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COASTLINE CHANGES ON THE SLOVENIAN COAST BETWEEN 1954 AND 2010

SPREMINJANJE OBALNE ČRTE NA SLOVENSKI OBALI MED LETOMA 1954 IN 2010

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Lucija leta 1954.
Lucija in 1954.

Coastline changes on the Slovenian coast between 1954 and 2010

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ABSTRACT: Due to a dense population and the presence of various activities, among which tourism and port activities must be highlighted, the Slovenian coast is subject to constant changes. This article analyzes the extent of these changes between 1954 and 2010, which coincides with a time of major coastline changes resulting from intense development of tourism and the commercial port. The analysis was based on a comparison of aerial photographs from 1954 and 2010. The changes were determined and measured on transects 50 meters apart. The land area gained and lost during this time was also calculated and the coastline was classified into four different types based on the level of naturalness and anthropogenic transformations.

KEY WORDS: geography, coastline, Slovenian coast, aerial photography, Digital Shoreline Analysis System

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1 Introduction

A coastline is an imaginary line along the land-sea interface. There are various methods for determining coastlines depending on their intended future uses. The coastline can be determined based on the mean sea level, the lowest sea level, the mean high sea level, and so on. This article discusses the coastline as a line determined by the mean high sea level over a long period of observations because the majority of countries have a coastline defined in this way (Jovanovič 1978). Principally, the coastline is the line above which the sea normally does not rise (Jovanovič 1978). Under natural conditions, this line is typically quite visible because the part of the coast that is usually submerged during high tide is a different color. Measured this way, the coastline is much longer than the distance generally used because it includes all structures that form the coast, including piers and other structures prominent in the sea and on land. The widely accepted and commonly used length of the Slovenian coast is 46.6 km (Internet 1), whereas the length of coastline measured for this study is 53.5 km.

The changes to the coastline during this fifty-six year period have been mostly anthropogenic, due to intense social development of the zone in the second half of the twentieth century. Natural changes to the coastline are much smaller and it is impossible to measure them with the methods used in this study because the changes are smaller than the method's degree of accuracy. For example, the speed of erosion processes on flysch cliffs is estimated as a few centimeters per year (Šegina, Komac and Zorn 2012). On parts where major anthropogenic changes have occurred, it is impossible to determine where the coastline originally lay.

The purpose of this research was to precisely determine the changes to the Slovenian coastline over the past fifty-six years and to classify these coastline changes. In addition, it also explored the extent, causes, and parts of the coast along which these changes are most extensive.

1.1 Short description of the region

The Slovenian coastline is mostly composed of rias, and lithologically it can be divided into three types: calcareous, representing 11% of the coast and thereby a less common type that appears only in Izola; flysch, extending across 60% of the coast; and alluvial plains with Holocene alluvial sediments, which comprise 29% of the coast (Orožen Adamič 1990). The main characteristics are high ridges that end at the coast with steep flysch cliffs and alluvial accumulation on parts where rivers flow into the sea, forming the accumulation type of coast. The only exception is the zone around Izola, where coastal karst was formed (Orožen Adamič 2002). The interface between land and sea can be classified into four natural classes: cliffs, a gentle sweep of land towards the sea, accumulation coast, and relatively gently sloping land that rapidly drops after becoming sea bottom (Kolega and Poklar 2012).

It is also important to mention that during the research period the research area was subject to intense social development. The annexation of the region to Yugoslavia in 1954 opened the door for organized and accelerated economic and social development in Koper. As the regional district center and later municipal center with numerous administrative, political, educational, and cultural institutions, Koper became the leading driver of intense economic development in the entire coastal zone. In 1957, construction began on the Port of Koper. This fast-growing industry attracted many people to settle in and near the city. Industrial, commercial, business, administrative, sport, and recreational activities together with storehouses and traffic facilities were located on the Semedela Polder (Sln. *Semedelska bonifika*) and Škocjkan Polder (Sln. *Škocjanska bonifika*). The port complex was developed northeast of the old city center and cargo, passenger, and railway traffic were situated on part of the Ankaran Polder (Sln. *Ankaranska bonifika*; Žitko and Simič 1999). All this was followed by intense tourism development and a doubling of the number of inhabitants from 42,665 in 1953 (Internet 2) to 86,604 in 2012 (Internet 3). There is no doubt that tourism and the port had major impacts on coastline changes.

1.2 Literature review

Not much has been written about coastline changes in Slovenia. The majority of studies on this topic were carried out and published in the early 1980s, when a series of analyses of Slovenian coastal zone were carried

out for establishing protected areas (e. g., Svetličič and Križan 1985). The course of the coastline in antiquity was studied by Kozličić (1986). Past changes to the coastline in and around Koper were studied by Rejec Brancelj (1991). After this, no detailed analyses of coastline changes in Slovenia were carried out.

Precise coastline measurement for the Ministry of Transportation was conducted in 2001 and 2002 by the Geodetic Institute of Slovenia together with Harpha Sea d. o. o., a subcontractor that performed the actual detailed coastline measurements (Karničnik et al. 2001; Karničnik and Radovan 2002). Coastline measurements were performed during high tide on areas where the high waterline was not visible and coasts were not artificial. For other parts, the measurements followed the signs of high tide: the end of the darker coloration on rocks and artificial coasts (Žerjal 2002).

2 Methods

The analysis of coastline changes between 1954 and 2010 was carried out with the help of aerial photographs from two different years. The photographs from 1954 were taken as part of a regular program of countrywide aerial photography. They are maintained by the Surveying and Mapping Authority of the Republic of Slovenia. The entire coastal zone of Slovenia is covered by eleven photographs. In 1954, however, the entire coast was not photographed; the extreme northern part – Debeli Rtič – was omitted. We used the photo from 1974 for this part. The first step was to orthorectify and georeference these photographs with photographs made during lidar scanning with a resolution of 0.1 m of the coast in 2010 (Harpha Sea 2010). The georeferencing was relatively complicated because in some places the coastal zone had changed to the point that it was very difficult to find common ground control points for georeferencing. Because the photographs were of varying quality and were also deformed in different ways, it was not possible to carry out orthorectification and georeferencing with the same degree of accuracy for all photographs. This is why the photographs and zones on them were treated separately and the degree of accuracy was also defined separately for each photograph. Georeferencing is performed by setting the ground control points on the photograph to be georeferenced and the reference photograph. The root mean square (RMS) of the georeferenced photograph is calculated as the difference between the position set for shifting of single known points and the position on which these points were actually set (Marinović 2004; Skumavec and Šabić 2005). Table 1 shows the zones covered by individual photographs and their degree of accuracy expressed by the RMS.

Table 1: Georeferencing accuracy for each photograph.

Zone on photograph	Root mean square
Debeli Rtič and Lazaret (1974 photo)	7.55
Valdoltra	3.21
Sveta Katarina and Ankaran	3.62
Port of Koper	4.72
Žusterna and Koper	3.37
Zone between Izola and Koper	6.76
Simon's Bay and Izola	3.55
Holy Cross Bay and Belvedere	6.90
Portorož, Piran, and Strunjan	3.41
Sečovlje salt pans (north) and Lucija	3.95
Sečovlje salt pans (south)	5.84

The coastline was first drawn on orthophotos from 2010 (Harpha Sea 2010) with a resolution of 0.1 m. During lidar scanning in 2010, the majority of the Municipality of Izola was not scanned, and so for this part of the coast we used orthophotos made during lidar scanning in 2007 (Harpha Sea 2007) with the same resolution. As with the terrain measurements of the coastline in 2002 (Žerjal 2002), on the orthophotos we focused on the end of the black area representing high tide level, which is seen in most photographs. The scale of coastline mapping was 1:200. All concrete piers and other structures that extend to the bottom were included in the coastline, but all wooden, assembled, and floating piers were omitted. The length of the coastline measured this way is 53.5 km.

