5.1.1- Capão Novo data integration

In the Capão Novo area, the information about the coastal evolution during the late Holocene was acquired through previous works developed in the north coast of the PCRS. The first studies were done in the area using the chronostratigraphic correlation and the geological map (Figure 2, *in chapter 1.1.2*) (Tomazelli *et al.*, 2005; Villwock & Tomazelli, 1995), along with the subsurface studies using the GPR, which have allowed the elaboration of a high resolution coastal model (Barboza *et al.*, 2011; Dillenburg *et al.*, 2009; Rosa, 2012).

Through the previous works, it has been possible to understand the long-term behaviour of the coastal-line, and the characteristics of the Capão Novo territory. According to the recent works, this territory is situated in an embayment zone of the PCRS, and presents a regressive trend. The GPR data obtained in this zone show a clear progradation of the system towards the ocean (Barboza *et al.*, 2011; Dillenburg & Barboza, 2014).

Regarding the Curumim holocenic barrier (Figure 1), aproximately 6 km north from Capão Novo, which presents the same behaviour as the barrier where Capão Novo is located (Dillenburg *et al.*, 2009), the regressive barrier prograded 4.7 km since the last 8-7 ky B.P. (Dillenburg & Barboza, 2014).

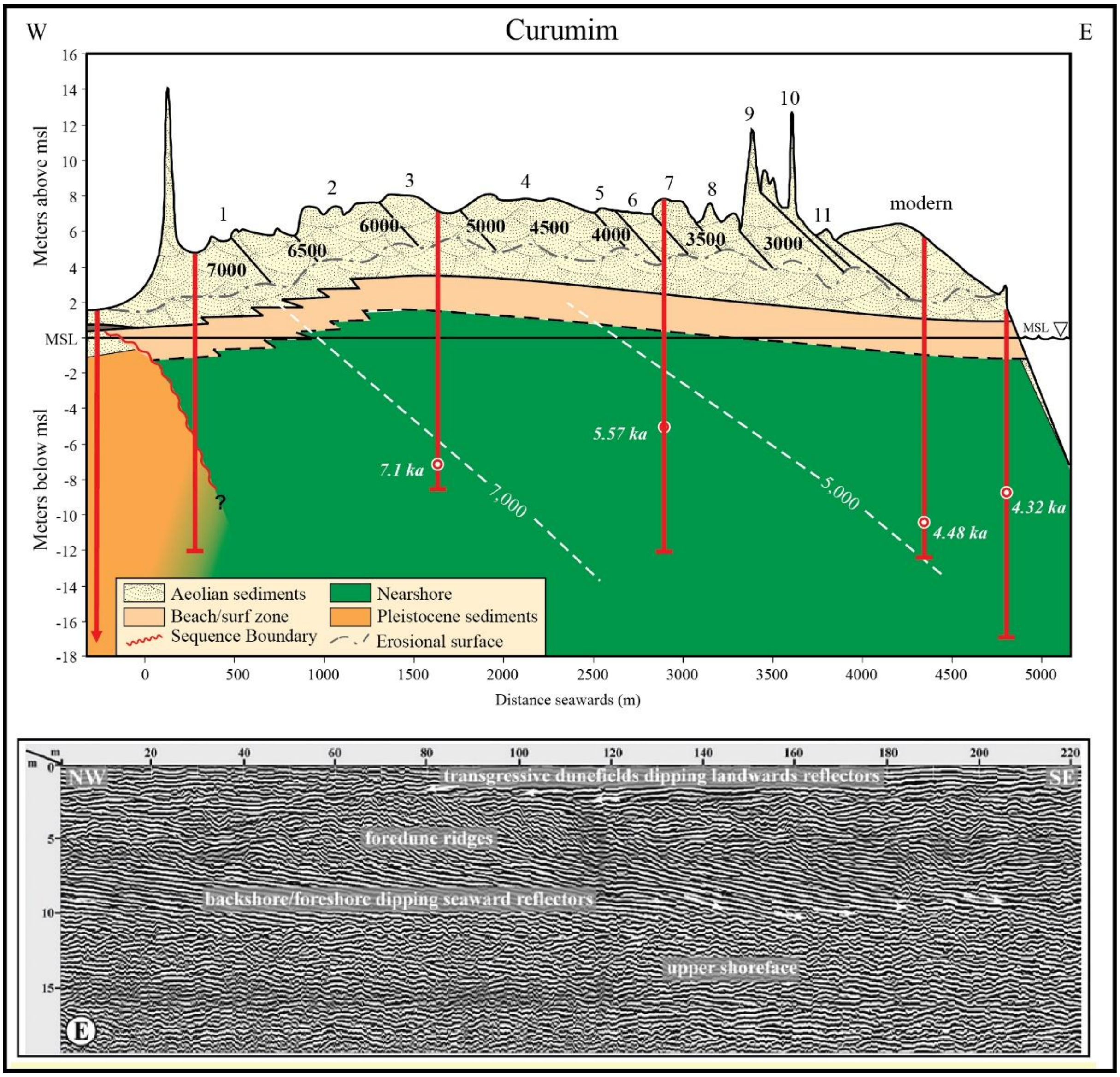

Figure 1: Above, the stratigraphic model with the Curumim Barrier evolution reconstruction (modified from Dillenburg & Barboza, 2014); bellow, the GPR profile with the identified radarfacies and the reflectors indicating the progradation towards the ocean (modified from Barboza *et al.*, 2011).

Considering the information obtained through the bibliographic research about the area (*see chapter 1.1.2*), it has been possible to obtain the coastal evolution model of the territory in a Holocene temporal scale, which defines the behaviour of the area during the Holocene.

Then, it is possible to affirm that the territory where Capão Novo coastal town is located presents a regressive behaviour, and it has been urbanized on an extensive sand barrier. Therefore, analysing the coastal system susceptibility and the coastal town vulnerability, Capão Novo is less susceptible and vulnerable to coastal erosion and sediment deficit due to natural factors, which increases the system resilience.

Considering the coastal system under study in a short temporal scale, existing data from the bibliography have been integrated with the high resolution DSM and orthophoto, obtained from the UAV survey, to help understand the present system trend.

According to Esteves (2004), from 1970 to 2000, in the Arroio Teixeira coastal town area (approximately 4 km northern of Capão Novo), the coast line has been presenting a progradation towards the ocean of 3 m/year, characterizing the zone currently as a regression zone. Through the comparison of the aerial photo from 1948 and a current satellite image (Figure 2), it is possible to observe the extinction of a transgressive dune field with barcan dunes without vegetation that moved above eolian deposits formed by the phases of the transgressive dune fields parallel to the coast line (Hesp *et al*., 2005, 2007).

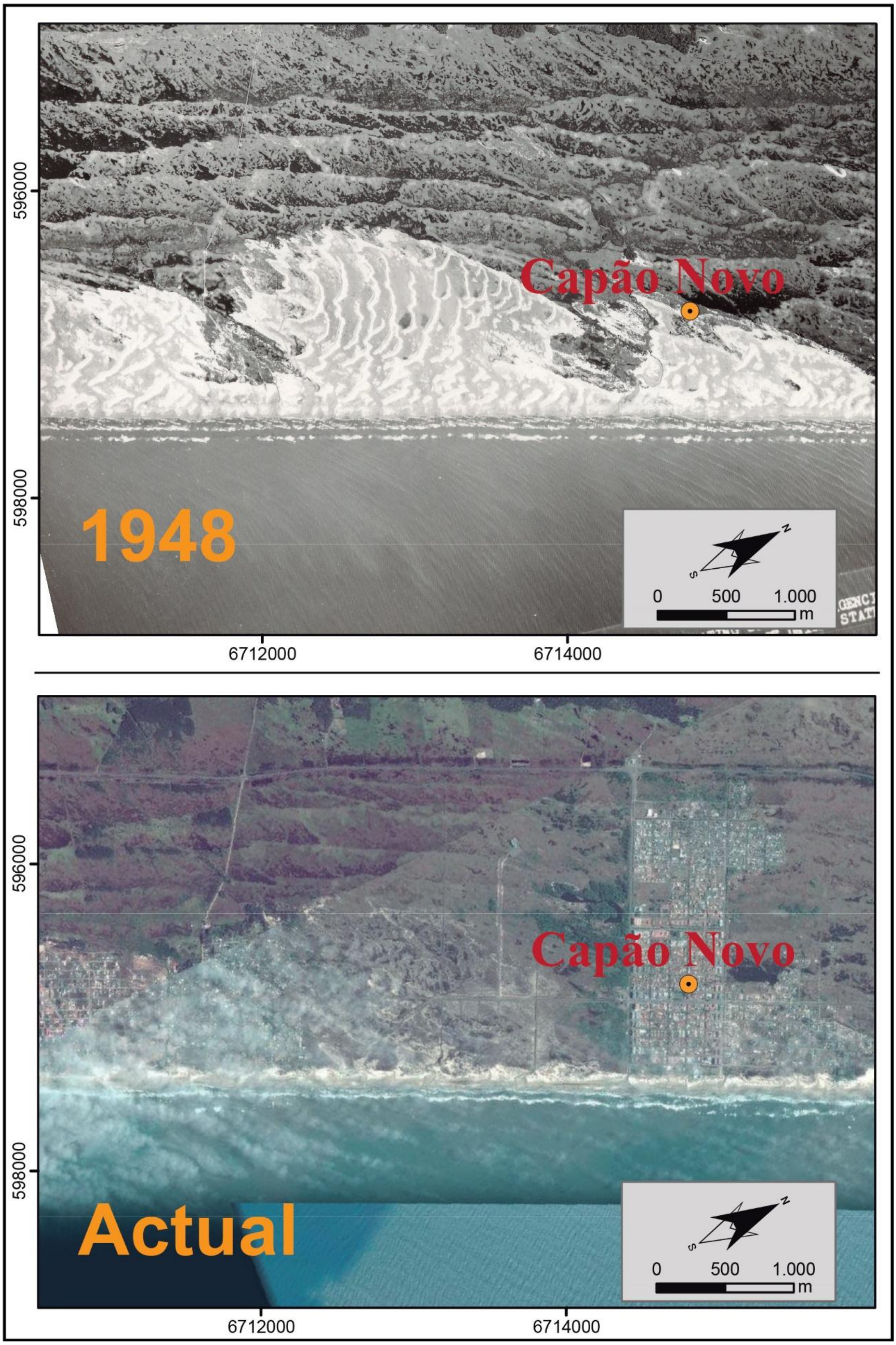

Figure 2: Above, aerial photo from 1948 showing the dunes field without anthropization in Capão Novo; bellow, a present image from Google Earth showing the anthropization on the same dunes field.