After georeferencing the 1954 photographs, we drew the coastline on them too, using the same methodology and scale. Determining the coastline on these photographs was more complicated because they are black-and-white and poor quality. Correspondingly, the border between sea and land is not clearly visible everywhere.

Then we analyzed coastline changes with the DSAS (Digital Shoreline Analysis System) program, working within the program package ArcGIS (Thieler 2009). This program allows us to analyze coastlines with transects 50 m apart. Transects are perpendicular to the coastline and baseline. The baseline is a line that is parallel to the coastline but is drawn on interior land. It has to be placed father into the interior than any part of the coastline. Then the distance between the two coastlines is measured on every transect. This program also allows various statistical variables to be calculated, but these are not applicable in our case because they require more than two coastlines.

3 Results and discussion

3.1 Comparison of coastlines in 1954 and 2010

Table 2 shows the distances between lines on the transects together with the RMS for the photograph on which the transect was placed. Only values on transects where the difference is greater than the RMS are displayed. Thus it can be seen that the difference between lines changes for different parts of the coast. The difference ranges from 0 to 2,359 m. The coastline was divided into nine parts according to the value of the difference between lines. These are shown in Figure 2. The first part comprises the coast from the border with Italy

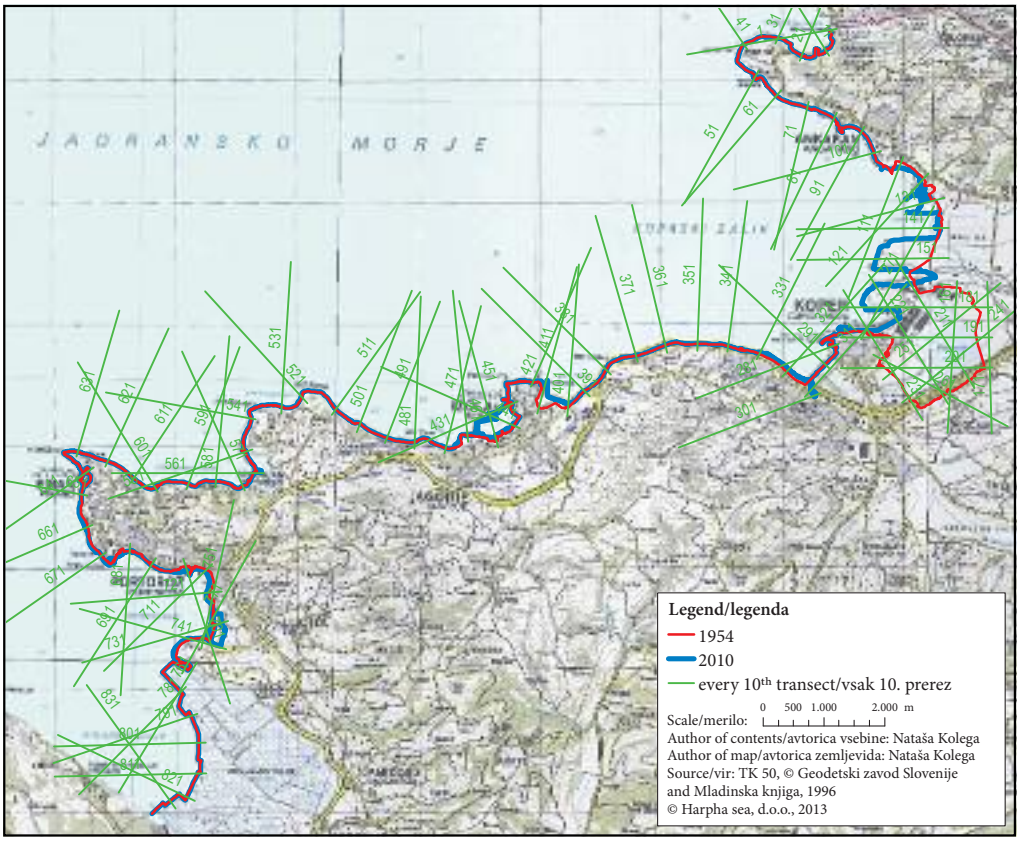

Figure 1: Coastlines in 1954 and 2010 and every tenth transect.

to Ankaran. The majority of the coast is flysch cliffs. The course of the coastline has not changed a lot here; that is, the difference is smaller than the degree of accuracy, although we know that slight changes such as small landslides on cliffs are constantly present (Furlani et al. 2011).

Table 2: Differences between coastlines together with RMS (The table is accessible on the internet page of the article).

The second part extends from Ankaran to Sveta Katarina. The differences between lines here are greater, especially in the approach to Sveta Katarina. All changes here are anthropogenic and are the result of building and expanding of the Port of Koper.

The third part represents the Port of Koper zone, for which the course of the coastline has totally changed. On some parts the coastline has moved more than 2 km towards the sea. In the past Koper was an island that was connected to the mainland by a causeway in 1827. Soon afterwards, drainage of the nearby wetlands and shoals began, and the island slowly became increasingly connected with the mainland (Rejec Brancelj 1991). In 1954 Koper was still a peninsula, which means that the area of today's Port of Koper was a bay, but by 2010 this was totally filled in. Koper's appearance in 1954 can be seen in Figure 3.

The fourth part is the city of Koper with the coast to Žusterna. Major anthropogenic changes to the coastline have also taken place here. A marina was built in the north part of the old city of Koper and the zone towards Žusterna was filled in, resulting in this coastline moving towards the sea.

The fifth part represents the coastal road between Koper (Žusterna) and Izola. In 1954 this road was already there, which means that the cliff behind the road was already »dead.« The course of coastline has not changed much here (Figure 4).