This comparison shows that the urbanization process on the north coast of RS has been the main factor to impact the local coastal systems, directly and indirectly, also causing the dune fields extinction (Tomazelli *et al.*, 2008). Oftentimes, misapplications of coastal plans have aggravated the situation (Esteves *et al.*, 2003).

To understand the current trend in the RS study area with more detail, in March 2015, DSMs and high resolution orthofotos were acquired, through aerial photogrammetry, using low-coast UAVs, an unprecedented work in this area (paper presented in chapter 4). Studies about the local coastal evolution and bibliography data show that the antropogenic factors are the main element putting the system in crisis in this area.

The orthophotos obtained from the photogrammetric survey allowed the analysis, for example, of the anthropization level in the natural area (Figure 3A), where it is possible to observe a dune field without man-made changes and the presence of a *sangradouro* with its natural flow. In the anthropogenic area (Figure 3B), adjacent to the natural area, it is possible to observe a different situation, with a fragmented dune, with several points of erosion, little vegetation, and the presence of anthropic elements, such as the boardwalk and a highely modified zone behind the dune.

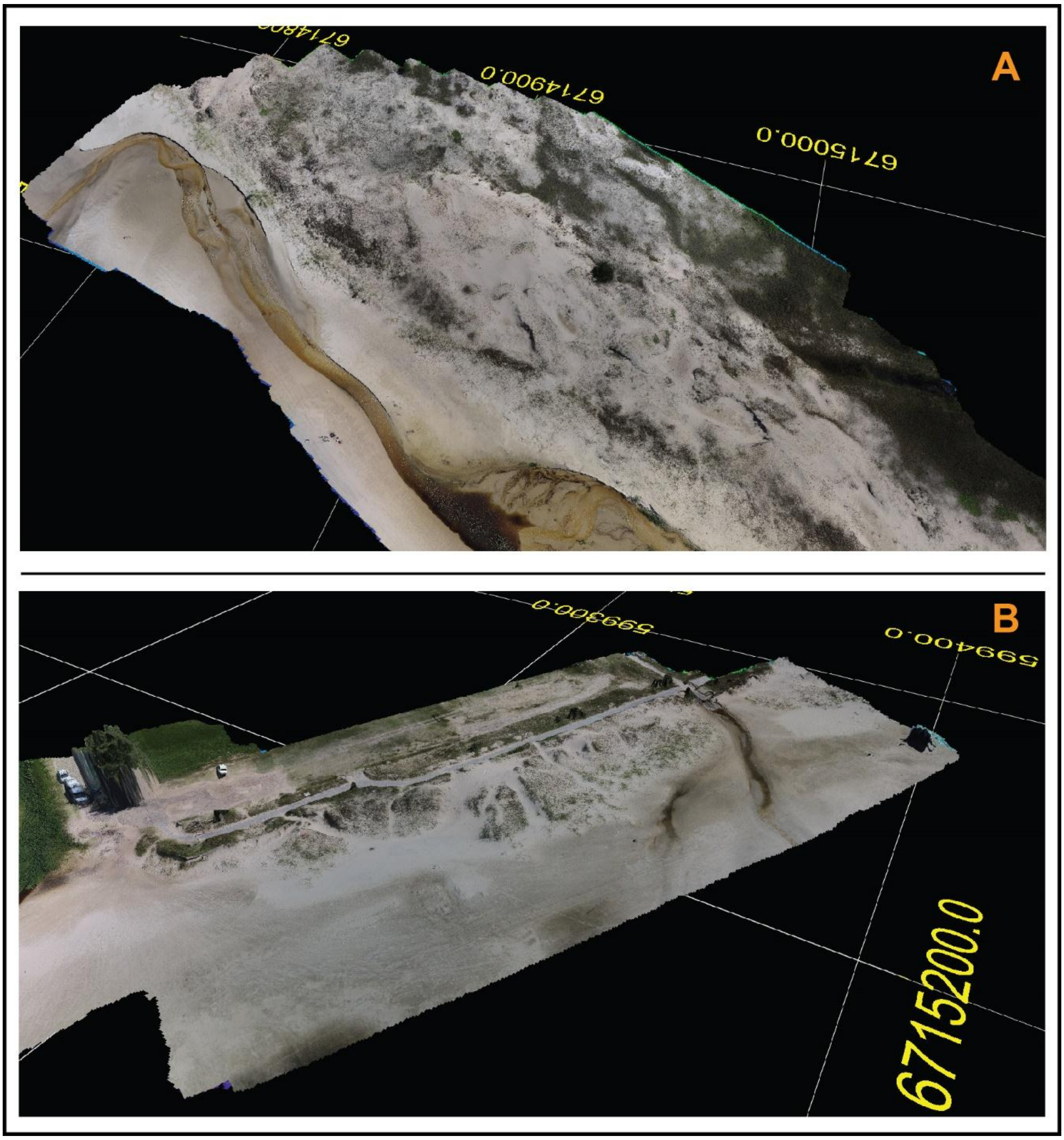

Figure 3: (A) High resolution orthophoto obtained through the UAV survey in the non-urbanized area adjacent to Capão Novo; (B) high resolution orthophoto in the urbanized segment in Capão Novo.

The DSMs were used to acquire high resolution topographic data. In Figure 4A it is possible to observe the dune filed topography, without blowout, especially in the foredune area, and the beach erosion by the washout. In the urbanized area (Figure 4B), the data clearly show the erosive process on the dune, with blowouts and the presence of anthropogenic elements, such as the trails on the foredune and the boardwalk.

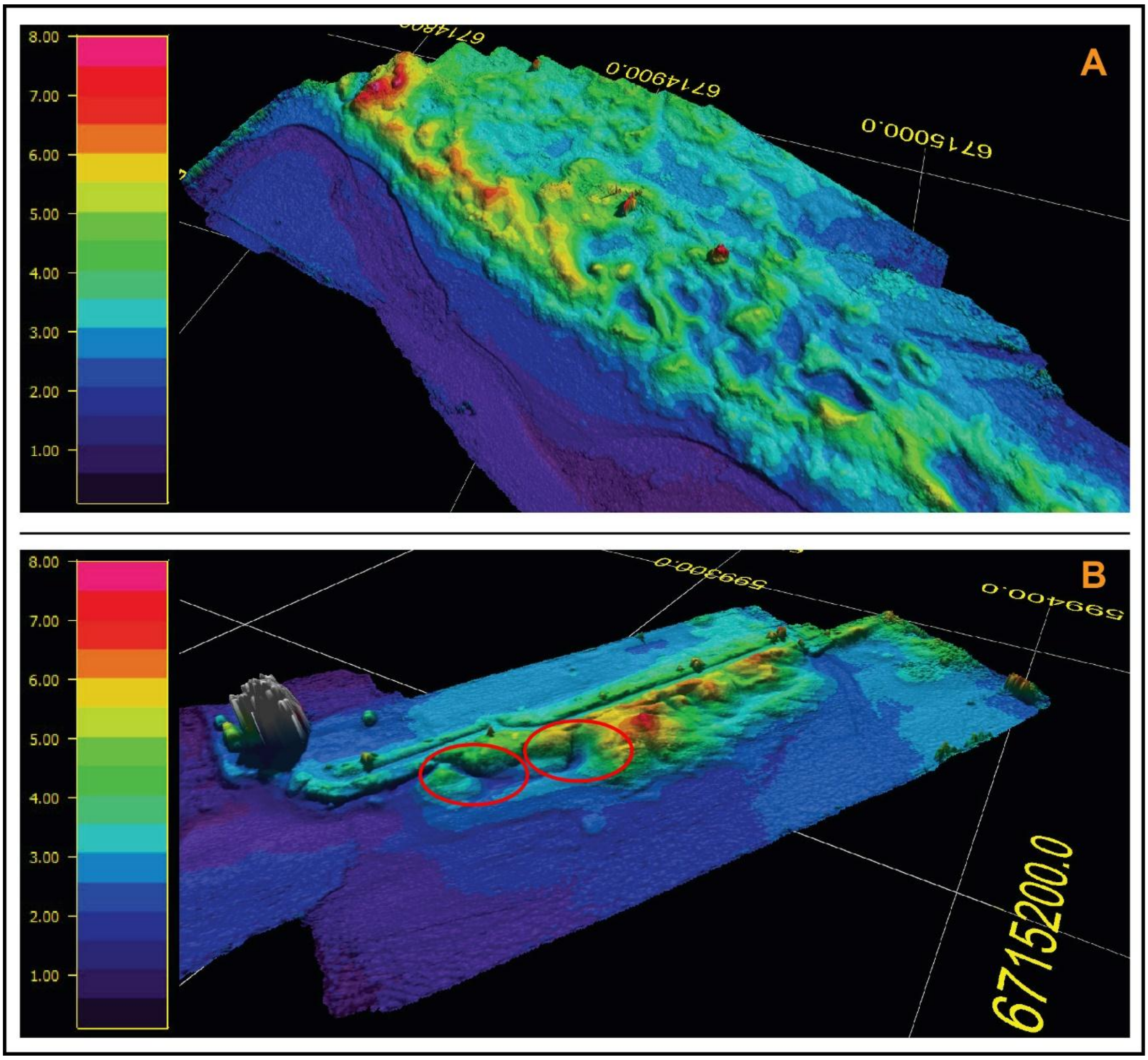

Figure 4: (A) High resolution DSM obtained through the UAV survey in the non-urbanized area adjacent to Capão Novo; (B) high resolution DSM in the urbanized segment in Capão Novo.

Through the comparison of the photogrammetric data, it is possible to recognize the dune susceptibility in the anthropogenic zone, and also the local vulnerability, since the dunes destruction may be caused directly by the damages of the anthropogenic elements. Moreover, this comparison shows that the anthropic factor is the main factor to put the local coastal system in crisis.