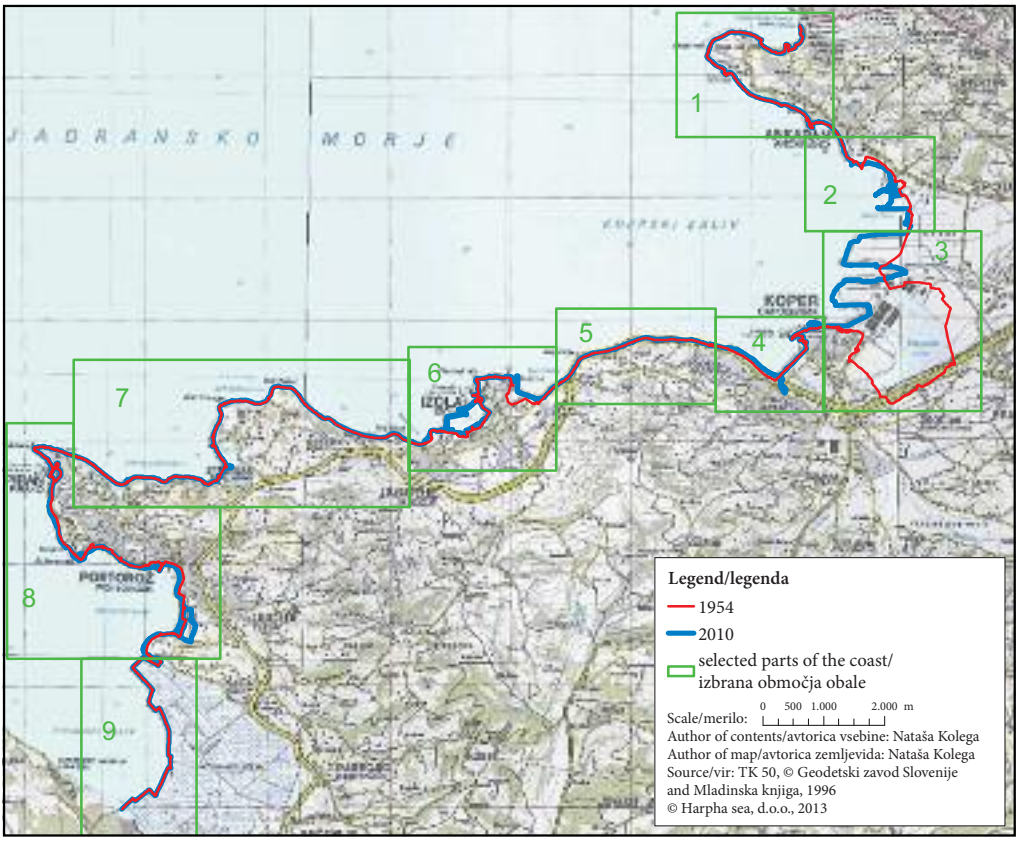

Figure 2: The coast divided into nine parts according to the difference between the 1954 and 2010 coastlines.

The sixth part represents the city of Izola, which, like Koper, used to be an island. Unlike Koper, in 1954 Izola was already strongly connected with the mainland and no large areas were filled in after that. The only part that was filled in after 1954 is where the shipyard lies (Figure 4). In the old city the course of the coastline has not changed much, but this is not true of the zone in the west part of the city, where a large marina has been built that made a significant change to the course of the coastline.

The seventh part of the coast begins at Simon's Bay, consisting mainly of flysch cliffs from Strunjan to Piran. The changes to the coastline along the cliffs are mainly smaller than the potential error in georeferencing the photographs from 1954. Principal factors contributing to coastline changes here are landslides and pieces of cliff breaking off. These incidents are relatively rare and thereby do not contribute much to coastline changes (Šeginam, Komac and Zorn 2012). Large changes are detected only on intermediate, anthropogenically changed sections such as Strunjan, Fiesa, and Pacug. This part also encompasses the Strunjan salt pans, along which the coastline has not changed significantly.

The eighth part of the coast includes Piran, Portorož, and Lucija. The changes here are substantial and entirely anthropogenic. From Piran towards Bernardin major areas have been filled in, which are large parking lots today. The course of the coastline at Bernardin was changed by the construction of a hotel complex and a small marina has been built on the former mainland. In Portorož the beach was extended by filling it in with soil, but the greatest changes took place in Lucija, where there were still salt pans in 1954 (Figure 5). The salt pan zone was changed into what is now the largest marina on the Slovenian coast, which has radically changed the course of coastline – in this case mainly towards the mainland. The zone below the Forma Viva outdoor exhibition area has also been filled in and thus the flysch cliffs were cut off from the sea.

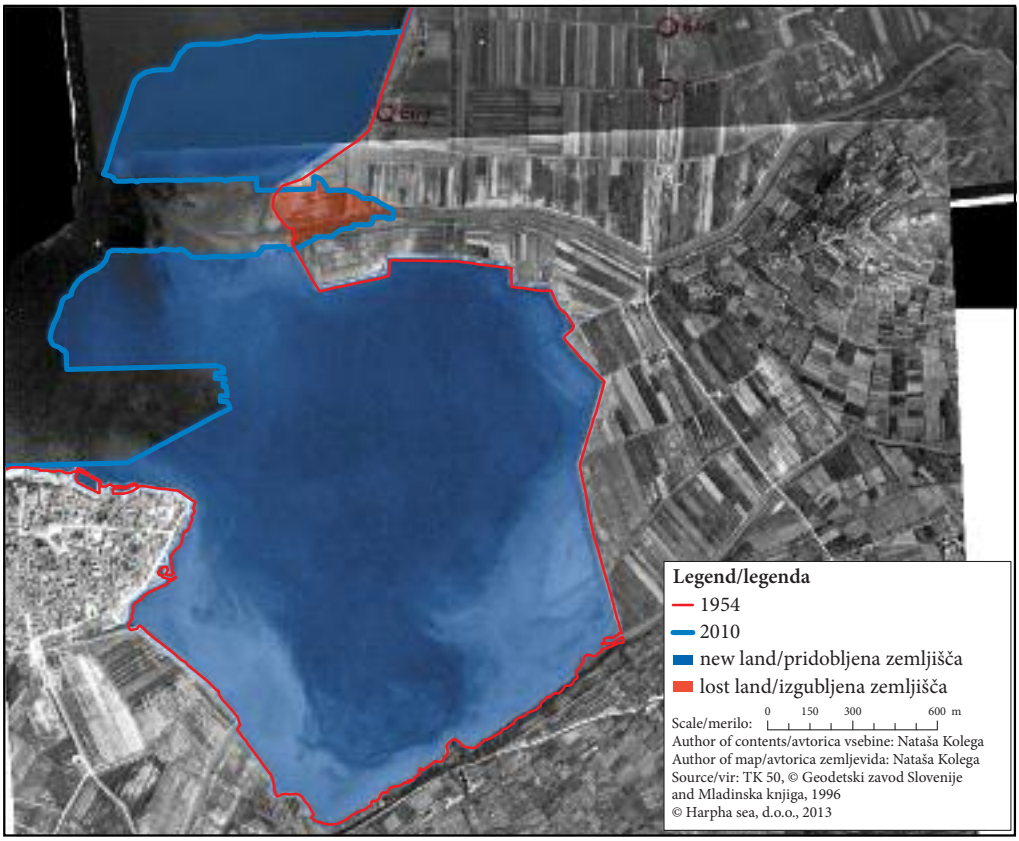

Figure 3: Coastlines in 1954 and 2010 and new and lost mainland at the Port of Koper.

The final, ninth part is the Sečovlje salt pans, where the course of the coastline has not changed much because the extent and borders of the salt pans have not changed.

3.2 New and lost mainland

In addition to determining the coastline changes from 1954 to 2010, we also investigated how large the areas were for which the mainland was actually extended or diminished. Figures 3, 4, and 5 show zones where these areas were most extended: the Port of Koper, the east part of Izola, and Portorož and Lucija.

Much more mainland was gained over this fifty-six year period than the amount of land lost; new land covers 364 ha and lost land only 18 ha. The largest land gains are at the Port of Koper, with smaller gains at Sveta Katarina, Izola, Bernardin, Portorož, and Lucija. Major losses took place only at the Lucija marina and the second basin of the Port of Koper, which indents inwards past the mainland.