Unlike the data presented for the Ravenna area, these high resolution data in the north coast of RS have been acquired for the first time in the area. Due to the inexistence of a consistent database, it is not possible to do a quantitative analysis, such as, for example, the volume difference of distinctive dates that was shown in chapter 3. This survey is the first step to create this database with surface high resolution data, which is fundamental for the coastal system studies and also to be used by the local authorities as a subsidy to make decisions.

Therefore, to decrease the susceptibility and the vulnerability of the coastal system, and, consequently, avoid economic, social and environmental losses, the main actions should focus on the coastal processes that act on the system in the short term. Special attention should be given to the urban territorial plan, driving the actions to the dune and beach recovery processes, management plans and local monitoring.

Due to the disordered growth of coastal towns in the past, some coastal towns in the north coast of RS are requesting a master plan, which is the case of the Xangri-Lá municipality (Gruber *et al.*, 2005, 2008), and applying the ICZM to avoid future damages. The actions include: i) the construction of fluvial galleries for the *sangradouros*, to contain the sand bypass from the dunes to the shoreface (Tabajara & Weschenfelder, 2011), thus avoiding the dune erosion and the negative sediment deficit in the emerged system; and ii) the foredunes recuperation (Portz, 2012).

5.1.2- Ravenna data integration

Regarding the data used for the Ravenna coastal zone, this study presented the first coastal evolution model constructed using 2D subsurface data (*chapter 2*), from the GPR survey, while using a know-how exchange from the studies done in the PCRS. The previous works, which investigated the local coastal evolution, used mainly 1D data obtained from boreholes and penetrometer tests. These were used as the conceptual basis for the application of the new method.

The model presented in this Thesis still lacks dating to reconstruct a more accurate model of the region. However, the result obtained is a first step to increase the knowledge about the region and encourage the use of modern methods for coastal geology studies, contributing even more to the existent database.

Along with the historical cartography, it was possible to analyse qualitatively the morphological changes on the coast line and in the region, due to anthropic and natural factors in the past four centuries. Combining the historical cartography and the data obtained from previous works, it was possible to propose the surface geological model for the Ravenna coastal plain without the anthropic changes (*chapter 2*).

The importance of the proposed model is demonstrated by the fact that the Ravenna coastal plain is a region under strong human influence, that has transformed it for its' own benefit. Until nowadays, this region has required integrated management to reduce its susceptibility and vulnerability. This management, however, has a high economic cost, which is payed by the Emilia-Romagna region and the districts.

Due to these strong changes, several morphological indicators for the reconstruction of the regional genesis have been cancelled. In many cases, the lack of these indicators may change the interpretation of the real genesis of the territory. This implies a lack of knowledge about the area when developing the guidelines for the management and territory design, thus increasing the area vulnerability and, consequently, the economic costs.

The model in Figure 5 was elaborated to show the genesis of the region, helping future studies and the actions associated with the ICZM. From the results obtained, it is possible to affirm that unlike the barrier-lagoon system in Capao Novo, the Ravenna coastal system consists of an older barrier system and of a current barrier-lagoon, formed in the last four centuries, and these have been controlled mainly by the climate anomalies caused by the LIA.

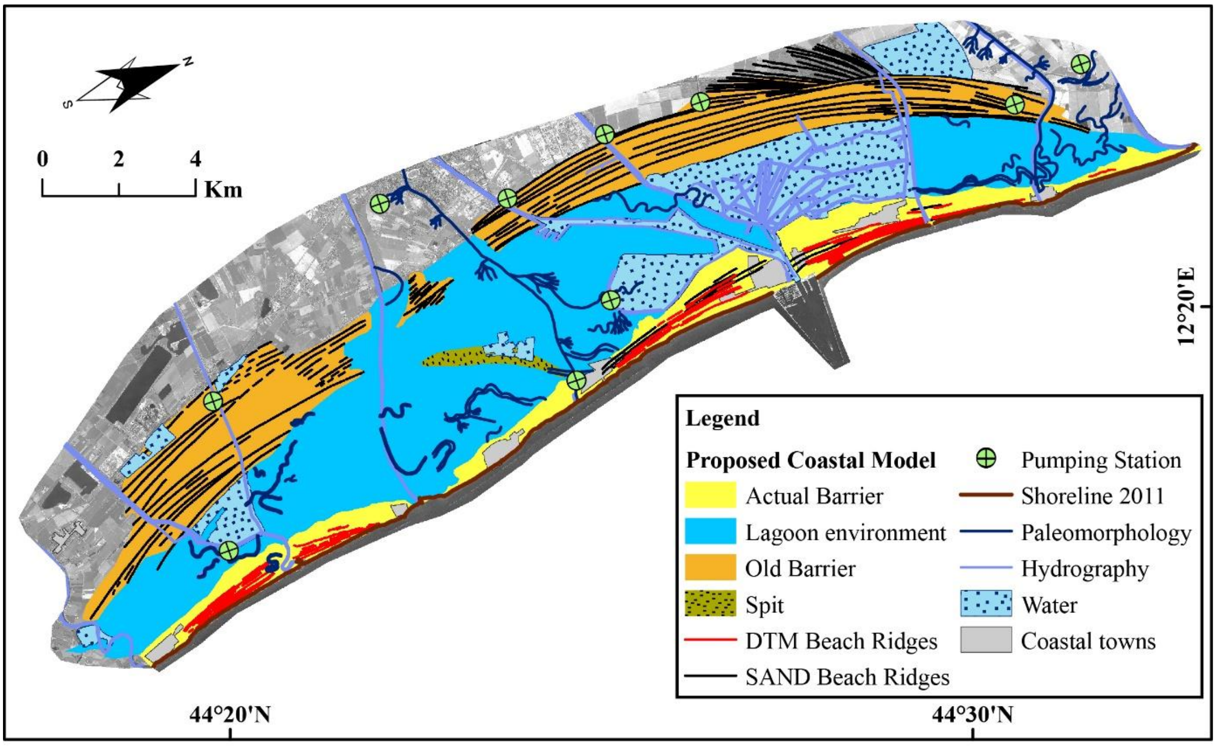

Figure 5: Surface geological model constructed to represent the surface geology in the Ravenna coast zone, with the identified beach ridges and the local paleomorphology, without human interventions on the territory.

The current barrier, where most of the coastal towns are located, was shaped due to the erosion of the deltas and the sediment rework by the waves; this dynamic has been described in previous works (Carbognin & Tosi, 2002; Marabini & Veggiani, 1992; Simeoni & Cobau, 2009). Through this dynamic, a narrow sand barrier was formed, where the water bodies among the barriers were recuperated by people mainly to be used in agriculture fields.

This model also updated the local geological chart in the 1:50.000 scale, where beach ridges, which could lead us to understand that the area had regressive ridges that formed the current barrier, have been mapped. The model presented, together with the data from previous works, shows that this is not a regressive barrier, it is a barrier formed by the sediment reworked by the waves as cited above.

Unlike the works related to the recent coastal evolution in Ravenna, works that describe the present state of the coastal system are plentiful. These works from scientific papers and technical reports, are elaborated in several areas of knowledge and by several organizations related to the region, the municipality, and research groups, creating a rich database.

The Emilia-Romagna region and the Ravenna municipally have a rich database in web-GIS format, with interactive cartography and free access, where, in some cases, data can be downloaded freely. This database contains the mapping of parks and areas under the jurisdiction of the region, the geological and the soil cartography, the coastal and marine informative system, the territorial informative system and others (Provincia di Ravenna, 2015; Regione Emilia-Romagna, 2013).

The works realized in the area and cited in this Thesis (*chapter 1.1.3; chapter 3*) contribute to the furthering and increasing of the knowledge about the current coastal system trend. These data allowed a better analysis of the real state; moreover, it was possible to quantify this trend through the comparison of the seasonal coastal system changes.

The paper presented in chapter 3, which used new technologies through the UAVs survey, served as a base for the considerations about the current state, comparing and quantifying the changes to the coastal system during the period between September 2014 and April 2015 (Figure 6). In this paper, the local changes caused by humans and the current system vulnerability in relation to the natural factors are clear.

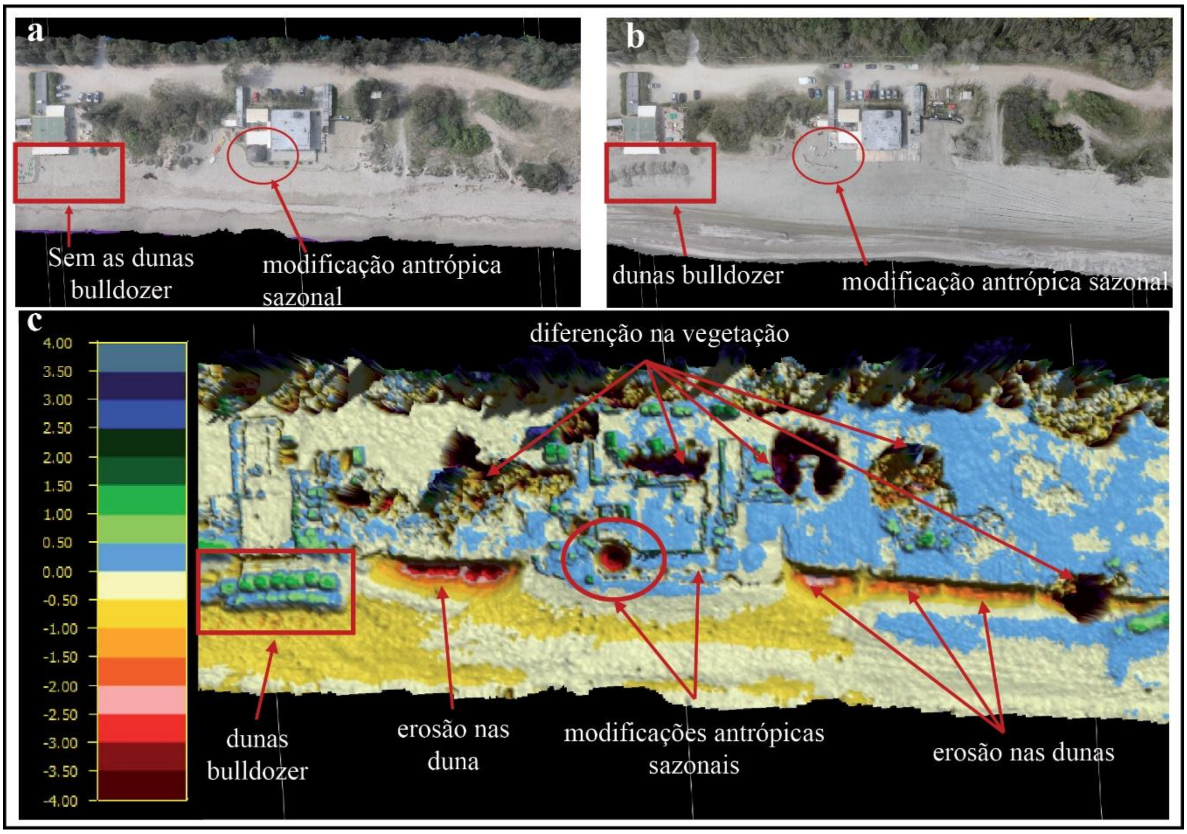

Figure 6: Seasonal comparison showing the changes due to anthropogenic and natural factors between September 2014 and April 2015. (a) Details of the survey with UAV done in

2014; (b) details of the survey with UAV done in 2015; (c) details of the surface difference between 2014 and 2015.