3.3 Classification of coastline changes

We classified coastlines from 1954 and 2010 according to the level of naturalness or anthropogenic transformations. Coastline was classified as four types: relatively natural coast, somewhat natural coast, filled but unfortified coast, and artificially fortified coast (i.e., wall or rocks). The lengths of these coast types are given in Table 3 and their locations are shown in Figure 6.

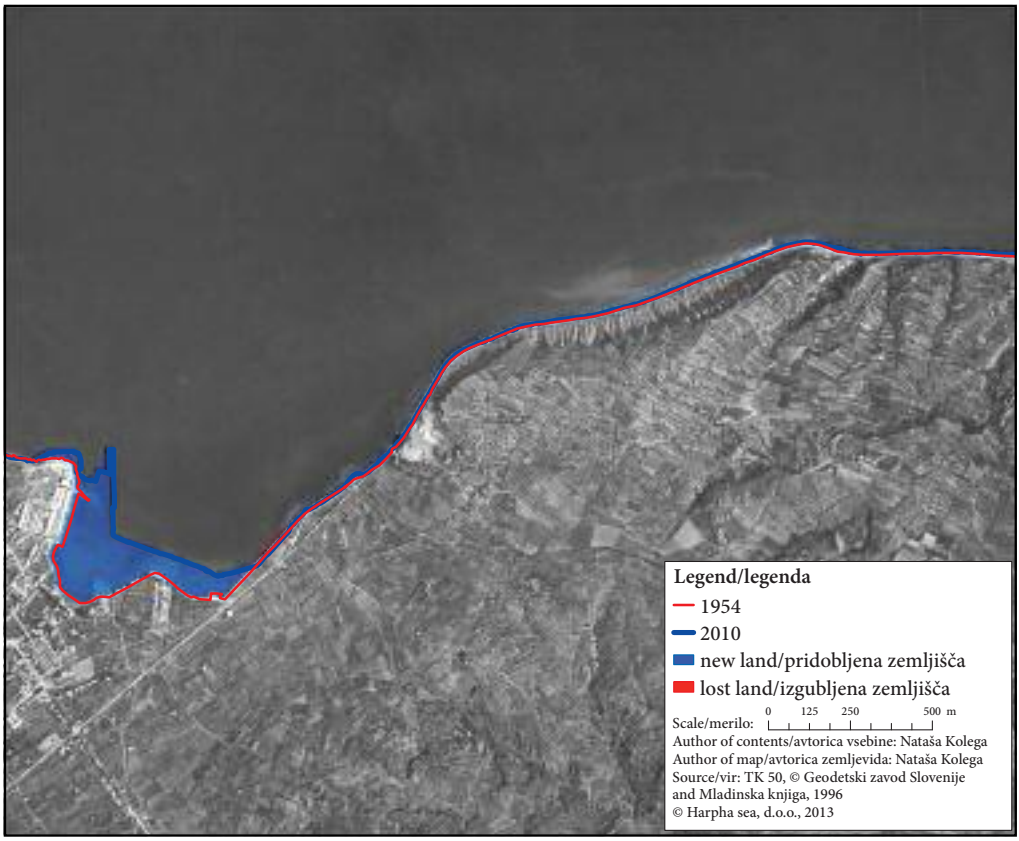

Figure 4: Coastlines in 1954 and 2010 and new and lost mainland in the east part of Izola along with the coastal road from Koper to Izola.

Table 3: Lengths (in km) of coastline types in 1954 and 2010.

Types of coastline	1954	2010
Relatively natural coast	17,7	10,3
Somewhat natural coast	1,8	1,4
Filled but unfortified coast	0	2,8
Artificially fortified coast (wall, rocks)	29,7	39,0
Total coast length	49,2	53,5

The majority of the relatively natural coast in 2010 was the cliff zones and it was the same in 1954. In 1954 the naturally preserved cliff zones were more extensive than today; in this category there are now also some strongly anthropogenically transformed cliffs, such as the cliff below the Forma Viva exhibition area and the cliff between Izola and Belvedere. The natural preservation of cliffs categorized in this type of coast currently varies from cliff to cliff. More naturally preserved cliffs include those at Debeli Rtič, the cliffs between Izola and Strunjan, and the cliffs between Strunjan and Fiesa. An example of a cliff with slightly more anthropogenic changes is the one between Piran and Fiesa, beneath which a footpath has been created. There were also some zones categorized as the »relatively natural« type in 1954 that are no longer natural: part of Bernardin, the north coast of Izola, the Izola marina, the part east of Koper, which has now been filled in, and Sveta Katarina. The area of somewhat natural coast has not significantly diminished between 1954 and 2010, but the locations of these zones have changed. In 1954 these zones were at

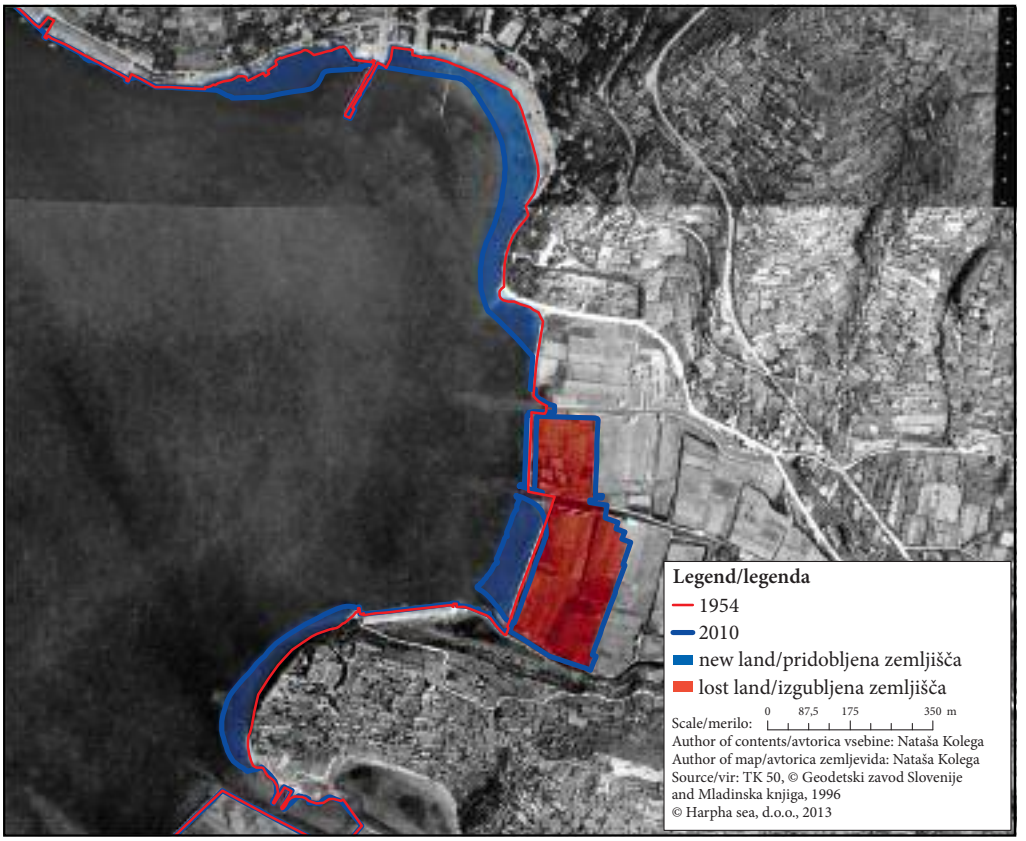

Figure 5: Coastlines in 1954 and 2010 and new and lost mainland in Portorož and Lucija.

Bernardin, Fiesa, the east coast of Koper's old center, Ankaran, and Debeli Rtič. Today these zones are artificially fortified coasts, and somewhat natural coasts are found in Strunjan between Izola and Belvedere and the north part of Izola. Filled but unfortified coast did not exist in 1954, and today it extends to Sveta Katarina. Like today, in 1954 artificially fortified coast was the most common type of coast and it includes all zones not mentioned above. Today it represents approximately three-quarters of the coast.

4 Conclusion

This analysis of changes to the Slovenian coastline indicates that anthropogenic changes to the coastline dominate. During the period studied, a relatively large amount of anthropogenic coastline changes were carried out that affected the length of the coastline. Natural changes to the coastline in the rare zones of natural coast were particularly small and it is impossible to measure them with this methodology because they are smaller than the potential error in georeferencing photographs from 1954. To determine natural changes it would be necessary to have more precise photographs, but they did not exist in the 1950s.

On many parts of the coast anthropogenic changes are so extensive that it is no longer possible to see, either in person or in photographs, where the coastline lay in 1954. Of the nine study zones, the Port of Koper is the one that changed the most. In addition to zones with significant changes there are also some zones that hardly changed at all, such as the Sečovlje salt pans, of which the outer border (a wall) was created a long time ago and remained unchanged during this period. In addition to the salt pans, the zones with very few changes are the cliff zones between Debeli Rtič and Ankaran and from Belvedere to Strunjan.

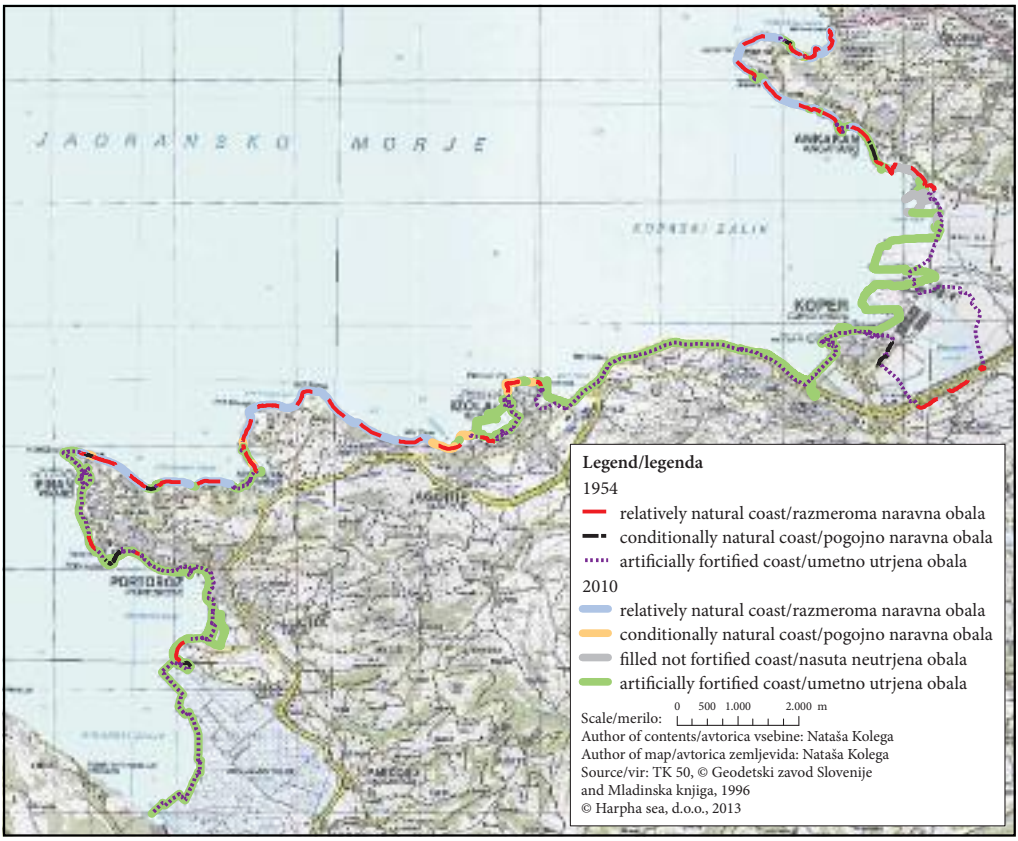

Figure 6: Types of coastlines in 1954 and 2010.

Considering the nature of cliffs, it is impossible to say that nothing has changed in fifty-six years – only that the difference is too small to be measured with this methodology.

The area of new mainland grew by 364 ha over the fifty-six year period, primarily due to the construction of the Port of Koper. Here it should be noted that the area of the Port of Koper is still increasing because it was also expanded from 2007 to 2010 (Kolega 2009).

It is important to mention that today approximately three-quarters of the coastline is artificially fortified with walls or rocks and the portion of relatively natural coast decreased by 7 km during the period studied.

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Spreminjanje obalne črte na slovenski obali med letoma 1954 in 2010

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IZVLEČEK: Obalna črta na slovenski obali je zaradi poseljenosti in prepletanja različnih dejavnosti med katerimi je treba izpostaviti turizem in pristanišče, podvržena nenehnim spremembam. Članek poskuša analizirati obseg sprememb v obdobju med letoma 1954 in 2010, kar sovpada z obdobjem velikih sprememb obalne črte zaradi intenzivnega razvoja turizma in pristanišča. Analiza sprememb je bila izvedena na podlagi primerjave letalskih posnetkov iz let 1954 in 2010. Spremembe so bile določene in merjene na podlagi prerezov med seboj oddaljenih 50 metrov. Izračunana je bila tudi površina pridobljenih in izgubljenih zemljišč na kopnem v tem času, obalni črti pa sta bili klasificirani v štiri različne tipe glede na stopnjo naravnosti oziroma antropogene preoblikovanosti.

KLJUČNE BESEDE: geografija, obalna črta, slovenska obala, letalski posnetki, Digital Shoreline Analysis System

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1 Uvod

Obalna črta je navidezna črta, ki poteka po stiku kopnega in morja. Njena natančna določitev je odvisna od namena za katerega obalno črto potrebujemo, saj za različne namene obstaja več načinov določanja obalne črte. Le-to lahko določamo na podlagi srednje gladine morja, najnižje nižje gladine morja, srednje vrednosti visokih voda, ipd. V naši raziskavi bomo o obalni črti govorili kot o črti določeni na podlagi srednje vrednosti visokih voda iz daljšega obdobja spremljanja višine gladine morja, saj ima tako definirano obalno linijo večina držav (Jovanovič 1978). Načelno velja, da je obalna črta linija, čez katero morje običajno ne gre (Jovanovič 1978). Ta je v naravi navadno dokaj dobro vidna, saj je del obale, do kamor sega morje, drugače obarvan. Dolžina tako izmerjene obalne črte je bistveno daljša kot splošno uporabljena dolžina obale, saj so v njej zajeti tudi vsi objekti, ki tvorijo obalo (npr. pomoli), ter drugi v morje izstopajoči in v kopno zarezujoči se deli obale. Tako je splošno uveljavljena dolžina slovenske obale 46,6 km (internet 1), dolžina izmerjene obalne črte v tej raziskavi pa kar 53,5 km.