According to studies done in the area, the Ravenna coast has an erosive trend (Armaroli *et al.*, 2012; Gambolati *et al.*, 1998; Harley & Ciavola, 2013), which requires an effective territorial plan and the ICZM application to decrease the local vulnerability due to the coastal towns and agricultural areas' presence, and the system susceptibility due to natural and anthropic factors exposure.

From the 1970s to the present, this area has been receiving many interventions for coastal protection, to contain the damages caused mainly by erosion. These interventions include fixed, transversal and parallel barriers; bulldozer dunes to protect the fixed structures from the damages of the storms; and the beach nourishment: currently, a very utilized method, that according to the Emilia-Romagna region studies, is the most efficient even though it requires a high economic investment.

The topographic profiles obtained on the UAVs surveys clearly show the current state of this zone and the attention that is needed (attachment 1, the topographic profiles showed in the chapter 3 with the location for each profile in each stretch).

When the results obtained from the coastal evolution model, the seasonal changes analysis, and bibliographic data are integrated, it is possible to understand the current system behaviour and the local territory occupation more clearly. The surface geological model (Figure 7) shows that the all coastal towns were built on the most recent sand barrier, formed by erosion on the deltas.

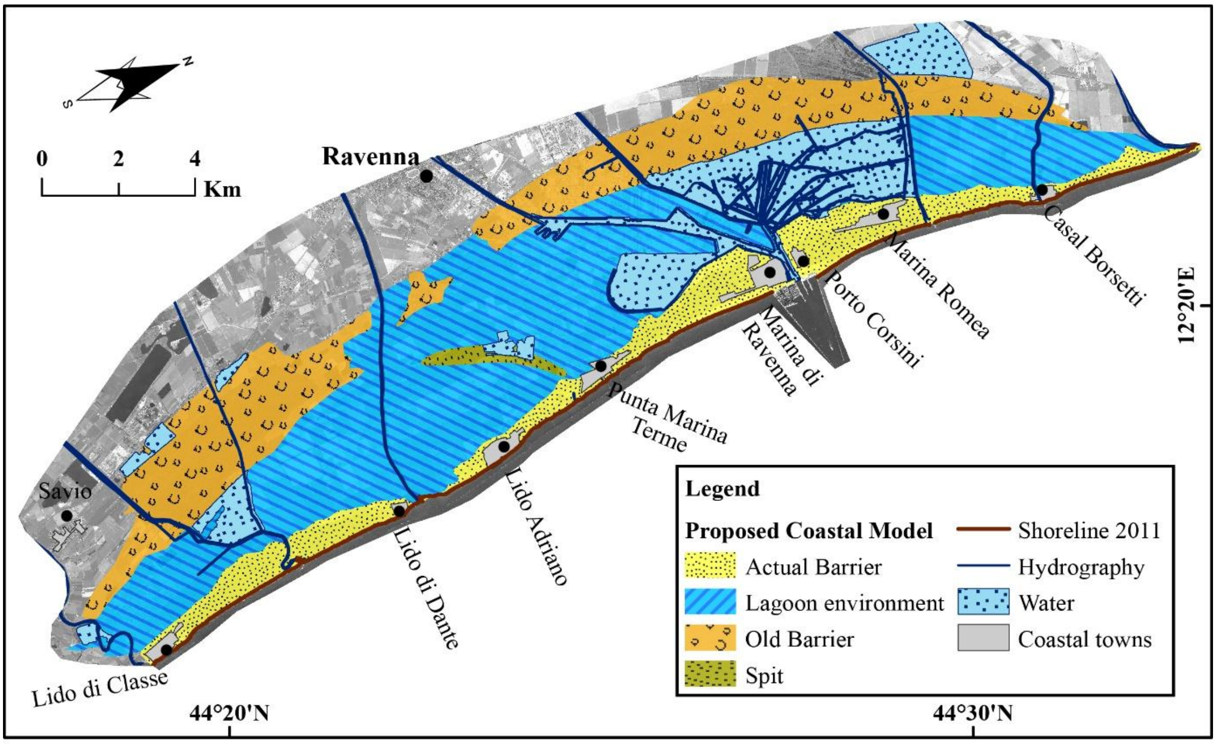

Figure 7: Geological model used to help the local ICZM actions, showing the coastal towns on the sand barrier.

The region has a narrow sand barrier that, in zones such as the ones between the Lido di Dante and Lido Adriano towns and in the Casal Borsetti area, is almost non-existent due to coastal erosion. Behind the sand barrier, there is a lagoon environment, recuperated and kept emerged due human-actions, with a topography that, in most parts of the area, does not exceed 0.5 m, where the current barrier, with its approximately 5 m, is the only protection against the sea intrusion in the agriculture fields.

Along with this factor observed from the recent coastal evolution reconstruction, the data from the Emilia-Romagna region technical reports are integrated, which indicate: i) the decrease of the river sediment input, that reduces the natural nourishment of the coast; ii) the intensive anthropization; iii) the present erosive trend (Regione Emilia-Romagna, 2011a).

The knowledge obtained in chapter 3 shows not only the intense human-changes, which occur every year in the area, but also how the occupation in the current barrier is vulnerable to natural factors, such as the winter storms. In others words, to maintain this zone occupied and decrease the economic, social and environmental risks, a high investment by the local authorities is necessary; this investment, between the years of 2006 and 2009, was around 7.8 million euros, being 2.2 million euros exclusively for the Ravenna coast (Regione Emilia-Romagna, 2010). This justifies the necessity to understand the local system behaviour in its most complex form, since its formation until its present behaviour.

5.2 –Scales integration in the ICZM

The studies about coastal evolution in the study area allow the understanding of the current morphology in the region. This is shaped mainly due to the antecedent morphology and due to climate variations which occured during the Holocene, such as the glaciation in Brazil and the LIA in Italy, that act upon the system changing the sedimentary balance (Dillenburg *et al.*, 2000; Oost *et al.*, 2012).

The studies about the coastal system behaviour on a short temporal scale, in their turn, showed the present state of the system, indicating the current trend and the main pressure elements, natural and anthropic. These studies are capable of indicating the immediate measures for the management and maintenance of the system in order to decrease its susceptibility and vulnerability, consequently increasing the system resilience.

However, the studies on a short temporal scale do not give indicators for the ICZM actions in a long term period, which seek the reestablishment of the natural system dynamic (Oost *et al.*, 2012), and therefore decrease not only the coastal vulnerability and susceptibility, but also the expenses for the maitanence of the territory. This provides for the sustainable use of the coastal zones with an appropriated management plan involving all stakeholders.

From the results, it was possible to make considerations for both study areas regarded in this work, showing the importance of the barrier-lagoon system study in different temporal scales.

5.2.1 –Capão Novo

Regarding Capão Novo, it is possible to conclude that, due to its evolutionary and geomorphological characteristics, this territory is a barrier-lagoon system with more resilience against erosion processes, which have a high financial cost to combat against. This higher resilience occurs because the system has been progradating since the Last Glacial Maximum to the present, with a large sedimentary surplus that contributes to the natural system maintenance.

Unlike other regions in the PCRS, which were with a transgressive trend (Dillenburg *et al*., 2009), as is the case in the case of the Farol da Conceição, which is located on a projection of the PCRS and due to its morphological configuration, has been under a strong erosion process, as shown in Figure 8.Concerning the ICZM, in case of urban occupation of this area, the planning and management must follow completely different guidelines from those applied in areas in progradation.

Figure 8: Coastal erosion on the Farol da Conceiçao location in the transgressive segment of the middle coast of RS. Photo from 1988 with the old lighthouse and the house behind; photo from 1997 with the old lighthouse destroyed; photo from 1999 with the house behind the old lighthouse destroyed (modified from Toldo Jr. *et al.*, 2006).

In the case of urban occupation in zones like the Farol da Conceição location, if the studies about the recent coastal evolution are not considered, these zones would require high economic investments for maintenance, repairing, and mitigation measures. The investments are to prevent cases such as the one in the Hermenegildo coastal town (Santa Vitória do Palmar) on the south coast of RS, where there was a disordered occupation on the beach/dune system, and, at the present, these zones represent a social and economic problem, with strong erosion processes (Figure 9).

Figure 9: Damages done by coastal erosion in the Hermenegildo coastal town (Santa Vitória do Palmar) in the south coast of RS.

Considering the current coastal state, it is clear that the local beach and dune system crises are caused mainly by the wrong territorial occupation and urbanization, increasing the pressures on the system, as it was possible to observe in the aerial photograph comparison, and in the DSM and orthophoto elaborated for the zone. These data are important to understand the real system state and essential for local actions that have the desidered effects with lower costs and higher effectiveness of the measures defined by the decision makers.

Hence, the precautions to be taken for the area occupation may concentrate in the natural dynamic maintenance through the reduction of the pressure on the coastal system. The application of coastal recovery and management models already applied in different municipalities in the north coast of RS, which consider mainly the recuperation of the dunes through methods that have already presented good results in the area (Portz, 2012) (Figure 10) can be cited as examples. The canalization of the *sangradouros* decreases the foredune erosion and the sediment bypass from the backshore to the shoreface (Tabajara & Weschenfelder, 2011) (Figure 10B and 10C).