Spremembe obalne črte v tem šestinpetdesetletnem obdobju so bile večinoma antropogene, saj je drugo polovico 20. stoletja zaznamoval predvsem intenziven družbeni razvoj območja. Naravne spremembe obalne črte so bistveno manjše in jih je zato nemogoče meriti z metodami, ki so bile uporabljene tekom te raziskave, saj so manjše od stopnje natančnosti metode. Na primer hitrost erozijskih procesov na flišnih klifih je ocenjena na nekaj centimetrov letno (Šegina, Komac in Zorn 2012). Na območjih, kjer je prišlo do večjih antropogenih sprememb ni več mogoče vedeti kje je v preteklosti potekala obalna črta.

Namen raziskave spreminjanja obalne črte je natančneje določiti, kako se je obalna črta na slovenski obali spreminjala v obdobju zadnjih šestinpetdeset let ter klasificirati ugotovljene spremembe. Poleg tega nas zanima tudi, kolikšne so te spremembe, na katerem delu obale so največje ter kakšni so njihovi vzroki.

1.1 Kratek oris območja

Slovenska obala je pretežno riaškega tipa, z vidika litologije pa jo lahko ločimo v tri tipe: apneniške obale, ki predstavljajo 11 % obale in so tako najmanj zastopan tip obale, pojavljajo se zgolj v Izoli; flišne obale, ki obsegajo 60 % obale; ob aluvialnih ravnicah pa se pojavljajo obale s holocenskimi aluvialnimi sedimenti, ki zavzemajo 29 % obale (Orožen Adamič 1990). Značilno je, da se višja, gričevnata slemena končujejo na obali s strmimi flišnimi klifi, na mestih, kjer pritekajo v morje vodotoki, pa se je zaradi nanašanja drobnega gradiva izoblikoval akumulacijski tip obale. Izjemo predstavlja območje Izole, kjer je prisoten priobalni kras (Orožen Adamič 2002). Stik med kopnim in morjem lahko razdelimo v štiri naravne tipe: klifi, položno spuščanje kopnega in morskega dna, akumulacijske obale in razmeroma položno kopno, ki se ob prehodu v morsko dno dokaj hitro spremeni v previs (Kolega in Poklar 2012).

Omeniti je treba tudi, da se je v obdobju, katerega spremembe preučujemo, območje iz družbenega vidika intenzivno razvijalo. Priključitev k Sloveniji leta 1954 je Kopru ponovno odprla vrata za organiziran in pospešen gospodarski in družbeni napredek. Kot regijsko-okrajno, kasneje pa občinsko središče s številnimi upravno-političnimi, izobraževalnimi in kulturnimi ustanovami je Koper prevzemal nase breme pospešenega gospodarskega razvoja celotnega obalnega območja. Leta 1957 se je začela izgradnja luke. Hitra rast industrije je privabila veliko novega prebivalstva v neposredno bližino mesta. Na semedelski in škocjanski bonifiki so se razvili industrijski obrati, trgovine, poslovni objekti, skladišča, upravne stavbe pa tudi športni objekti in rekreacijske površine ter prometnice. Severovzhodno od starega mestnega jedra se je razširil luški kompleks, na delu ankaranske bonifike pa tovorni, potniški in železniški promet (Žitko in Simič 1999). Intenzivno se je začel razvijati turizem, število prebivalstva pa je iz 42.665 leta 1953 (internet 2) naraslo na 86.604 leta 2012 (internet 3). Nedvomno sta prav turizem in pristanišče imela največji vpliv na spreminjanje obalne črte.

1.2 Pregled obstoječe literature

Na temo spreminjanja poteka obalne črte slovenskega morja na splošno ni bilo veliko napisanega. Največ se je o tematiki pisalo v začetku osemdesetih let prejšnjega stoletja, ko je nastala vrsta analiz slovenskega obalnega pasu in obalne črte za potrebe ustanovitve zavarovanih območji (npr. Svetličič in Križan 1985). Potek obalne črte v času antike je preučeval Kozličić (1986). S spreminjanjem in premikanjem obalne črte

v okolici Kopra v preteklosti se je ukvarjala Rejec Branceljeva (1991). Kasneje ni bila izvedena nobena druga podrobnejša analiza spreminjanja obalne črte v Sloveniji.

Natančno izmero obalne črte je v letih 2001 in 2002 za Ministrstvo za promet izvedel Geodetski inštitut Slovenije v sodelovanju s podjetjem Harpha sea, d. o. o. kot podizvajalcem, ki je natančne meritve obalne črte dejansko izvedlo (Karničnik s sod. 2001; Karničnik in Radovan 2002). Meritve obalne črte so potekale ob visoki plimi na območjih, kjer ni opazne linije visokih voda ali ni grajene obale, na ostalih območjih pa se je sledilo sledovom visokih voda (konec temnejše obarvanega območja na skalah) ali zidani obali (Žerjal 2002).

2 Metodologija

Analizo spreminjanja obalne črte med letoma 1954 in 2010 smo izvedli s pomočjo letalskih posnetkov dveh različnih starosti. Posnetki iz leta 1954 so nastali so kot začetek cikličnega aerosnemanja državnega ozemlja, hrani pa jih Geodetska uprava Republike Slovenije. Da pokrijemo celotno obalno črto slovenske obale, potrebujemo 11 letalskih posnetkov. Omeniti je treba, da v letu 1954 ni bila posneta obalna črta v celoti, saj ni bil posnet njen skrajni severni del, t. j. Debeli rtič. Za ta del je bil uporabljen posnetek iz leta 1974. Posnetke je bilo najprej treba ortorektificirati in georeferencirati z ortofoto posnetki, izdelanimi med lidarskim snemanjem leta 2010, z ločljivostjo 0,1 m (Harpha sea 2010). Samo georeferenciranje je bilo precej zapleteno, saj se je obalni pas ponekod spremenil do takšne mere, da je bilo izjemno težko najti skupne oslonilne točke za georeferenciranje. Ker so bili posnetki različnih kakovosti in so bile tudi različno deformirane, ortorektificiranja in georeferenciranja ni bilo mogoče izvesti za vse posnetke z enako stopnjo natančnosti. Zato so bili posnetki oziroma območja na posnetkih obravnavana vsako posebej, prav tako je bila za vsak posnetek določena stopnja natančnosti georeferenciranja. Georeferenciranje poteka s postavljanjem veznih točk na sliki, ki jo želimo georeferencirati, in referenčni sliki. Srednja napaka položaja georeferencirane slike se računa kot razlika med položajem, določenim za premik posameznih poznanih točk, in položajem, na katere so se točke dejansko preslikale (Marinović 2004; Skumavec in Šabić 2005). Preglednica 1 prikazuje območja, ki jih pokrivajo posamezni posnetki, in stopnjo natančnosti, izraženo s cenilko srednje napake položaja za vsak posnetek posebej.

Preglednica 1: Natančnost georeferenciranja posameznih letalskih posnetkov.

območje na posnetku	srednja napaka položaja
Debeli rtič in Lazaret (leto 1974)	7,55
Valdoltra	3,21
Sv. Katarina in Ankaran	3,62
Luka Koper	4,72
Žusterna in Koper	3,37
Območje med Izolo in Koprom	6,76
Simonov zaliv in Izola	3,55
Zaliv sv. Križa in Belveder	6,90
Portorož, Piran in Strunjan	3,41
Severni del Sečoveljskih solin z Lucijo	3,95
Južni del Sečoveljskih solin	5,84

Obalno črto smo najprej vrisali na ortofoto posnetke, izdelane ob lidarskem snemanju leta 2010 (Harpha sea 2010), z ločljivostjo 0,1 m. Ker pri tem snemanju večji del občine Izola ni bil posnet, smo za ta del obalne črte uporabili ortofoto posnetke nastale pri lidarskem snemanju leta 2007 (Harpha sea 2007) enake kakovosti. Na ortofoto posnetkih smo poskušali, podobno kot že pri meritvah na terenu leta 2002 (Žerjal 2002), upoštevati črto, do koder voda lahko seže, ki je na večini posnetkov vidna. Merilo, v katerem se je izvajalo kartiranje poteka obalne črte na ortofoto posnetkih, je bilo 1 : 200. V obalno črto so bili zajeti vsi zidani pomoli ter ostali objekti na obali (ki sežejo do dna), izpuščeni pa so bili vsi montažni (leseni) in plavajoči pomoli ter objekti. Skupna dolžina tako določene obalne črte je 53,5 km.

Po georeferenciranju posnetkov iz leta 1954 smo tudi na njih določili potek obalne črte, v istem merilu. Določanje poteka obalne črte je bilo bolj zapleteno, saj so posnetki črno-beli in slabše kakovosti. Temu primerno se ponekod slabše vidi tudi meja med kopnim in morjem.

Nadalje smo spremembe obalne črte poskušali analizirati s programom Digitalni sistem za analizo obale (ang. *Digital shoreline analysis system* – DSAS), ki deluje znotraj programskega paketa ArcGIS (Thieler 2009). Program omogoča analizo črt s prerezi, ki so pravokotni na obalno črto oziroma na bazno črto ter so oddaljeni med seboj 50 m. Bazna črta je črta, ki poteka vzporedno z obalno črto vendar bolj v notranjosti kopnega, na način, da se vedno nahaja bolj v notranjosti kopnega kot katera koli obalna črta. Na vsakem prerezu je nato izmerjena razdalja med obalnima črtama. Poleg tega nam program omogoča tudi izračun nekaterih statističnih spremenljivk, ki pa v našem primeru večinoma niso uporabne, saj sta za njihov izračun potrebni več kot dve obalni črti.

3 Rezultati in razprava

3.1 Primerjava obalnih črt leta 1954 in leta 2010

V Preglednici 2 lahko vidimo razdalje med črtama po prerezih skupaj s stopnjo natančnosti georeferenciranja, izraženo z RMS. Prikazane so zgolj vrednosti na prerezih pri katerih je mogoče določiti razliko med črtama, saj je njuna razlika večja od možne napake (RMS). Vidimo, da se razlika med črtama zelo spreminja po odsekih obale. Vrednost razlike se giblje med 0 m in 2359 m. Glede na vrednost razlike med črtama je bila obala razdeljena v devet delov, ki so prikazani na sliki 2. Prvi del obsega območje od meje z Italijo do Ankarana. Večji del območja predstavljajo klifi. Tu se potek obalne črte ni bistveno spremenil oziroma je sprememba povsod manjša od stopnje natančnosti (možne napake pri georeferenciranju), vemo pa da so očitne vendar manjše spremembe v obliki udorov redno prisotne (Furlani s sod. 2011).

Slika 1: Potek obalnih črt leta 1954 in 2010 ter vsak deseti prerez.
Glej angleški del prispevka.

Preglednica 2: Razdalje med črtama po prerezih.
Glej angleški del prispevka.

Slika 2: Obalo smo glede na vrednost razlike med obalnima črtama, v letih 1954 in 2010, razdelili v devet delov.
Glej angleški del prispevka.

Drugi del se razprostira od Ankarana do Sv. Katarine. Razlike med črtama so tu večje, posebno ko se približujemo Sv. Katarini. Vendar so vse te spremembe antropogene, saj so nastale pretežno z nasipavanjem med gradnjo Luke Koper.

Tretji del predstavlja območje Luke Koper, za katero je značilno, da se je potek obalne črte popolnoma spremenil. Obalna črta se je na nekaterih mestih premaknila na škodo morja za več kot 2 km. Kot je znano, je bil Koper v preteklosti otok, ki so ga leta 1827 povezali s kopnim z nasipom, kmalu za tem pa so začeli tudi z izsuševanjem bližnjih plitvin ter ga tako postopoma vedno bolj povezovali s kopnim (Rejec Brancelj 1991). Leta 1954 je bil Koper še polotok, kar pomeni da je bilo območje, kjer se danes nahaja del Luke Koper, zaliv, ki je bil do leta 2010 popolnoma zasut. Izgled Kopra leta 1954 prikazuje slika 3.

Četrti del predstavlja mesto Koper ter obalo do Žusterne. Tudi tu je prišlo do večjih antropogenih sprememb obalne črte. Na severni obali starega mestnega jedra Kopra so zgradili marino, območje proti Žusterni pa je nasuto, kar pomeni, da se je obalna črta premaknila na škodo morja.

Peti del predstavlja obalna cesta med Koprom (Žusterno) in Izolo. Omenjena obalna cesta je obstajala že leta 1954, kar pomeni, da je bil klif v njenem zaledju že takrat »mrtev«. Potek obalne črte se tu ni bistveno spreminjal (slika 4).

Šesti del predstavlja mesto Izola, ki je bilo tako kot Koper v preteklosti otok. V nasprotju od Kopra je bila Izola leta 1954 že veliko tesneje povezana s kopnim in po tem letu okolice niso več tako bistveno zasipavali. Dodatno so zasipali le del, kjer se nahaja Ladjedelnica Izola (slika 4). Na območju starega mestnega jedra se potek obalne črte ni bistveno spreminjal, tega pa nikakor ne moremo reči za zahodni del mesta, kjer je bila zgrajena velika marina, ki je tu zelo spremenila potek obalne črte.

Naprej od Simonovega zaliva se začne sedmi del obale, pretežno klifi, od Strunjana do Pirana. Spremembe obalne črte ob klifih so večinoma manjše od možne napake pri georeferenciranju, saj so poglavitni dejavniki spreminjanja obalne črte tu predvsem usadi in odlomi, ki pa so razmeroma redki in zato ne prispevajo bistveno k spreminjanju obalne črte (Šegina, Komac in Zorn 2012). Večje spremembe zasledimo le na vmesnih, antropogeno preoblikovanih delih obale, kot so Strunjan, Fiesa in Pacug. Na tem delu se nahajajo tudi Strunjanske soline, ob katerih se obalna črta prav tako ni bistveno spreminjala.

Na osmem delu obale se nahajajo Piran, Portorož in Lucija. Tu so spremembe velike in popolnoma antropogene. Naprej od Pirana proti Bernardinu so bila nasuta večja območja, kjer se sedaj nahajajo parkirišča, potek obalne črte na Bernardinu pa je spremenil kompleks hotelov; iz nekdanjih kopnih zemljišč je bil narejen mandrač. V Portorožu je bila z nasipavanjem umetno podaljšana plaža, največje spremembe pa so se zgodile v Luciji, kjer so leta 1954 še bile soline (slika 5). Območje solin je bilo spremenjeno v trenutno največjo marino na slovenski obali in s tem se je zelo spremenil tudi potek obalne črte, v tem primeru predvsem na škodo kopnega. Tudi območje pod *Formo vivo* je bilo umetno nasuto, s tem pa so bili klifi odrezani od morja.