Figure 10: Foredunes recovery in the north coast of RS: A) beginnig of the intervention to recover the foredune; B) sediments accumulated by the eolian transport; C) washout canalization to prevent dune erosion; D) dunes recovery above the canalization (A and B modified from Portz, 2012; C and D modified from Tabajara & Weschenfelder, 2011).

From the scales integration, it is recommended that an occupation with less pressure on the coastal system should be considered for the future actions. This can be done with constructions more distant from the foredunes prohibiting the occupation in active dynamic areas, such as the emerged beach and the foredunes, and creating alternatives to avoid the traffic of people on the dunes through the construction of footbridges. Moreover, it is also indispensable for the development and application of the integrated management plans to follow the guidelines on national, regional and municipal levels, with a continuous monitoring program in order to prevent future economic, social, and environmental losses and maintain the high resilience of the coastal system.

5.2.2 –Ravenna Coastal Plain

From the studies done on the Ravenna coastal plain investigating the system in two temporal scales, it can be concluded that, based on the recent coastal evolution studies about this barrier-lagoon system, this system is in a more critical situation if compared to the Capão Novo area.

In this case, the current barrier is not a regressive barrier, it is a barrier formed due to the erosion of the deltas, showing that the sediment supply was not abundant enough to create a regressive strandplain. The major sediment supply occured at the beggining of the LIA, when the coast was dominated by the rivers. This barrier is more susceptible and has less resilience if compared to a regressive barrier because there is a lagoon environment behind the sand barrier which is approximately 800 m narrow in the case of Ravenna, compared to the nearly 4000 m in Capão Novo. This narrow barrier started to be occupied with intensive urbanization (Figure 11A and 11B), generating several modifications to the territory, which increased the pressure on the beach/dune system; the foredune and the emerged beach have been occupied with towns and fixed structures to accomodate the tourism demand during the summer season.

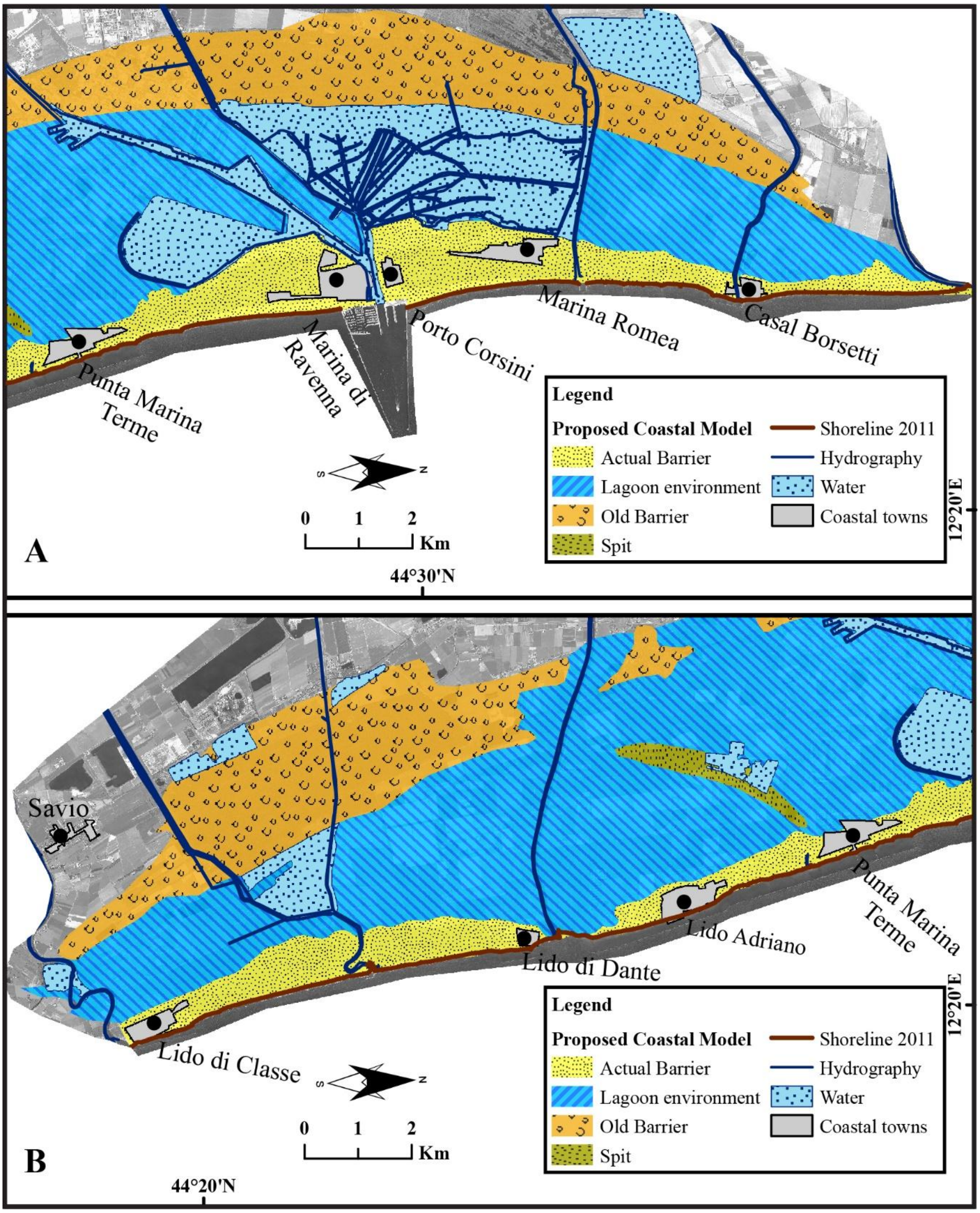

Figure 11: Detail of the coastal towns above the current sand barrier. A) North segment of the Ravenna coastal plain; B) south segment of the Ravenna coastal plain.

Due to the high anthropic pressures on the system (urbanization, subsidence due to fluid exploration, and river dams), combined with the local natural pressures (subsidence and winter storms), this territory came to be really vulnerable (Figure 12). Consequently, significant amounts have been invested to reduce and avoid greater damages to maintain the region.

Figure 12: A and B) Coastal protection works in the Ravenna coast with parallel and transversal groynes; C and D) fixed structures on the beach in the Ravenna coast damaged by the winter storms.

The main actions taken since the 80's to contain the damages caused by the cited factors were the construction of coastal protection works using groynes emerged and submerged, parallel and transversal to the coast line. Lately, the main action is the beach nourishment; two big interventions were done in 2002 and in 2007, with a cost of approximately 13 million euros (Regione Emilia-Romagna, 2010).

According to studies done by the Emilia-Romagna geological survey (Regione Emilia-Romagna, 2010), between 1984 and 2007, 8.1 x 10^5 m^3 of sand for the beach nourishment was used. Considering the price of the sand as being 13 euros/m^3, around 105 million euros were spent for the coast maintenance without considering others costs, such as the cost to maintain the territory drainage. This value shows the importance of an effective application of the ICZM and of an appropriate management plan for the zone, knowing the variables that act in this system, through the analysis of the current system behaviour, then justifying the importance of the studies done on a short temporal scale.

Based on the results obtained in this work about the Ravenna coastal plain, this zone needs more severe measures if compared to the ones proposed to Capão

Novo. It is an unappropriated territory for urban occupation, which requires high investment for maintainance. Nowadays, the most appropriated measures for the Ravenna coastal territory are the reduction of the urban expansion, and an appropriate master plan. These measures should begin with the end of constructions near the areas adjacent to foredunes and the emerged beach, foreseing in the future the change of the fixed strcutures by removable structures which can be set up during the summer season and removed before the winter. Reducing the pressure due the anthropic factors together with the coastal maintenance program already existant, it will be possible to apply recuperation measures for the foredunes, following the successfull cases such as the ones on the north coast of the PCRS.

All these measures have a main objective to decrease the system vulnerability and increase the system resilience. This will also decrease the future economic investments to maintain the coastal system and repair the social, economic and environment damages, and will allow the use of the services offered by the coastal system in a more sustainable way, avoiding the errors committed in the past.

5.3 –Conclusion

From this work, it is possible to conclude that barrier-lagoon depositional systems require studies from their genesis to their current behaviour, investigating the geomorphology characteristics of the region. These characteristics are the base for the biotic development, which has a direct and important interaction when considering the territorial occupation by humans.

The scales integration treated in this Thesis demonstrates the key to understanding and knowing the coastal territories. This integration allows an appropriate analysis of the entire system, helping to understand the natural and anthropogenic actions on the coastal system. This Thesis also proposes the use of news tools with good cost-benefit to develop works in the academic scope and in the territorial management field, since one of the objectives of this Thesis was to use methods that are easily accessible and operable, that can be operated with basic knowledge about the area.

The main methods in this study that are unprecedented in the studied areas are the surveys done with the GPR and UAVs. These data were integrated with the data from the already existent database and with the information obtained from the previous works, which are extremely important to construct the coastal evolution model to understand the current system state. Data obtained with the other validated methods for application in the coastal zone studies and cited in this work in the methods chapter were also integrated.

The GPR, which was used to acquire the subsurface data in 2D to construct the Ravenna coastal plain model, is presented in chapter 2. Although the equipment has a high cost, a solution to acquire this data with low costs in the academic scope, may be the sharing of the equipment between research groups that already have the instrument and the expertise.

One way to decrease the costs in the case of the GPR used by the local authorities to be applied in the coastal management to characterize the subsurface in specific situations may be to rent the instrument for a few days, amortizing costs and also considering the need for experts to interpret the acquired data. Generally, for the GPR surveys only a few days are necessary to acquire the data, for example, only three days were necessary to complete all the surveys in the Ravenna area.

Considering the UAVs surveys, this method allowed the obtainment of DSMs and orthophotos with high resolutions. Professionals UAVs were used, which have a hard operability; the use of these instruments allowed the elaboration of the research presented in the chapter 3 of this Thesis.

In this Thesis a new method to obtain the same data with the same resolution using commercial UAVs with low cost and with easy operability was developed. The applicability of this method in the coastal systems was presented in chapter 4. The main advantages of these UAVs (Figure 12; *chapter 1*) are the easy operability of the equipment and the low cost.

The proposed methods have been successfull and allowed the acquisition of the data to elaborate this work and to test and validate the hypothesis that: “The anthropization in the coastal zones under study in this research changed the coastal morphology and dynamic, reflecting in their resilience, susceptibility and vulnerability, if compared with natural coastal systems”. In addition, they demonstrated the utility of this work when applied for the ICZM and for the barrier-lagoon systems that are in different geologic contexts.

This Thesis is important due to the fact that by studying the coastal systems in different temporal scales the knowledge obtained can help to determine the actions to be taken in the ICZM. Specific guidelines for each barrier-lagoon system can be defined, since the behaviour of these systems are very dependent on the context which they are in, varying for each location, as explained along this work.

Considering the two barrier-lagoon systems studied, it is possible to affirm that, although they are two similar barrier-lagoon systems, there is a difference in their spatial scale, where in Brazil all morphological elements present in the territory are bigger than in the Italy area. This difference may be observed in the morphology aspects ranging from the depositional basin dimensions to the size of the lagoon environments. Despite this scale difference between the areas, they have similiar problems, which are problems related to the coastal system sedimentary equilibrium, linked with unplanned urbanization; these cause social, economic and environmental damages in both areas as it was shown in this thesis.

By expanding the results of this work to other barrier-lagoon coastal systems, it can be affirmed that: the specific actions for each system must be determined based on the local coastal evolution studies and on the current system state, while also considering the factors that determine the system evolution and its current behaviour. These results validate the hyphotheis that: “For effective coastal zone management, the integration of the knowledge about the recent territorial evolution with the knowledge about the current state is fundamental in the ICZM of barrier-lagoon depositional systems”. It is possible to elaborate an appropriate management plan for each zone and integrate the biotic and social components to make an integrated territorial plan only after obtaining all of this information.

This work shows not only the importance of understanding the barrier-lagoon system behaviour and studying these systems since their formation until their present behavior due to natural and anthropogenic factors that act on the areas; it also showed methods with appropriate cost-benefit to be applied to both the knowledge and characterization of the area when used in the academic scope, and to assist in the understanding of the territory and monitoring programs by local authorities, providing further information to guide decision making by managers and other decision makers in the coastal area.

This Thesis describes the authors’ ideas, that consider that the relation between the scales, temporal and spatial, have a fundamental importance for the future of the

Integrated Coastal Zone Management, since the major scales determine and condition the minor scales' development, through the scales hierarchy.

Moreover, this thesis showed that the applicability of the new instruments, integrated with previous works, is the base for any scientific development, stressing the importance of initianing any scientific study from the basic concepts of the scientific field under study, which must be applied through the scientific reasoning, thus bringing us to more complex results through theoretical fundamentals.

In conclusion, it is important to explain the results obtained during this doctorate project , which provided a knowledge exchange between the Geoscience Institute from UFRGS and the Biologic, Geologic and Environmental Science Department from UNIBO, and the creation of a Joint Laboratory for Coastal Studies between UFRGS and UNIBO (http://www.magazine.unibo.it/archivio/2014/10/06/alma-mater-e-universidade-federal-do-rio-grande-do-sul-insieme-per-la-ricerca; http://www.ufrgs.br/ufrgs/noticias/comitiva-da-universidade-de-bologna-visita-a-ufrgs; last access 28/12/2015), this project was mentioned as a successful project with concrete results already obtained and other ongoing projects, supported by the institutions and by the Ravenna and Porto Alegre municipalities (http://www.ravennatoday.it/cronaca/scienze-ambientali-collaborazione-ravenna-porto-alegre-brasile.html; last access: 28/12/2015).

New research methods were taken to UNIBO through the use of the GPR, with training courses and field surveys realized in Italy; and for UFRGS, the new methods presented include the UAVs surveys in the coastal zone, also with training courses and field surveys. Furthermore, ICZM actions were discussed and exchanged in both areas to obtain a better efficiency in the future actions on the coastal zone, more specifically the coastal zones located in systems of barrier-lagoon type.

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ATTACHMENTS

ATTACHMENT 1

Supplementary material (chapter 2):

Proposed soil association	Soil Acronym	Depth - cm (from	- to)	Sand (%)	Silt (%)	Clay (%)
MUD SOIL	GLS 2	0	50	2	60.2	37.8
		50	90	.5	55.5	44
		90	140	1.3	58.7	40
		140	160	4.6	75.4	20
	GLS 3	10	40	3.3	49.9	46.8
		70	100	1	45.2	53.8
	MCB 1	0	50	20	52	28
		50	70	17	54	29
		70	90	7	62	31
		90	110	6	68	26
		110	140	9	70	21
	SVO 1	10	35	17.5	61.5	21
		55	65	22.2	64.1	13.7
		75	85	86	8	6
		110	130	93	5.5	1.5
		140	145	11.7	73.5	14.8
	RNV 1	0	65	14	49	37
		65	85	14	39	47
		85	100	12	45	43
		100	130	16	55	29
	SMB 1	0	50	6	72	22
		50	75	3	71	26
		75	105	5	73	22
		105	150	7	79	14
	VIL 1	0	50	58.3	28.9	12.8
		50	80	60.5	27.8	11.7
		80	120	89.3	7.5	3.2
		120	150	12.5	71	16.5

Soil Type from I Suoli dell'Emilia-Romagna (2015).
The representative soil profiles for MUD SOILS:

Galisano - loan clayey silt
(GLS2)

Galisano - clayey silt to silt and sandy substrate, in coastal plain
(GLS3)

Marcabò - loan silt
(MCB1)

Soil Type from I Suoli dell'Emilia-Romagna (2015).
The representative soil profiles for MUD SOILS:

Savio - loan silt
(SVO1)

Roncole Verdi - loan clayey silt
(RNV1)

Soil Type from I Suoli dell'Emilia-Romagna (2015).
The representative soil profiles for MUD SOILS:

Sant'Omobono - loan silt (SMB1)	Villalta - loan sand very fine (VIL1)
	

Proposed soil association	Soil Acronym	Depth - cm (from - to)		Sand (%)	Silt (%)	Clay (%)
SAND SOIL	CER 1	0	60	96	3	1
		60	80	98	2	0
		80	110	99	1	0
		110	120	99	1	0
	CER 3	0	3	93	5.5	1.5
		5	10	91.3	6.9	1.8
		15	30	94.5	4.8	.7
		40	80	98.2	1.3	.5
		90	115	99.5	.3	.2
	CER 4	0	40	76.6	12.6	10.8
		40	50	79	13.5	7.5
		50	80	82	9	9
		80	110	88.4	7.1	4.5
	SAV 1	3	17	91	6	3
		17	60	95	5	0
		60	100	95	5	0
	SAV 3	10	35	97.8	1.2	1
		40	70	97.5	.7	1.8
		90	120	98	.3	1.7
		130	160	97	2.2	.8
	PIR 1	0	20	81	9	10
		20	60	93	1	6
		60	70	94	1	5

Soil Type from I Suoli dell'Emilia-Romagna (2015).
The representative soil profiles for SAND SOILS:

Cerba - fine sand (CER1)

Cerba - fine sand with superficial organic horizon (CER3)

Cerba - loan sandy with high contents of carbonate (CER4)

Soil Type from I Suoli dell'Emilia-Romagna (2015).
The representative soil profiles for SAND SOILS:

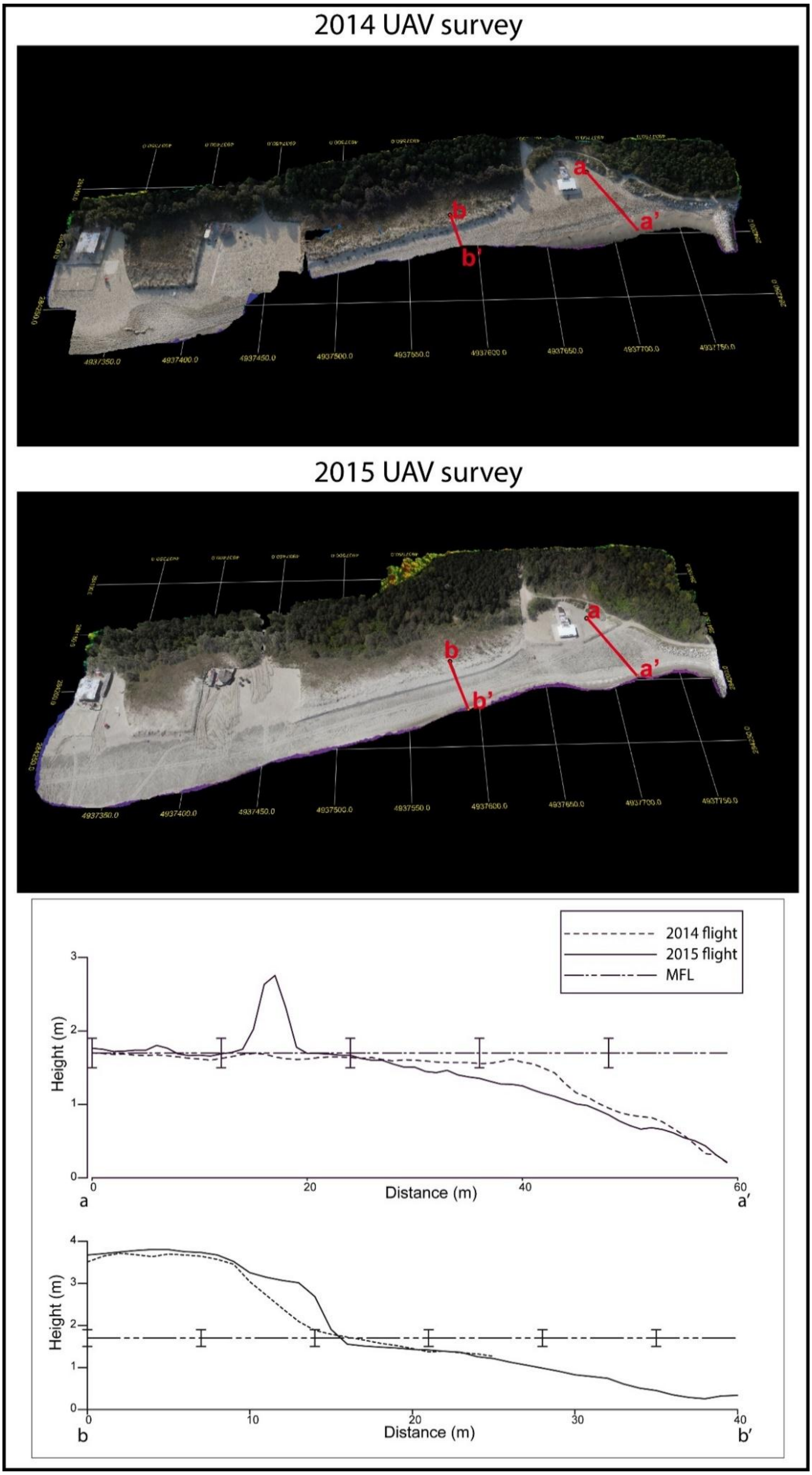
San Vitale - fine sand (SAV1)