Zadnji, deveti del predstavljajo Sečoveljske soline, kjer ni prišlo do omembe vrednih sprememb v poteku obalne črte, saj se zunanja podoba oziroma obseg solin v obravnavnem obdobju ni spremenil.

3.2 Pridobljena in izgubljena zemljišča na kopnem

Poleg določanja samih premikov obalne črte med letoma 1954 in 2010 nas je zanimalo tudi, kako velika so zemljišča, ki so bile dejansko pridobljena ali izgubljena z vidika kopnega. Slike 5, 6 in 7 prikazujejo območja, kjer so te območja najobsežnejša; območje Luke Koper, vzhodni del Izole in Portorož ter Lucijo.

Slika 3: Obalni črti leta 1954 in 2010 ter pridobljena in izgubljena območja kopnega na območju Luke Koper.
Glej angleški del prispevka.

Slika 4: Obalni črti leta 1954 in 2010 ter pridobljena in izgubljena območja kopnega na območju vzhodnega dela Izole ter obalna cesta med Koprom in Izolo.
Glej angleški del prispevka.

Slika 5: Obalni črti leta 1954 in 2010 ter pridobljena in izgubljena območja kopnega na območju Portoroža in Lucije.
Glej angleški del prispevka.

Površine, ki jih je kopno v teh letih pridobilo, so veliko večje od zemljišč, ki jih je kopno izgubilo, saj je pridobljenih 364 ha, izgubljenih pa 18 ha zemljišč. Največji del pridobljenih površin se nahaja v Luki Koper, manjši deli pa še na Sv. Katarini, v Izoli, na Bernardinu, v Portorožu in Luciji. Večji izgubljeni zemljišči sta le v marini v Luciji in v drugem bazenu Luke Koper, ki se zajeda v nekdanje kopno.

3.3 Klasifikacija preoblikovanosti obalne črte

Obalni črti v letih 1954 in 2010 smo poskušali klasificirati glede na stopnjo naravne oz. antropogene preoblikovanosti. Klasificirali smo ju v štiri tipe: razmeroma naravna obala, pogojno naravna obala, ki bi ji lahko rekli tudi utrjena obala s sledmi naravne obale, umetno nasuta neutrjena obala in umetno utrjena obala (zid, skale). Dolžine naštetih tipov obale oziroma obalne črte so predstavljene v preglednici 3, lokacije pa na sliki 6.

Slika 6: Tipi obalne črte leta 1954 in leta 2010.
Glej angleški del prispevka.

Največji del razmeroma naravne obale so zavzemala območja klifov tako leta 1954 kot 2010. Leta 1954 je bilo naravno ohranjenih območij klifov več kot danes, saj so mednje sodili tudi danes močno antropogeno preoblikovani klifi, kot je klif pod *Forma vivo* in klif med Izolo in Belvederjem. Naravna ohranjenost klifov, ki smo jih umestili v to kategorijo, se danes od klifa do klifa razlikuje. Med bolj naravnimi lahko izpostavimo klife na Debelem rtiču, klife med Izolo in Strunjanom ter med Strunjanom in Fieso, kot klif

Preglednica 3: Dolžine (v km) tipov obalne črte leta 1954 in leta 2010.

tipi obalne črte	1954	2010
razmeroma naravna obala	17,7	10,3
pogojno naravna obala	1,8	1,4
nasuta neutrjena obala	0	2,8
umetno utrjena obala (zid, skale)	29,7	39,0
skupna dolžina obale	49,2	53,5

z nekoliko večjimi človeškimi posegi pa klif med Piranom in Fieso, na vznožju katerega je utrjena sprehajalna pot. Leta 1954 so v kategorijo razmeroma naravne obale sodila tudi nekatera območja, ki jih danes ne moremo več kategorizirati kot naravna; to so: del Bernardina, severna obala Izole, obala kjer je danes marina Izola, del vzhodno od Kopra, ki je danes zasut in območje Sv. Katarine. Površina območij pogojno naravne obale se ni bistveno zmanjšala od leta 1954 do leta 2010, vendar so se spreminjale lokacije teh območij. Leta 1954 so se nahajala na Bernardinu, v Fiesi, na vzhodni obali starega mesta Koper, v Ankaranu in na Debelem rtiču. Danes našteta območja sodijo med umetno utrjene obale, pogojno naravna obala pa se nahaja v Strunjanu, med Izolo in Belvederjem ter na severni strani starega mesta Izole. Nasuta neutrjena obala leta 1954 ni bila prisotna, danes pa je prisotna na Sv. Katarini. Umetno utrjena obala je bila tako leta 1954 kot 2010 najprisotnejši tip obale in zavzema vsa območja, ki niso bila predhodno našteta. Danes obsega približno tri četrtine celotne obale.

4 Sklep

Analizo spreminjanja obalne črte lahko sklenemo z ugotovitvijo, da so na slovenski obali poglavitne predvsem antropogene spremembe obalne črte. Antropogenih sprememb poteka obalne črte se je v preučevanem obdobju glede na celotno dolžino obale zgodilo relativno veliko. Naravne spremembe obalne črte na redkih območjih ohranjene naravne obale so zelo majhne in jih zato ni mogoče meriti na takšen način, saj so pogosto manjše od razpona napake, ki je nastala pri georeferenciranju in ortorektificiranju posnetkov iz leta 1954. Da bi lahko določili naravne spremembe, bi potrebovali natančnejše posnetke, vendar v petdesetih letih prejšnjega stoletja natančnejši posnetki niso obstajali.

Na mnogih mestih so antropogene spremembe tako velike, da ni več mogoče opaziti, ne v naravi ne na posnetkih, kje je obalna črta v preteklosti (leta 1954) potekala. Med njimi najbolj izstopa območje Luke Koper. Najdemo pa lahko tudi nekaj območij, kjer je sprememb zelo malo ali skoraj nič. Gre za območje Sečoveljskih solin, katerih zunanji rob, po katerem poteka obalna črta, je bil utrjen že davno in se zato tudi v preučevanem obdobju ni spreminjal. Poleg solin sta se kot območji z zelo majhnimi spremembami pokazali območji klifov od Debelega rtiča do Ankarana in od Belvederja do Strunjana. Vendar bi glede na naravo klifov težko rekli, da se v šestinpetdesetih letih na njih ni nič spremenilo, gre le za to, da so spremembe premajhne glede na metodo merjenja.

Površina kopnega se je v šestinpetdesetletnem obdobje povečala za 364 ha, predvsem na račun Luke Koper, na tem mestu pa je treba omeniti, da se njena površina še povečuje, saj se je od leta 2007 do 2010 tudi nekoliko povečala (Kolega 2009).

Zanemariti ne smemo tudi dejstva, da je danes približno tri četrtine obalne črte umetno utrjene, bodisi z zidovi ali s skalami, ter da se je delež razmeroma naravne obale v preučevanem obdobju zmanjšal za dobrih 7 km.

5 Literatura

Glej angleški del prispevka.