San Vitale - loan sandy with high contents of carbonate (SAV3)

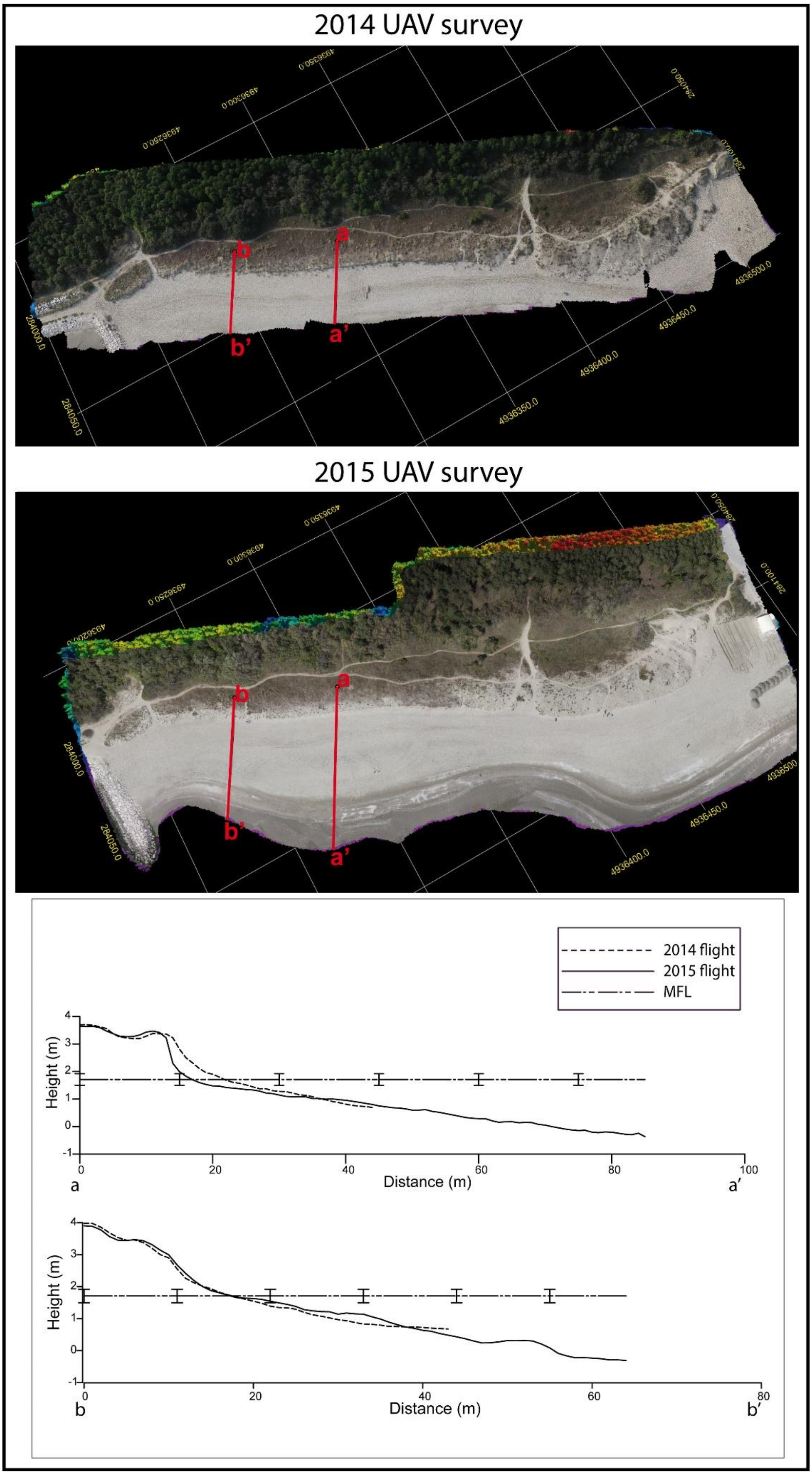
Pirottolo - fine loan sandy (PIR1)

ATTACHMENT 2

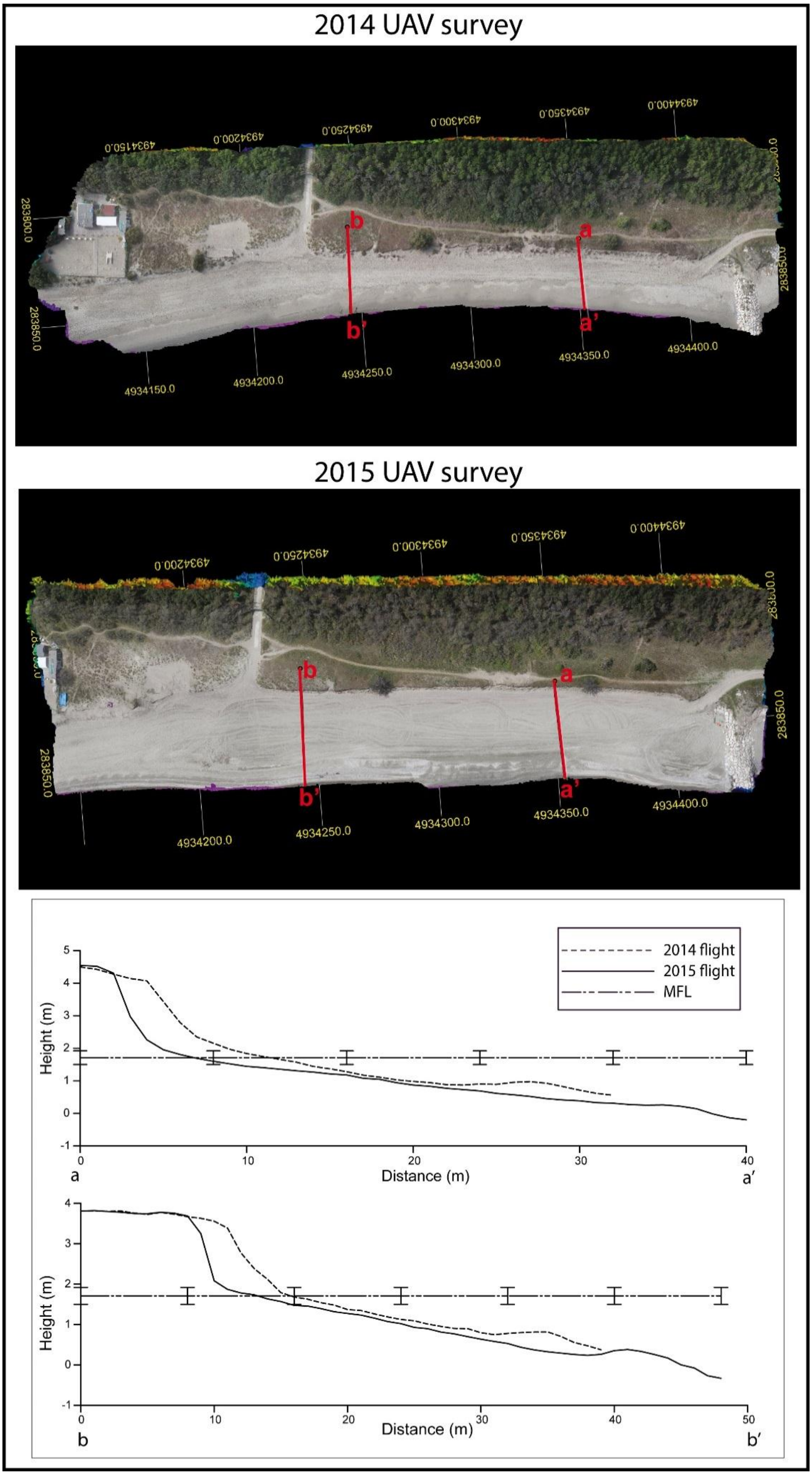
Casal Borsetti Nord:



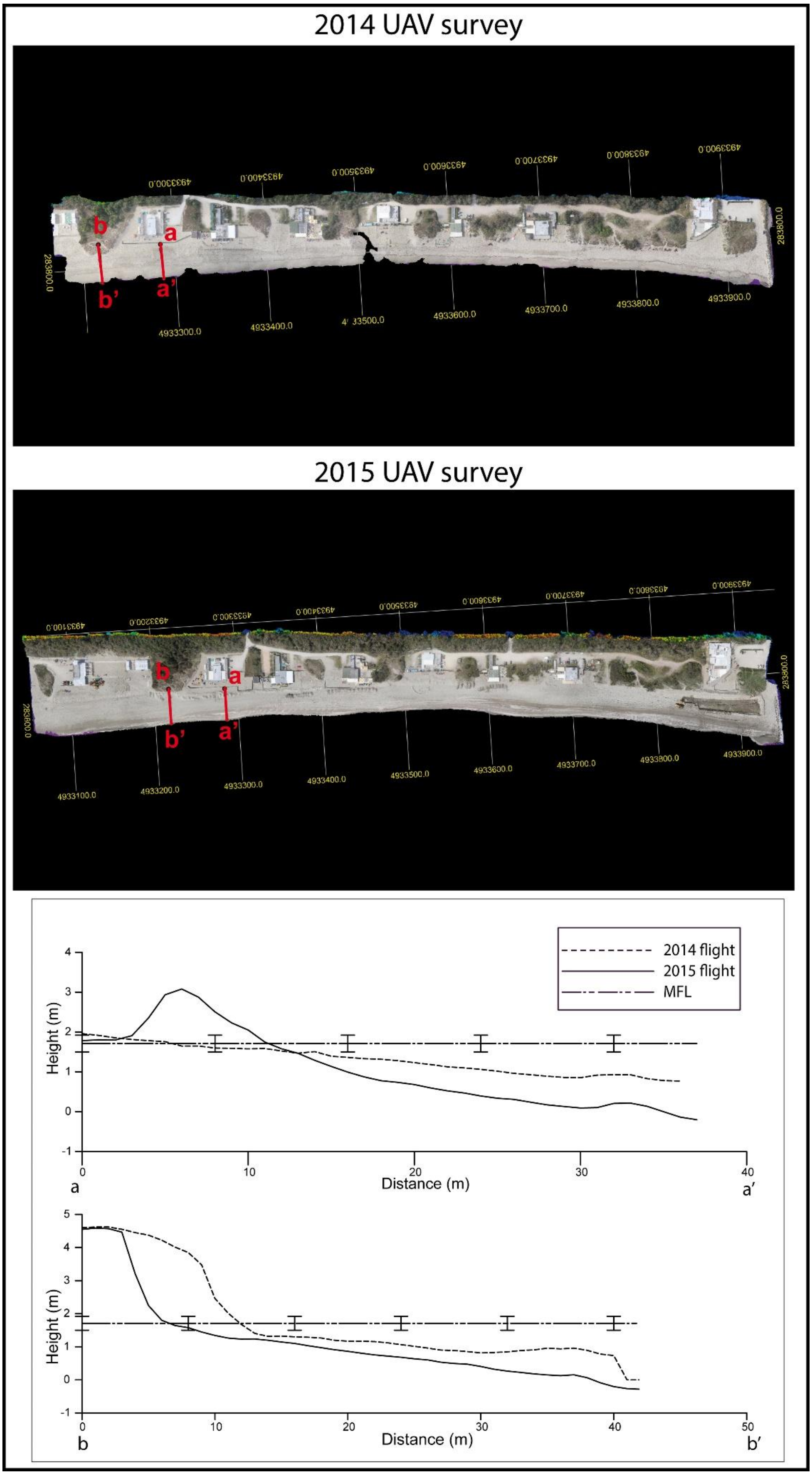
Casal Borsetti Nord:



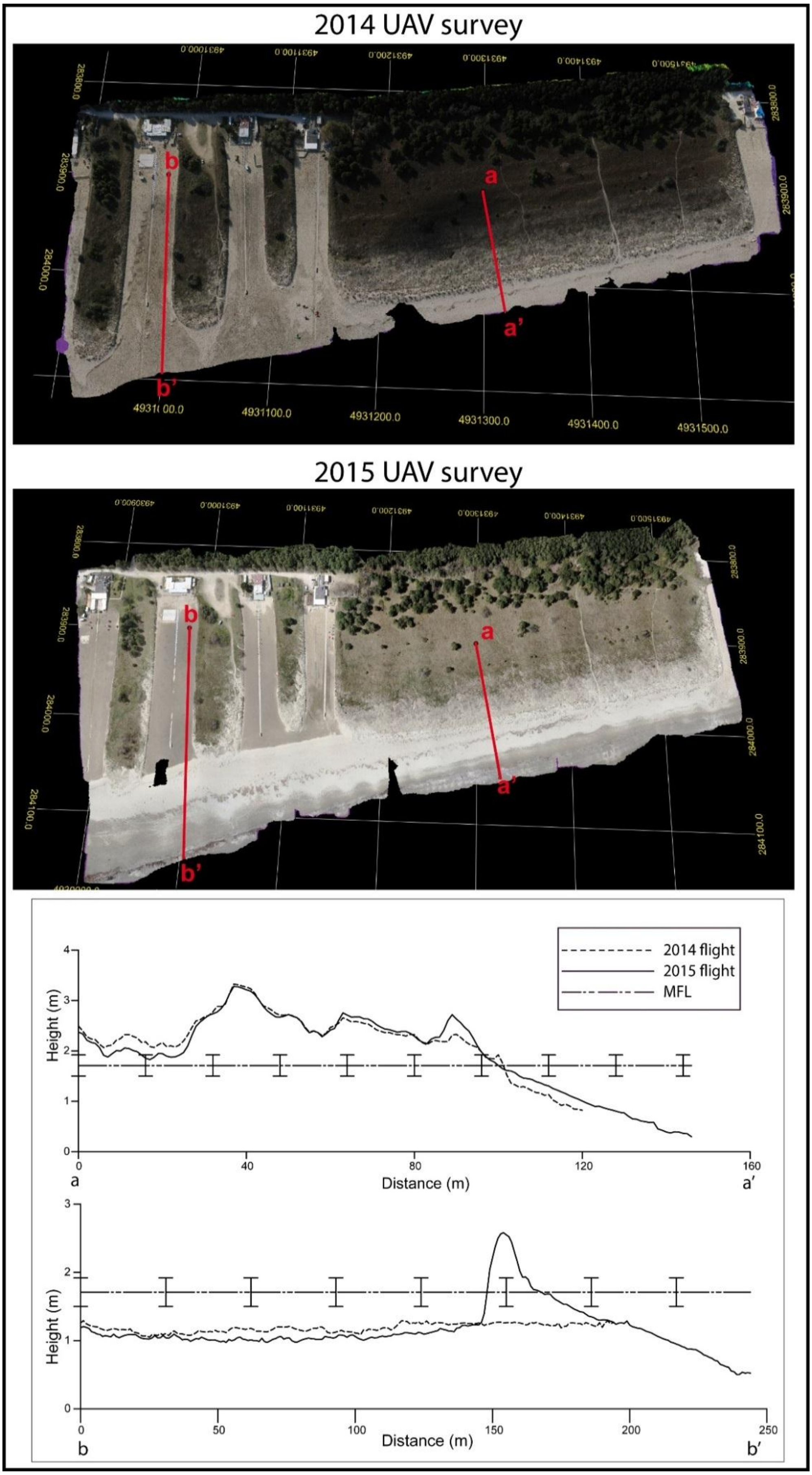
Marina Romea Nord:



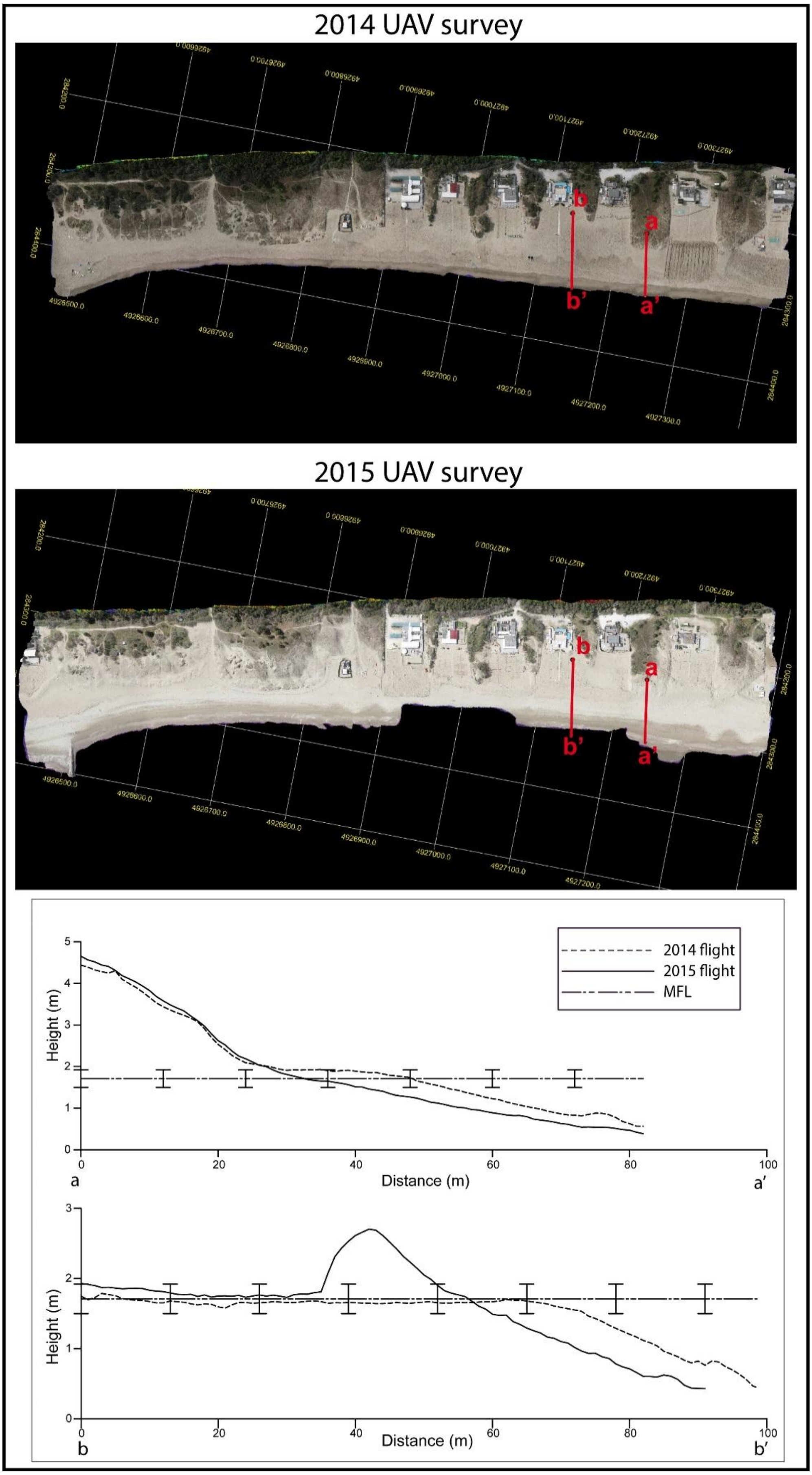
Marina Romea Sud:



Porto Corsini:



Marina di Ravenna:



Pineta Ramazzotti: