Mediterranean Deltas

Assessment of general intactness based on hydromorphological criteria and land use obstruction

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euronatur RiverWatch fluvius

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Cover image: Nestos Delta, Greece (Google Earth 2023).

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1. Introduction

Deltas are dynamic riparian-coastal landscapes composed of various habitats driven by river discharges, sediment supply, the permanent fight between land and wave-powered seashore, and wind and dune development leading to different delta types (see Figure 1). In this context, river sediment input from the upstream catchments and sea level changes play an essential role in the delta development. The most extensive delta expansion can be observed where mountainous, sediment-rich catchments with high precipitation meet shallow coastal reaches. Those preconditions prevailed in many Mediterranean countries, supporting the development of broad coastal plains within only a few millennia.

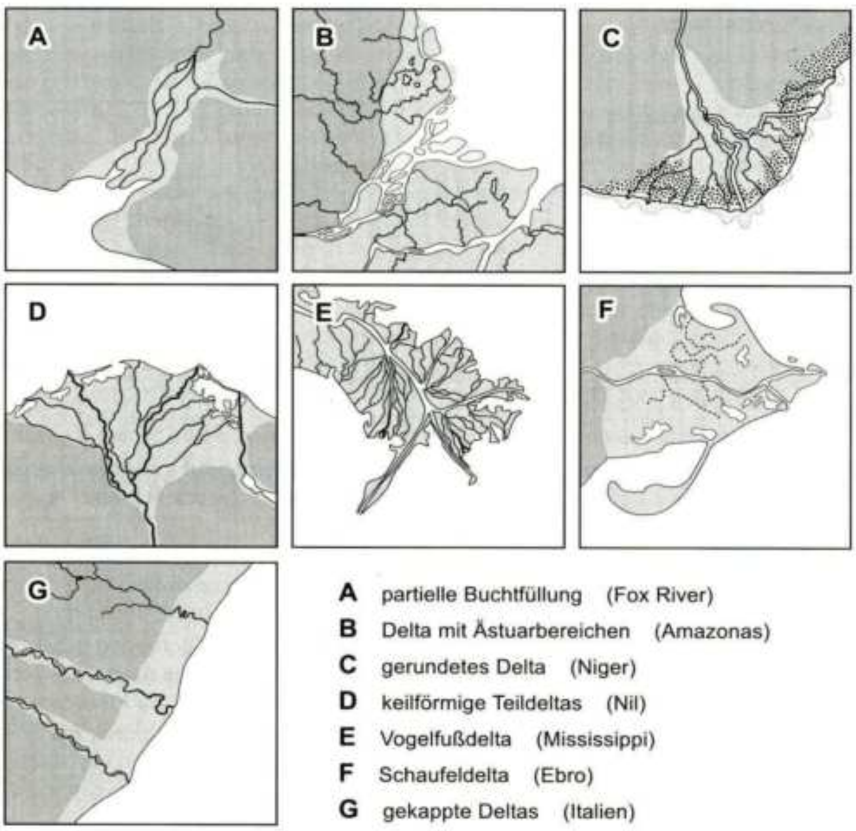

Figure 1: Types of deltas (from Ahnert 2001). Different types of deltas and namely Mediterranean Deltas (D, F, G): A) partial bay filling; B) delta with estuarine areas; C) rounded delta; D) wedge-shaped partial deltas; E) Bird's Foot Delta; F) Shovel Delta; G) capped deltas. The Mediterranean deltas are generally river-sediment-driven and not predominantly wave-formed or tidal.

Significant changes in land use within catchments and deltas have profoundly impacted key factors in delta formation, particularly in the last century and most recent decades. Modifications to rivers, such as the construction of dams in catchments and water abstraction primarily for irrigation, have altered the hydromorphological conditions in deltas. Moreover, the effects of climate change and rising sea levels have added to the evolving conditions of the deltas. Historical deforestation, dating back to the Roman Empire, amplified erosion and sediment transport to the deltas. However, the shift from wood to coal during the Industrial Revolution prompted a partial afforestation in catchments, contributing to reduced accumulation rates.

Anthony et al. (2021) observed the sediment flux for Mediterranean deltas and compared the amount of sediment transported before the period of dam construction and after 1970. The balance is negative for all deltas assessed in the study. The Nile and Ebro rivers lost 98% of sediments transported (Ebro from 20 Mio t/a to 0.5 Mio t/a), and other major rivers like the Rhone lost 83% (from about 30 Mio t/a to 5.2) and Po 71 % (16 Mio to 4.7). The Arno River (-64%) and Ceyhan-Seyhan River system (-49%) lost significant parts of sediment discharge due to dam construction within the past decades. In all cases, large-scale dams in the middle courses caused a decrease in sediment transport.

While a clear relationship exists between dam construction and the decrease of sediment load affecting delta expansions, other factors should be considered in this respect. An important one is the land cover (change) in the catchment, particularly deforestation. Due to deforestation, mountain slopes are destabilised, increasing erosion. Afforestation (human-made or natural via succession, leading to the re-establishment of shrubs and eventually forests, e.g. due to reducing the use of firewood) can stabilise slopes again. The engineering and changes in the deltas themselves, namely the regulation of channels, the construction of infrastructures or the reduction of flooded areas, impact the natural generation of deltas.

Furthermore, the analysis of land-to-water and water-to-land changes (erosion and aggradation) in deltas underlines the complex development of deltas due to land-cover changes (including dam construction). It highlights the vulnerability of deltas to subsidence and shoreline erosion. Generally, wetlands in the deltas are the core indicators for trends.

Anthony et al. (2014) conducted a comprehensive analysis of the geomorphological evolution of Mediterranean deltas spanning the past 6000 years. They emphasised the crucial role of fluvial sediments and coastal plains formed by rivers, particularly after the stabilisation of seawater levels following the last ice age, which set the stage for developing modern deltas. The study also highlighted the historical influence of human civilisation, noting frequent changes in harbours due to rapid silting caused by sediments from new agricultural practices since the Neolithic period across the Mediterranean.

However, the destabilisation of deltas has become more pronounced in the last 200 years, with a notable increase in the previous 50 years. While the retention of sediments behind dams remains a key factor in this phenomenon, other contributors include forest degradation, sediment dredging, and fluvial regulation. These factors play a significant role in the observed destabilisation of Mediterranean deltas.

Due to hard engineering of many coastlines and deltas and rising sea levels, further erosion and destruction of deltaic environments is expected.

Figure 2: The sediment transport from the mountains to the coastal plains in all grain fractions, particularly coarse material, is essential. The Mati River -due to the blockage of larger grain fractions (i.e. gravel) by several larger dams only transports fine suspended material. This becomes particularly evident by the muddy colour of the river.

2. Approach

Within this study, a comparative assessment of all river deltas in the Mediterranean Region was conducted to highlight the few intact deltas. For this purpose, roughly 250 river deltas and river mouths into the Mediterranean Sea were assessed. Eighty of the assessed deltas reach over 1,000 ha in size. A few smaller deltas/river mouths were not considered because they are overbuilt.

Previous studies on the locations of planned and existing hydropower plants along rivers in countries in the Mediterranean Basin (Schwarz 2020a), as well as studies concerning the landscape development for Adriatic deltas (Schwarz 2020b), delivered important base data which was used to assess the status of deltas regarding their hydromorphological intactness. Those previous assessments also provided insights into present land use obstructions visible from high-resolution satellite imagery.

2.1 Methodology: Criteria and scoring

For the comparative assessment, four steps were taken. The first two steps focussed on the conditions in the river basin forming the delta. In steps three and four, attention was paid to the status of the delta itself.

Comparative assessment steps:

1. *Identification of dams in the catchment.*
   Dams significantly alter the sediment transport throughout the deltas and are thus important indicators for the intactness of deltas. Hence, the number, size and position of barriers (on main rivers and tributaries, in middle/lower course, relevant for sediment transport) were recorded and depending on the amount, size and position of the dams, the delta was ranked higher or lower.
2. *Analysis of the overall hydromorphological status of main rivers and tributaries in the catchment.*
   Hydromorphological conditions indicate alterations in a river's hydrological regimes (e.g. flooding) and morphology (e.g. the planform/cross section or gravel and sand bars), ultimately affecting the delta. In addition, strongly regulated and, in most cases, also altered rivers (e.g. by water abstraction for irrigation, influx of wastewater sewerage) often transport a high load of organic pollution into the deltas. In many, but not in all, cases, regulated rivers are indicators for intensive

land use in the respective catchments.

3. *Rough assessment of hydromorphological conditions in the delta regarding the channels, banks and adjacent riparian zone of the delta river branches and the shoreline.*
   An intact delta is free of artificial construction, such as bank stabilisations of natural channels, groynes and other construction measures impacting the natural flow regime and the regulation of shoreline erosion. Additionally, intact riparian zones along the delta river branches are an important indicator.
4. *Assessment of floodplains and wetlands (including lagoons) located in the deltas.*
   Deltas are composed of various elements, including floodplains and wetlands formed over time by "its river". In many cases, wetlands were drained, floodplains impoldered for land reclamation, and lagoons were used for fisheries. Both are indicators helping to understand the overall level of degradation of the delta area.

All rivers and deltas were assessed, taking into consideration the criteria mentioned above, and assigned to three main scoring classes as follows:

Status	**Colour**	**Score**
Best	Blue	3
Moderate	Yellow	2
Bad	Red	1

The matrix table 1 on next page summarises the criteria and scoring for the four main parameters allowing a minimal score of four points (each criterion ranked with only one point) up to 12 points (each criterion ranked with three points).

Dams were assessed by number and location in the catchment, and the assessment of the delta itself regarded its hydromorphological status for channels/banks/riparian zones as well as the status of floodplains/wetlands following the CEN 2010 standard (CEN 2010). As the assessment of the hydromorphology in the catchments used a five-class system, classes needed to be summarised to match with the chosen "three-class approach":

- Rivers assessed with Classes 1 and 2 (near-natural and slightly modified) in the primary ranking of the study used were ranked best and attributed three points.
- Rivers assessed with Class 3 (moderately modified) were ranked moderate and

attributed two points.

- Rivers assessed with Classes 4 or 5 (extensively and severely modified) were ranked Bad and attributed one point.

Table 1: Criteria for the main assessment parameters (scores) (images: Google Earth 2023).

Score	**1 Dams in the catch-ment (number/ size and location)**	**2 Hydromorpho-logical status of main rivers and tributaries in the catchment**	**3 Hydromorpho-logical status of delta channels, banks and adjacent riparian zones**	**4 Hydromorpho-logical status in delta floodplain and wetlands (e.g. lagoons)**	**Integrative assessment ∑ scores [1-4] = [4-12] Example per total score**
Score 3 (Best)	No major dams (> 10 MW) or chain of smaller dams 1-10 MW) in relevant river sections	Hymo classes 1-2 (near-natural, slightly modified)	No river regulation works and free shift of channels (no lateral obstructions)	No significant reduction of core delta area and provision of typical habitats including lagoons and swamps	
Score 2 (Mode-rate)	Only smaller dams (1-10 MW) in relevant river sections	Hymo class 3 (moderately modified)	Moderate regulation of channels, including shorter meander cut-offs	Significant reduction of typical delta habitats, namely wetlands and obstructions and agricultural usages	
Score 1 (Bad)	Major dams on relevant river sections	Hymo class 4-5 (extensively and severely modified)	Extensive or total regulation and rectification of channels	Loss of most of the typical delta habitats and wetlands, intensive land use, not only agriculture but also settlements and touristic development	

2.2 Data used for the analysis

For the study, data from previous studies, supplemented by additional data, was used. Data used:

- Mapped delta area and centroid points (GIS transformation to represent a polygon by a point for better assessment visualisation).
- Corresponding river basins and the drainage network extracted from EU Hydro[1] and World Hydro[2] sheds data sets.
- Dams extracted for the relevant catchments from previous projects (Schwarz 2020a) and amended for dams and reservoirs other than hydropower purposes (e.g. irrigation).
- Hydromorphological assessments of main rivers and including main tributaries (Schwarz 2017, for the purpose of the study amended for small rivers).
- Hydromorphological assessment for deltas prepared within the study.

Recent Google Earth images from 2020-2023 (GE 2023) were used for all assessments.

2.2.1 Major dams in the catchment

The assessment of dams in the catchment, namely within the main rivers and tributaries in their middle and lower courses, is based on previous findings (Schwarz 2022 Balkan update, 2017) and was a great asset for this assessment. However, checks done during this study revealed that within five years of the dam survey, including all countries in the Mediterranean Region (Schwarz 2017), further dams had been constructed (e.g., in Morocco and Turkey).

[1] https://land.copernicus.eu/en/products/eu-hydro/eu-hydro-river-network-database
[2] https://www.hydrosheds.org/

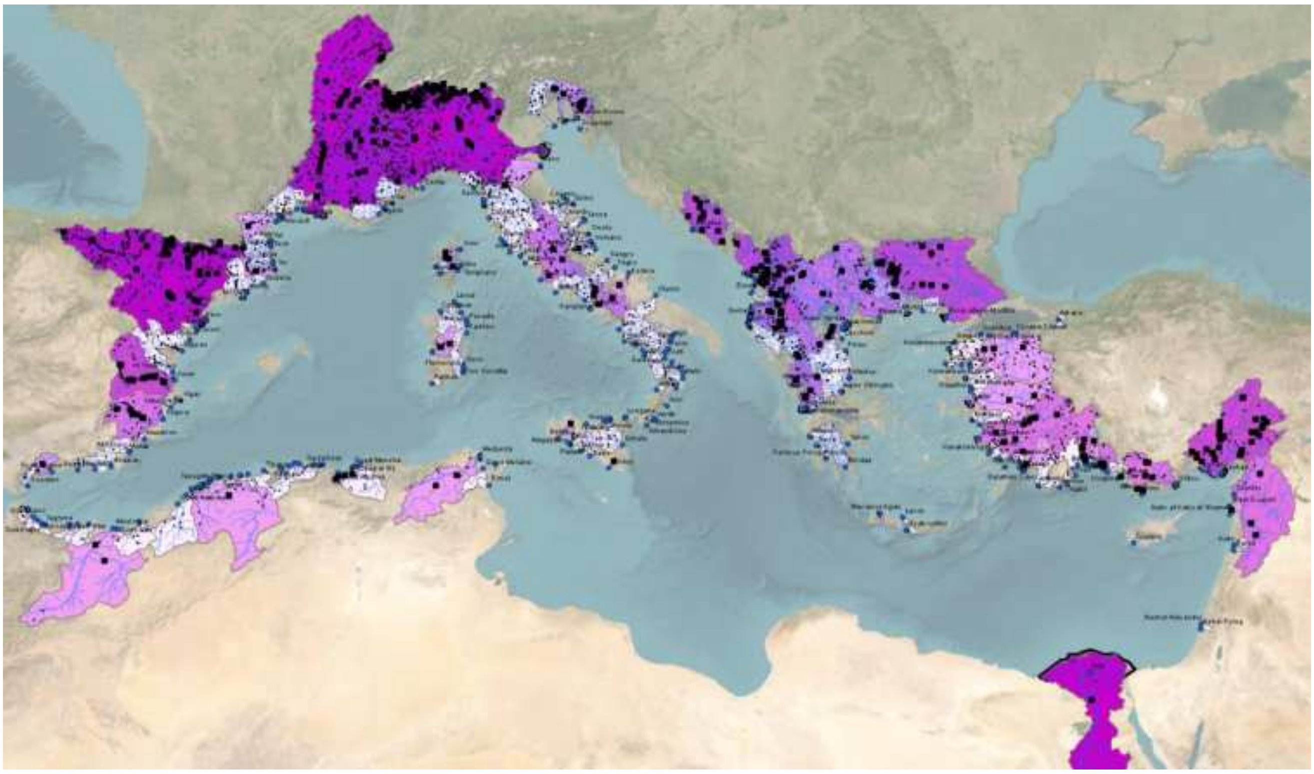

Figure 3: Only a few catchments remain free of large dams (> 10 MW), mostly within less water-rich rivers or rivers with many weirs and small hydropower plants (1-10 MW), e.g.Arno or Piave Rivers in Italy. The second “larger” river remaining without larger hydropower dams is the Pineios River in Greece, which is 217 km long. However, one hydropower dam is under construction in its lower course.

Figure 4: Large dams, such as this one on the Devoll River in Albania, trap a significant amount of coarse sediments. This leads to downstream consequences, including substantial bed incision and a reduced flow of sediments reaching the deltas—in this instance, the Semani Delta (Google Earth 2023).

2.2.2 Hydromorphological status of main rivers in the catchment

The availability of previous hydromorphological assessments for most of the rivers in the area studied in the current context significantly helped prepare this study. Amendments were made for rivers missing in previous assessments.

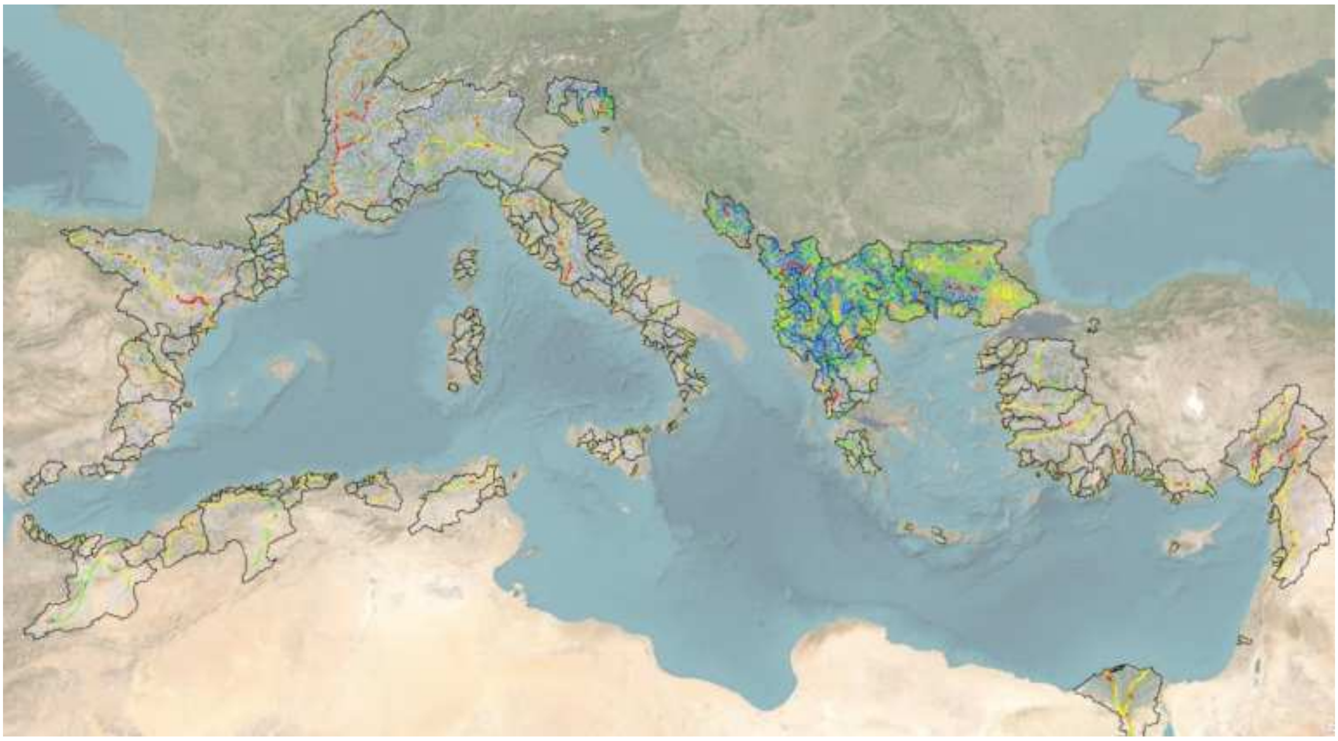

Figure 5: Hydromorphological assessments in five classes are available for rivers located on the Balkan Peninsula (Schwarz 2020a) (high density mapping) and the Mediterranean Region (2017, only major rivers).

Figure 6: Main rivers and tributaries strongly influence the river deltas and can be seen as an indicator of the intactness of the entire catchments. In the Rhone River (France), strong river regulation, navigation, hydropower development, and sediment retention in barrier reservoirs prevail (Google Earth 2023).

Figure 7: Excessive dredging in lower courses contributes to sediment transport deficits causing incision and degradation of deltas (example from Morača River, Montenegro) (Google Earth 2023).

2.2.3 Hydromorphological assessment of deltas: Intactness of channels, intactness of wetlands

Deltas were assessed in two steps. The first step focused on the delta branches, banks and adjacent riparian zones. The second step analysed the floodplain and, namely, the deltaic habitats and wetlands such as lagoons and coastal swamps.

Figure 8: Examples of river regulations in the delta area: fixation of riverbanks, meander cut-offs, construction of canals with sluices and outlets and the disconnection of floodplains by dykes (agricultural or even industrial usage), the case example from Po Delta (Google Earth 2023).

Figure 9: Changes in the coastal environment and pressures on deltas, mainly by hydromorphological alterations and land reclamation. The corresponding circles in both maps show the land use changes, namely in the coastal plain, by strong land reclamation and drainage. The extensive coastal wetlands were naturally only interrupted by the natural levees and floodplains of the rivers (elevated land along the main rivers with settlements and agriculture in the historical map). Example for the Albanian coast (Mati Delta) between 1900-2000 (Austrian Military Map 1:75.000, 1890-1910, Google Earth 2023).

3. Results

A comprehensive mapping effort covered 258 deltas and river mouths that discharge into the Mediterranean Sea, encompassing a vast expanse of 3.742 million hectares. Among these, 83 deltas exceed 1,000 hectares, with 18 surpassing the 10,000-hectare mark. The Nile Delta constitutes a significant portion of this area, spanning 2.768 million hectares. Other noteworthy examples include the expansive Rhone Delta in France, spanning 126,000 hectares, and the Po Delta in Italy, covering 86,000 hectares. Excluding the Nile Delta, the average size of the mapped deltas and river mouths is approximately 3,460 hectares.

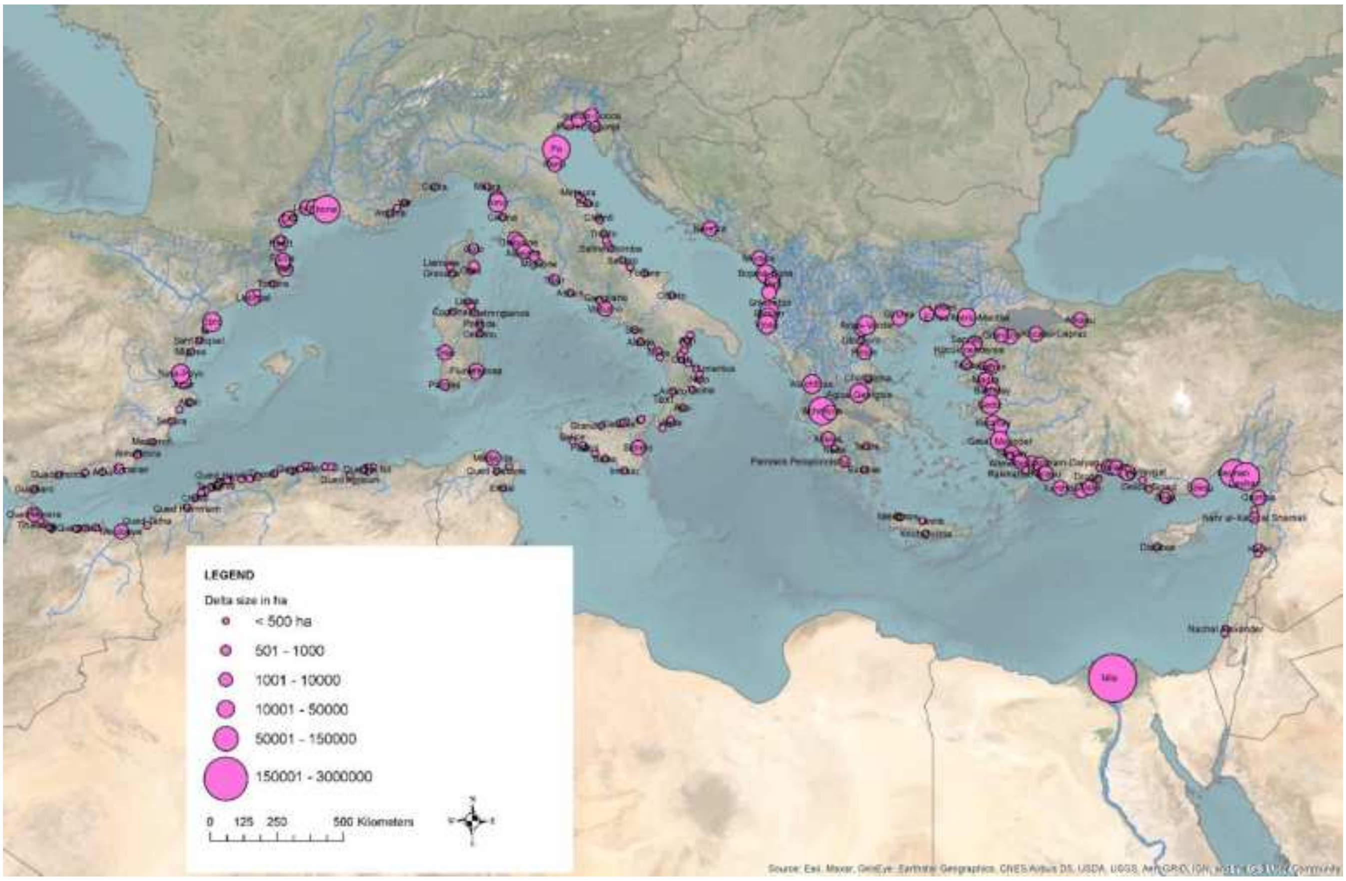

Figure 10: Overview of the 258 mapped deltas and their size classes.

3.1 Overall assessment of deltas – results

Out of 258 assessed deltas with in total 3,739,417 ha, none received the full score of 12, and only three smaller deltas fell in the second-highest scoring, 11. Thirteen deltas are attributed to very good conditions, receiving a score of 10. It's important to highlight that most deltas with scores of 10 and 11 are relatively small.

Figures 11 and 12 present the distribution of assessment scores and total area size, while Figure 13 shows the overview map of the primary assessment.

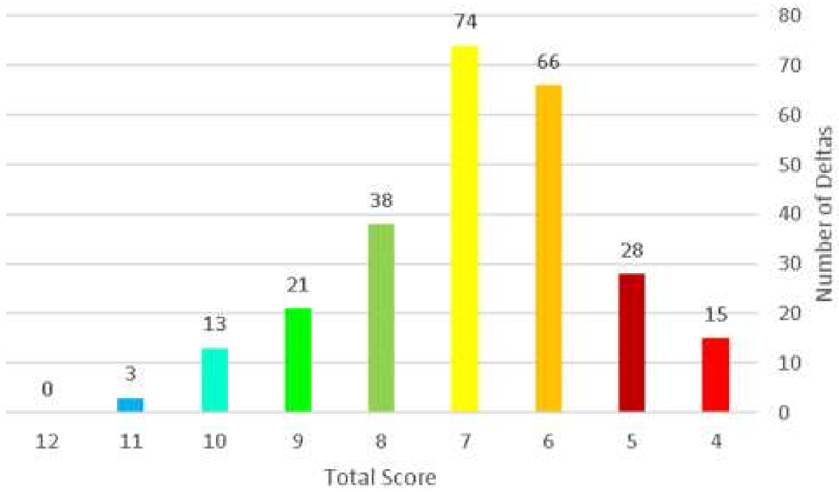

Figure 11: Distribution of assessment scores. Only 6% (16) of all deltas assessed (258) fall into the best scores with total scores of 10 or 11. None of the deltas reached the top score (i.e. 12 points). On average, deltas reached 7 to 9 points (52%), while 42% of the deltas assessed scored only between 4 and 6 points.

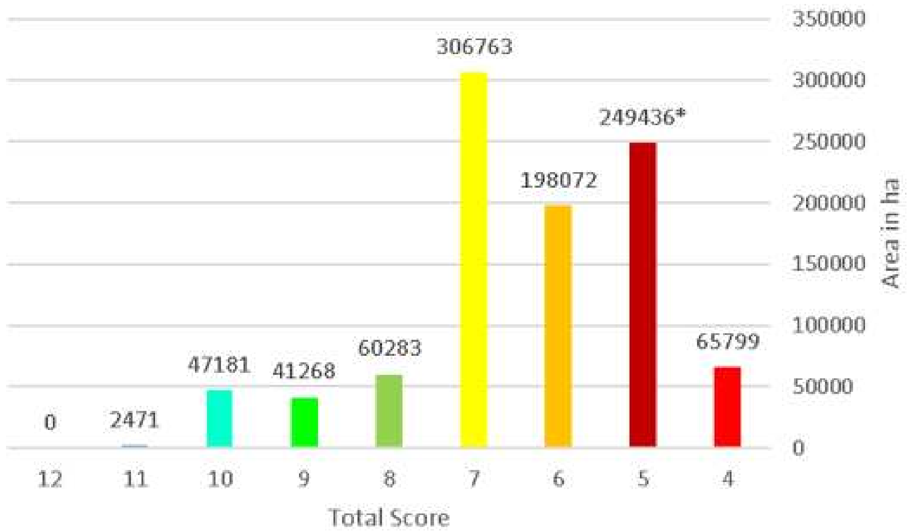

Figure 12: Distribution of the total area size of deltas in ha for each score (*the Nile with 2,768,144 ha scoring 5 points is not included in the chart to prevent distortion). The result drastically shows the poor condition of deltas in the Mediterranean in general. Additionally, no larger delta is still in good shape. Score 10 consists mainly of the few Albanian deltas. All others (including score 11 deltas) are small.

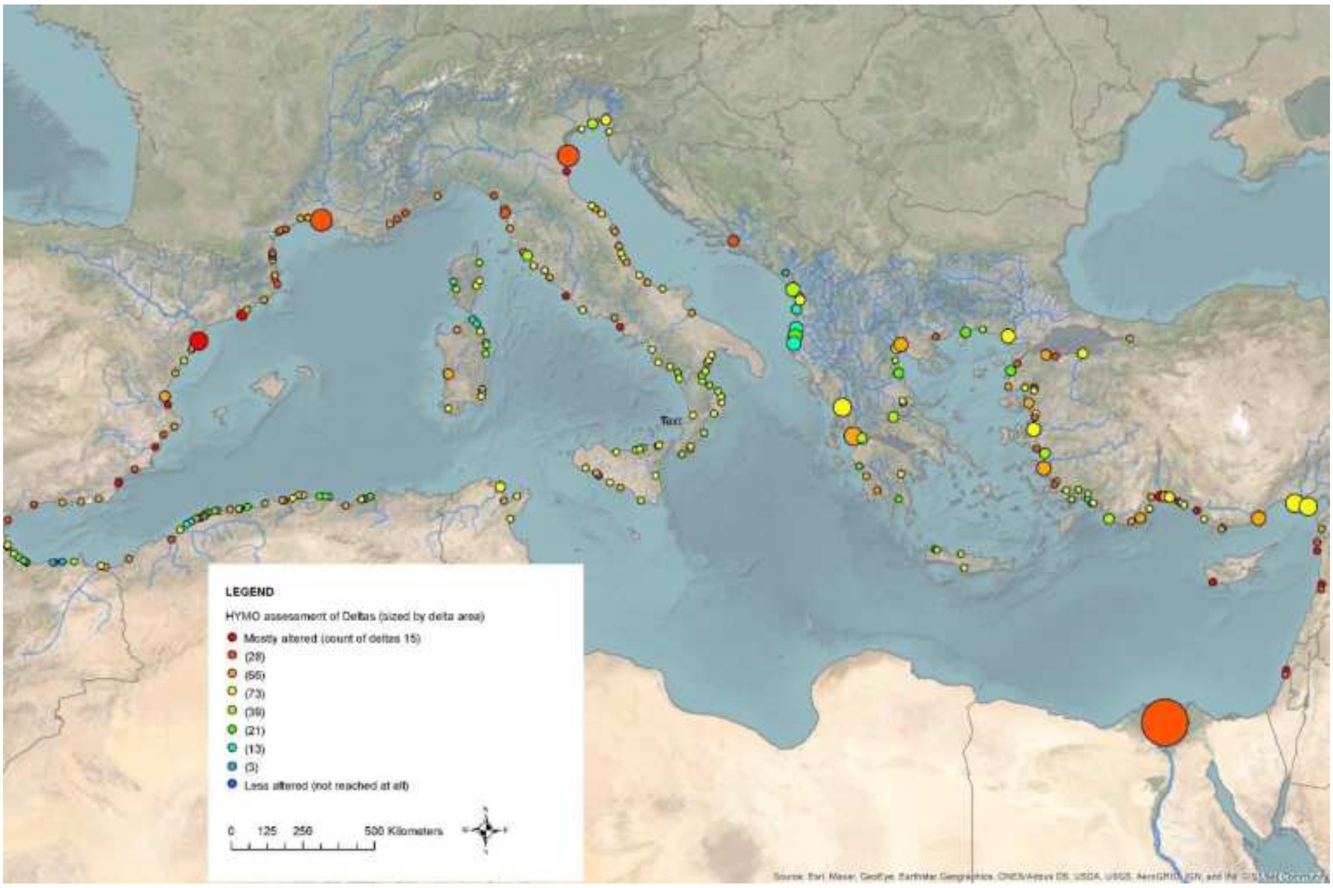

Figure 13: Overall assessment of hydromorphological intactness of deltas by total scores.

Most of the higher-ranked deltas are in the northeastern Mediterranean Basin, while the northwestern (European) part mainly hosts deltas with poor status. All deltas and river mouths in Morocco and Algeria are of small size, which might be a reason for less alteration of those areas. Some small deltas with good conditions still exist in southern Italy and Sicily, as well as in Corsica (France) and Sardinia (Italy). In contrast, the numerous Turkish deltas underwent a continuous decrease in intactness due to hydropower construction, land reclamation and tourism. Greece still hosts a few deltas with rather good conditions. However, the famous Nestos Delta, a protected area (National Park of Eastern Macedonia and Thrace), is significantly impacted by a chain of hydropower reservoirs in its catchment.

Albania contains the deltas with scores of 10 and 11. Of great importance are the Vjosa, Semani, and Shkumbin deltas. The proximity of these deltas highlights their collective significance, forming what is referred to as a "triple delta." However, these deltas face growing pressures due to various factors in Albania, including the construction of hydropower dams, sediment extraction, agricultural activities, and the expansion of tourism infrastructure, exemplified by projects like the Vlora Airport. Detailed information on these pressures and their impact on the deltas is presented in Tables 2 and 3.

Notably, none of the deltas achieved the maximum score of 12 points, and none of the larger deltas, exceeding 25,000 hectares, were assigned to the top scores 10-12. The Vjosa and Shkumbin deltas in Albania stand out as the only ones reaching a total score of 10, primarily due to the hydromorphological integrity of their entire catchment. The Semani Delta, also in Albania, follows closely with a score of 9, exhibiting particular intactness in the delta area despite two major dams in its significant tributary, Devoll.

Among the top-ranked deltas, the Moraca Delta in Montenegro is noteworthy for being a distinctive inland freshwater delta that discharges into Skadar Lake and connects to the Bojana Buna delta.

Table 2 and Figure 14 highlight the major deltas app. > 10,000 ha in size (in total 18) and underline the outstanding importance of the Albanian deltas, particularly Vjosa, Shkumbin and Semani.

Table 3 shows the full scoring results.

Table 2: Larger deltas (> 10,000 ha)

Name	**Country**	**Area in ha**	**Ass1 Dams**	**Ass2 Hymo River**	**Ass3 Hymo DeltaCha**	**Ass4 Hymo DeltaWetl**	**Ass Delta Total**
Shkumbin	AL	16,628	1	3	3	3	**10**
Vjosa	AL	23,691	2	3	3	2	**10**
Nestos	GR	9,588	1	2	3	3	**9**
Semani	AL	20,413	1	2	3	3	**9**
Agios Georgios	GR	12,753	2	3	1	2	**8**
Bojana-Buna	AL-ME	16,424	1	2	2	3	**8**
Atachthos	GR	42,391	1	2	2	2	**7**
Seyhan	TR	65,129	1	1	3	2	**7**
Ceyhan	TR	63,592	1	1	2	3	**7**

Name	Country	Area in ha	Ass1 Dams	Ass2 Hymo River	Ass3 Hymo DeltaCha	Ass4 Hymo DeltaWetl	Ass Delta Total
Gediz	TR	32,958	1	2	2	2	**7**
Evros-Meric-Maritsa	GR	32,437	1	2	2	2	**7**
Acheloos	GR	50,244	1	1	2	2	**6**
Axios-Vardar	GR	27,547	1	2	2	1	**6**
Meander	TR	26,367	1	2	1	2	**6**
Göksu	TR	18,943	1	2	2	1	**6**
Turia-Poyo	ES	10,038	2	2	1	1	**6**
Arno	IT	14,000	1	1	1	2	**5**
Nile	EG	2,768,144	1	1	2	1	**5**
Po	IT	86,491	1	2	1	1	**5**
Rhône	FR	126,931	1	1	1	2	**5**
Ebro	ES	41,901	1	1	1	1	**4**

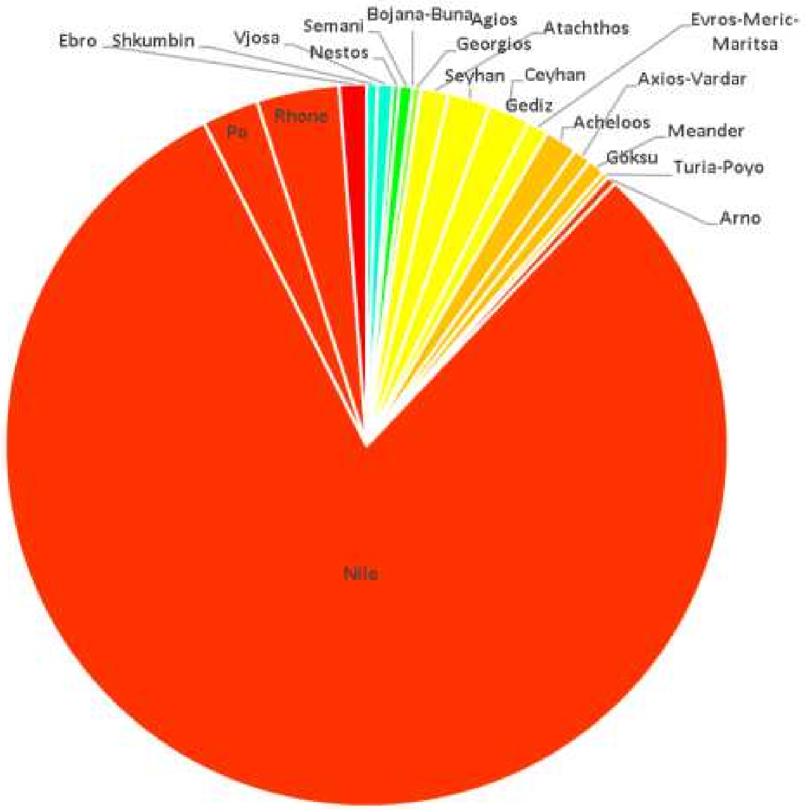

Figure 14: This visualisation demonstrates the extremely limited size of the top-scored large deltas.

Table 3: Tabular overview of all river deltas assessed, sorted by total score (and alphabetic order).

Name	Country	Area in ha	Ass1 Dams	Ass2 HymoRiver	Ass3 Hymo DeltaChan	Ass4 Hymo DeltaWetl	Ass Delta Total
Morača (Skadar Lake)	ME	2,419	3	3	2	3	**11**
Qued Amkrane	MA	47	3	3	3	2	**11**
Qued Ghis	MA	5	2	3	3	3	**11**
Dalyan sea delta	TR	1,672	3	2	3	2	**10**
Ddas	DZ[3]	39	3	3	2	2	**10**
Erzem	AL	4,642	3	2	2	2	**10**
Liamone	FR	108	3	3	2	2	**10**
Liscia	IT	91	3	2	3	2	**10**
Nterianos	GR	31	3	2	2	3	**10**
Qued el Abid	DZ	14	2	3	3	2	**10**
Qued Ouringa	MA	52	3	3	2	2	**10**
Qued Roumane	DZ	11	3	2	3	2	**10**
San Giovanni	IT	197	3	2	3	2	**10**

[3] Algeria

Name	Country	Area in ha	Ass1 Dams	Ass2 HymoRiver	Ass3 Hymo DeltaChan	Ass4 Hymo DeltaWetl	Ass Delta Total
Shkumbin	AL	16,628	1	3	3	3	**10**
Taghssa	MA	4	3	3	2	2	**10**
Vjosa	AL	23,691	2	3	3	2	**10**
Alfeios	GR	2,154	2	3	2	2	**9**
Azeffoun	DZ	78	3	2	2	2	**9**
Diarizos	CY	20	3	2	2	2	**9**
Evrotas	GR	473	3	3	1	2	**9**
Kücükmenderes	TR	4,054	2	2	3	2	**9**
Marsa	DZ	5	3	2	2	2	**9**
Nestos	GR	9,588	1	2	3	3	**9**
Noce	IT	37	3	2	2	2	**9**
Ouled Boughalem	DZ	6	3	2	2	2	**9**
Pinios	GR	3,631	2	3	2	2	**9**
Qued Achem	DZ	20	3	2	2	2	**9**
Qued el Kebir	DZ	253	2	2	3	2	**9**
Qued Messelmoun	DZ	50	3	2	2	2	**9**
Qued Mjer	MA	9	3	3	1	2	**9**
Qued Poluruah	DZ	4	3	2	2	2	**9**
Ques el Amri	DZ	7	3	2	2	2	**9**
Saraceno	IT	365	3	2	2	2	**9**
Seman	AL	20,413	1	2	3	3	**9**
Taougrite	DZ	21	3	2	2	2	**9**
Tayda	DZ	14	3	3	2	1	**9**
Tihissass	MA	63	3	2	2	2	**9**
Agias	GR	10	2	2	3	1	**8**
Agios Georgios	GR	12,753	2	3	1	2	**8**
Akbarpinar	TR	736	3	1	2	2	**8**
Almiros	GR	72	3	2	1	2	**8**
Amendolea	IT	16	2	2	2	2	**8**
Assi	IT	10	3	2	2	1	**8**
Bojana-Buna	AL-ME	16,424	1	2	2	3	**8**
Caronia	IT	138	3	2	1	2	**8**
Cedrino	IT	80	3	2	2	1	**8**
Crati	IT	340	2	2	2	2	**8**
Fiumenica	IT	53	3	2	2	1	**8**
Fortore	IT	182	2	2	2	2	**8**
Gidomandritis	GR	5,025	2	3	2	1	**8**
Golo	FR	894	2	2	2	2	**8**
Gravona	FR	188	2	2	2	2	**8**
Irminio	IT	81	2	1	3	2	**8**
Kücük Meander	TR	1,482	2	2	2	2	**8**
Lahsar	DZ	4	3	2	2	1	**8**
Lavris	GR	3	3	2	2	1	**8**

Name	Country	Area in ha	Ass1 Dams	Ass2 HymoRiver	Ass3 Hymo DeltaChan	Ass4 Hymo DeltaWetl	Ass Delta Total
Lissos	GR	1,586	3	2	2	1	**8**
Litochoro	GR	479	2	3	1	2	**8**
Mazzarra	IT	16	3	2	2	1	**8**
Namnam-Dalyan	TR	2,708	2	2	2	2	**8**
Ombrone	IT	4,206	2	2	2	2	**8**
Posada	IT	351	3	2	2	1	**8**
Quad Kert	MA	128	1	2	2	3	**8**
Qued Baker	DZ	6	2	2	2	2	**8**
Qued es Sebt	DZ	11	3	2	2	1	**8**
Qued Laou	MA	314	2	2	2	2	**8**
Qued Taghzoult	DZ	11	3	2	2	1	**8**
Rakiname	TR	104	3	2	2	1	**8**
Rosmarino	IT	21	3	2	2	1	**8**
Sant Miquel	ES	62	3	2	1	2	**8**
Siniscola	IT	198	3	1	2	2	**8**
Tagliamento	IT	4,157	2	3	2	1	**8**
Tech	FR	116	3	2	2	1	**8**
Trionto	IT	105	3	2	2	1	**8**
Xanthos	TR	7,213	2	2	2	2	**8**
Agri	IT	469	2	2	2	1	**7**
Ahmetler	TR	1,332	3	2	1	1	**7**
Albegna	IT	3,401	2	2	1	2	**7**
Alento	IT	81	2	2	1	2	**7**
Aliakmonas	GR	9,954	1	2	2	2	**7**
Amato	IT	363	3	2	1	1	**7**
Astura	IT	173	2	2	2	1	**7**
Atachthos	GR	42,391	1	2	2	2	**7**
Bakirkay	TR	2,816	2	2	2	1	**7**
Basento	IT	269	2	2	2	1	**7**
Belice	IT	119	2	2	2	1	**7**
Bonamico	IT	24	3	2	1	1	**7**
Bussento	IT	60	2	2	1	2	**7**
Cervol	ES	13	3	2	1	1	**7**
Ceyhan	TR	63,592	1	1	2	3	**7**
Cheliff	DZ	199	1	2	2	2	**7**
Chienti	IT	39	2	2	2	1	**7**
Cholorema	GR	107	3	2	1	1	**7**
Delice-Sinad	TR	289	3	2	1	1	**7**
Dragon	TR	1,258	2	2	1	2	**7**
Dragonja	SI	940	3	2	1	1	**7**
Droge	TR	473	3	2	1	1	**7**
Durci	IT	399	2	2	2	1	**7**
Ermal	TN	247	2	1	2	2	**7**

Name	Country	Area in ha	Ass1 Dams	Ass2 HymoRiver	Ass3 Hymo DeltaChan	Ass4 Hymo DeltaWetl	Ass Delta Total
Esino	IT	19	3	2	1	1	**7**
Evros-Meric-Maritsa	GR	32,437	1	2	2	2	**7**
Ferro	IT	24	3	2	1	1	**7**
Fiora	IT	920	2	2	1	2	**7**
Foxi Gonatta	IT	972	3	2	1	1	**7**
Fratello	IT	36	3	2	1	1	**7**
Gediz	TR	32,958	1	2	2	2	**7**
Grande	IT	34	2	2	1	2	**7**
Isonzo-Socca	IT	6,015	1	2	2	2	**7**
Kannakkale	TR	48	3	2	1	1	**7**
Karasu	TR	2,026	3	2	1	1	**7**
Karinka	TR	274	3	2	1	1	**7**
Karpuzcay	TR	1,415	3	2	1	1	**7**
Kocasu-Capraz	TR	4,598	1	2	2	2	**7**
Köprücay	TR	7,884	2	2	2	1	**7**
Koutsoulidis	GR	20	2	2	2	1	**7**
Lao	IT	26	2	2	2	1	**7**
Lipuda	IT	166	3	2	1	1	**7**
Longane	IT	7	3	2	1	1	**7**
Magazzolo	IT	20	2	2	2	1	**7**
Mati	AL	5,986	1	1	3	2	**7**
Medjerda	TN	7,719	1	2	2	2	**7**
Metaura	IT	27	2	2	1	2	**7**
Moulouya	MA	1,305	1	2	2	2	**7**
Naro	IT	9	2	2	2	1	**7**
Neto	IT	457	2	2	2	1	**7**
Orbu	FR	330	2	2	2	1	**7**
Oued El Abid	TN	107	3	1	2	1	**7**
Palmas	IT	660	3	2	1	1	**7**
Patrongianus	IT	325	3	2	1	1	**7**
Piave	IT	997	2	2	2	1	**7**
Platani	IT	181	2	2	2	1	**7**
Qued Djen Djen	DZ	46	1	2	2	2	**7**
Qued el Maleh	MA	70	2	2	1	2	**7**
Qued el Nil	DZ	563	3	2	1	1	**7**
Qued Isser	DZ	154	1	2	2	2	**7**
Qued Mencha	DZ	54	1	2	2	2	**7**
Qued Nekor	MA	24	1	2	2	2	**7**
Sangro	IT	35	2	2	1	2	**7**
Sele	IT	273	2	2	1	2	**7**
Senia	ES	10	2	2	2	1	**7**
Seyhan	TR	65,129	1	1	3	2	**7**
Simeto	IT	1,914	1	2	2	2	**7**

Name	Country	Area in ha	Ass1 Dams	Ass2 HymoRiver	Ass3 Hymo DeltaChan	Ass4 Hymo DeltaWetl	Ass Delta Total
Sinni	IT	577	2	1	2	2	**7**
Tacina	IT	145	2	2	1	2	**7**
Tanos	GR	6	2	2	2	1	**7**
Tavignano	FR	565	2	2	1	2	**7**
Tordino	IT	24	3	2	1	1	**7**
Ulugünej	TR	122	2	3	1	1	**7**
Vomano	IT	44	2	2	1	2	**7**
Acheloos	GR	50,244	1	1	2	2	**6**
Adra	ES	365	2	2	1	1	**6**
Alakli	TR	4,550	2	2	1	1	**6**
Algar	ES	12	2	1	1	2	**6**
Almanzora	ES	370	2	2	1	1	**6**
Andarax	ES	643	2	2	1	1	**6**
Argens	FR	375	1	2	1	2	**6**
Arkasu	TR	1,324	2	2	1	1	**6**
Axios-Vardar	GR	27,547	1	2	2	1	**6**
Belek	TR	8,741	3	1	1	1	**6**
Besos	ES	47	2	2	1	1	**6**
Boga	TR	492	2	2	1	1	**6**
Bruna	IT	1,793	2	2	1	1	**6**
Cecina	IT	168	2	2	1	1	**6**
Centa	IT	83	2	2	1	1	**6**
Cesano	IT	24	2	2	1	1	**6**
Coghinas	IT	276	1	2	2	1	**6**
Dalaman Cayi	TR	1,685	1	2	1	2	**6**
Demre	TR	2,119	2	2	1	1	**6**
Drinit	AL	3,040	1	2	1	2	**6**
Edremit	TR	803	2	2	1	1	**6**
Flumendosa	IT	1,146	1	2	1	2	**6**
Fluvia	ES	2,023	2	2	1	1	**6**
Garigliano	IT	157	1	2	1	2	**6**
Göksu	TR	18,943	1	2	2	1	**6**
Granikos	TR	3,588	2	2	1	1	**6**
Guadalfeo	ES	226	2	2	1	1	**6**
Havran	TR	1,606	2	2	1	1	**6**
Lez	FR	2,599	3	1	1	1	**6**
Madra	TR	5,012	2	2	1	1	**6**
Meander	TR	26,367	1	2	1	2	**6**
Mignone	IT	108	2	2	1	1	**6**
Mijares	ES	156	2	1	2	1	**6**
Muga	ES	1,094	2	2	1	1	**6**
Neda	GR	183	2	2	1	1	**6**
Ofanto	IT	185	2	2	1	1	**6**

Name	Country	Area in ha	Ass1 Dams	Ass2 HymoRiver	Ass3 Hymo DeltaChan	Ass4 Hymo DeltaWetl	Ass Delta Total
Orb	FR	1,731	1	2	1	2	**6**
Ören	TR	971	3	1	1	1	**6**
Orontes	TR	1,376	1	2	1	2	**6**
Pamisos Peloponnisou	GR	715	2	2	1	1	**6**
Qued Agrioun	DZ	81	1	1	2	2	**6**
Qued Hamlil	DZ	12	1	1	2	2	**6**
Qued Kiss	MA	32	3	1	1	1	**6**
Qued Kramis	DZ	27	1	1	2	2	**6**
Qued Meliane	TN	213	2	2	1	1	**6**
Qued Sebaou	DZ	131	1	2	2	1	**6**
Qued Tafna	DZ	29	1	2	1	2	**6**
Reart	FR	1,274	1	2	2	1	**6**
Reghaia	DZ	65	3	1	1	1	**6**
Saline-Piomba	IT	109	2	2	1	1	**6**
Salso	IT	26	2	2	1	1	**6**
Saricay	TR	2,500	2	2	1	1	**6**
Serchio	IT	3,439	1	1	2	2	**6**
Sosio	IT	31	2	2	1	1	**6**
Tenes	DZ	7	3	1	1	1	**6**
Tenna	IT	11	2	2	1	1	**6**
Tet	FR	213	1	2	2	1	**6**
Tipasa	DZ	35	1	2	1	2	**6**
Tirso	IT	3,739	1	1	2	2	**6**
Tordera	ES	387	2	2	1	1	**6**
Trigno	IT	60	2	2	1	1	**6**
Tronto	IT	187	2	2	1	1	**6**
Turia-Poyo	ES	10,038	2	2	1	1	**6**
Tuzla	TR	932	2	2	1	1	**6**
Verde	IT	53	2	1	2	1	**6**
Vidourle	FR	1,556	2	2	1	1	**6**
Agly	FR	456	1	2	1	1	**5**
Arno	IT	14,000	1	1	1	2	**5**
Aude	FR	2,361	1	1	1	2	**5**
Bared	LB	25	1	2	1	1	**5**
Gönen Cayi	TR	2,840	1	2	1	1	**5**
Guadalhorce	ES	394	2	1	1	1	**5**
Guadiaro	ES	74	2	1	1	1	**5**
Güzelhisar	TR	726	2	1	1	1	**5**
Herault	FR	345	1	1	1	2	**5**
Kavaklarbogazi	TR	269	2	1	1	1	**5**
Kocacay	TR	1,423	2	1	1	1	**5**
Magra	IT	245	1	2	1	1	**5**

Name	Country	Area in ha	Ass1 Dams	Ass2 HymoRiver	Ass3 Hymo DeltaChan	Ass4 Hymo DeltaWetl	Ass Delta Total
Mazarron	ES	71	2	1	1	1	**5**
Montnegre	ES	15	1	1	1	2	**5**
Nahal Poleg	IL	59	1	1	1	2	**5**
Neretva	HR	7,243	1	2	1	1	**5**
Nile	EG	2,768,144	1	1	2	1	**5**
Po	IT	86,491	1	2	1	1	**5**
Qued Bou Douaou	DZ	56	1	1	1	2	**5**
Qued Hammam	DZ	177	1	1	2	1	**5**
Qued Heiera	MA	1,392	2	1	1	1	**5**
Rhône	FR	126,931	1	1	1	2	**5**
Sancay	TR	1,180	1	2	1	1	**5**
Siagne	FR	17	1	2	1	1	**5**
Struma	GR	1,266	1	2	1	1	**5**
Ter	ES	1,203	1	1	1	2	**5**
Var	FR	167	1	2	1	1	**5**
Wadi Quandil	SY	9	1	1	2	1	**5**
Aksu	TR	6,205	1	1	1	1	**4**
Antas	ES	35	1	1	1	1	**4**
Dimcayi	TR	103	1	1	1	1	**4**
Ebro	ES	41,901	1	1	1	1	**4**
Jucar	ES	1,132	1	1	1	1	**4**
Kabir	LB	705	1	1	1	1	**4**
Llobrgat	ES	7,585	1	1	1	1	**4**
Manavgat	TR	1,735	1	1	1	1	**4**
Nachal Alexander	IL	108	1	1	1	1	**4**
Nahr al-Kabir al Shamali	SY	737	1	1	1	1	**4**
Paphos	CY	9	1	1	1	1	**4**
Reno	IT	2,346	1	1	1	1	**4**
Segura	ES	385	1	1	1	1	**4**
Tiber	IT	687	1	1	1	1	**4**
Volturno	IT	2,125	1	1	1	1	**4**

3.2 Selected examples for main assessment scores 10-12 (deltas assessed best)

Most remarkable is the concentration of three relatively intact deltas, known as the "triple-deltas," situated along the southern coast of Albania—the Vjosa, Semani, and Shkumbin rivers. These deltas, spanning 24,000 hectares (Vjosa), 20,000 hectares (Semani), and 17,000 hectares (Shkumbin), fall into the category of large deltas with expansive coastal plains. Various lagoons, extensive deltaic dunes, and stretches of coastal swamps shaped by river sediments and the forces of waves and wind, characterise all three deltas.

The Semani Delta appears to be the most pristine. However, the construction of two major dams on the Devoll River, a significant tributary to the Semani River, exerts a considerable impact on both sediment and the hydromorphological regime downstream of the dams. Consequently, this resulted in a lower overall assessment score, considering factors such as dams and the hydromorphological status of the main rivers in the catchment.

The region between the Shkumbin and Semani rivers is safeguarded as the Karavasta National Park. Nonetheless, it's important to note that the protected area does not encompass the entirety of the delta areas but primarily focuses on lagoon habitats. While the Vjosa River remains the sole free-flowing river of its size in the Mediterranean, the sediment extraction along its lower course poses a threat to the sediment flux reaching the delta.

Figure 15: The triple deltas in a glance: In the foreground the Vjosa Delta, in the middle the Semani Delta and far upper left the Shkumbin Delta (Google Earth 2023).

Figure 16: The Semani Delta covers a large variety of habitats. Agricultural areas are located far away from the coast, leaving the coastal area mainly untouched (Google Earth 2023).

Figure 17: The Shkumbin Delta can be seen from the north and the extensive Karavasta Lagoon in the background (Google Earth 2023).

Figure 18: The Vjosa delta mouth provides the most discharge and sediment load of all three deltas. The Vjosa Delta still hosts a remarkable delta front and a highly dynamic small lagoon system, particularly on the southern delta area. On the other hand, agricultural usage has spread into the delta area, and now, fishery activities and impacts of keeping water in the lagoons deteriorate and endanger the site protected as Pishe Poro - Narte Protected Landscape (Google Earth 2023).

Figure 19: Inside the Vjosa Delta. Shifting channels with side erosion are inevitable for living deltas.

3.3 Selected examples for main assessment scores 7-9 (Deltas assessed moderate)

The Evros/Maric Delta on the border between Greece and Turkey (total score 7) still hosts valuable habitats. However, river regulation and excessive irrigation schemes along the lower course of the river significantly reduced the ranking of the hydromorphological intactness. The fresh and brackish water zone is changing within the totally rectified main channel enforcing saltwater intrusion. By strong irrigation upstream the delta and its canal systems, the natural shield of freshwater keeping seawater away from land is deteriorated and pollution can be concentrated in those regulated confluences.

Figure 20: Evros Delta, another large delta (32.400 ha) but regulated to a large extent (Google Earth 2023).

3.4 Selected examples for main assessment scores 4-6 (Deltas assessed worst)

To better enable direct comparison with the deltas depicted as examples for top and medium scores, Arno River Delta, which is comparable in size, was chosen as an example for this ranking. The delta received a score of 5 points, as it shows an extensively altered delta with only a few remnants of typical habitats. The main features in the area are regulated rivers, even canals, touristic areas along the former delta coast and pine plantations between arable fields, entirely converting the former delta landscape.

Figure 21: Extensively altered delta of the Arno River in Italy (Google Earth 2023).

Within the Annex, additional 57 deltas (mostly large) can be found for all scores as Google Earth web images for illustration.

4. Conclusions

Based on the assessment conducted, the following conclusions and needs for protection and restoration of deltas can be drawn:

- Within the study, 258 river deltas and river mouths in the Mediterranean Basin with a total surface area of 3,739,417 ha were analysed. This covers most of the confluences in this area.
- According to the analysis, only 4% of the deltas assessed are in good condition. None of the deltas remained fully unaltered and only one quarter (25%) of the deltas assessed provide at least partial habitats typical for delta landscapes.
- The assessment indicates the rareness of large intact deltas in the Mediterranean Basin (out of 21 only two received 10 scores with in total 40,319 ha, the Shkumbin and Vjosa deltas, both in Albania).
- The deltas in Albania, specifically those of Vjosa, Shkumbin and Semani River, are still of outstanding quality as they remained mostly unchanged in the past decades. They are thus of utmost importance for the entire Mediterranean Sea.
- Most of the deltas under favourable conditions are still subject to coastal erosion, partly due to the increasing construction of dams, and partly due to excessive sediment exploitation in the lower courses.
- The vulnerability of deltas is increasing due to infrastructure development in the delta area as well as touristic development and urban sprawl since the 1970s.

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6. Annex: Representative delta images from Google Earth Web

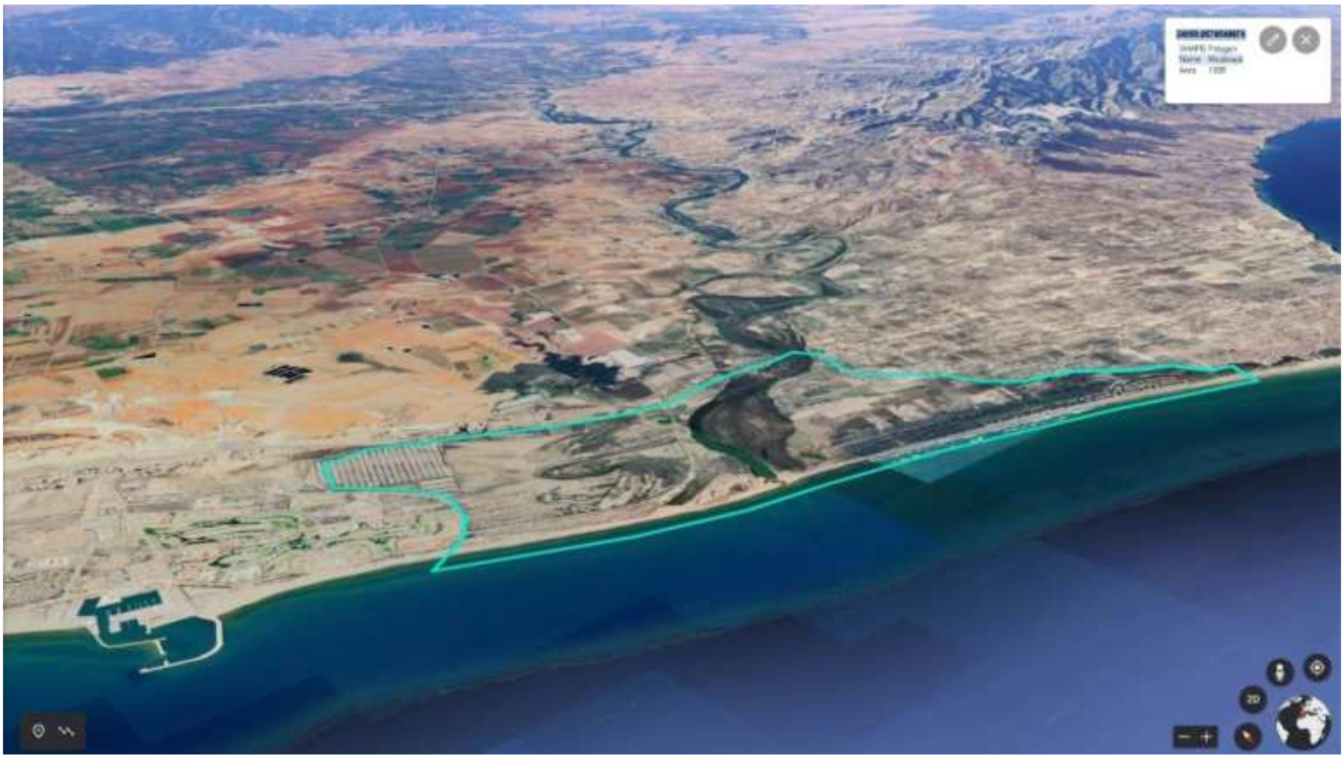
In the following, many representative deltas will be presented in images and described in a brief sentence. The order of presentation is anti-clockwise from Morocco (Africa) over Turkey (Asia), the Balkans, Italy and finally Western Europe (Europe). The respective delta names are indicated in the box in the upper right corner of each picture.

Many deltas are shrunk by urban sprawl and infrastructure development (Google Earth 2023).

Settlements and airports, which must be protected against flooding, can be found frequently on deltas (Google Earth 2023).

Agricultural usage often delimited natural areas and deltaic wetlands (Google Earth 2023).

This assessment also includes all larger naturally looking river mouths into the sea, even if they do not fall into the strict delta definition (Google Earth 2023).



Often, rivers cross intensively used lowlands before discharging into the sea (Google Earth 2023).

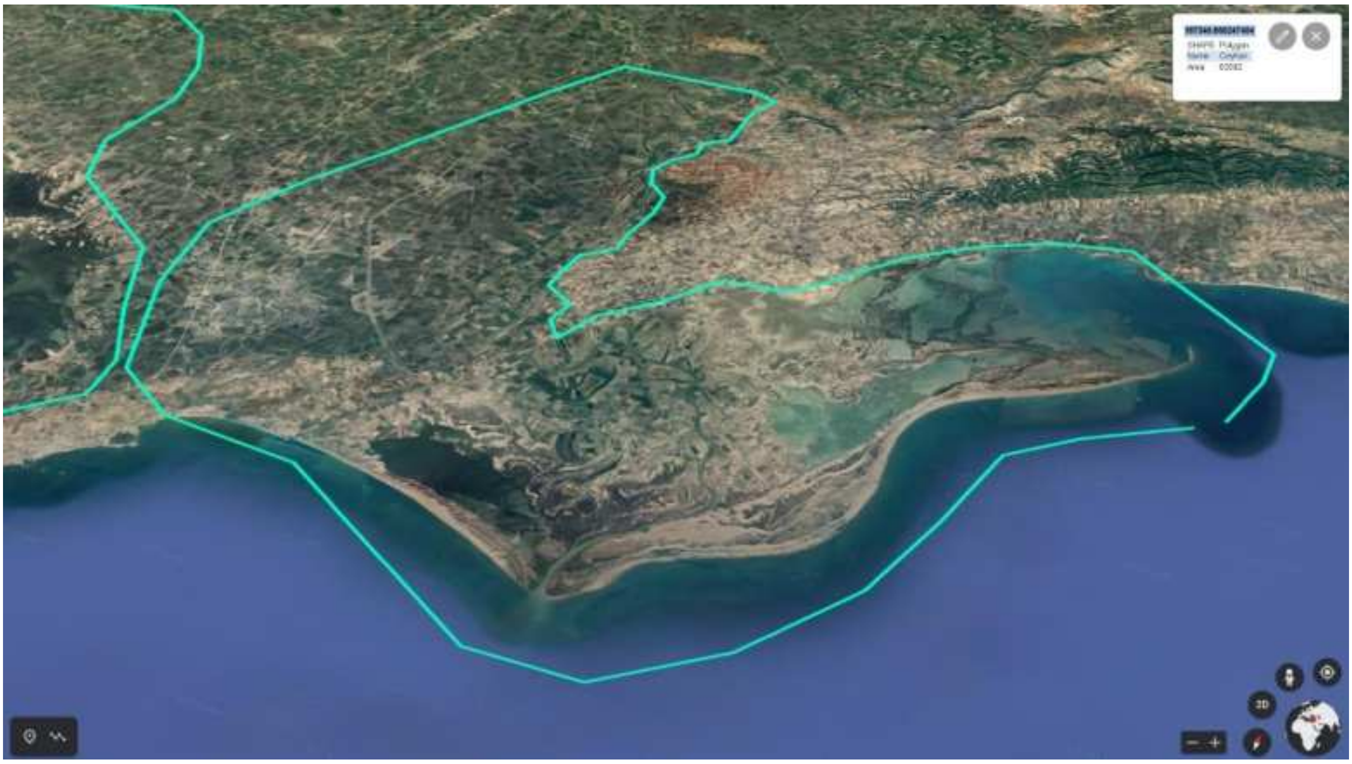
Deltas have become highly productive areas for humans with the building of glass houses, nearby railways and intensive agriculture. Even railway lines were built near deltas (Google Earth 2023).

Deltas, or larger river mouths, are often easily accessible from beaches. This leads to disturbances, including hunting or waste deposits (Google Earth 2023).

Where discharges are mainly used for irrigation, former deltas slowly die out, and only lagoons remain as deltaic features (Google Earth 2023).

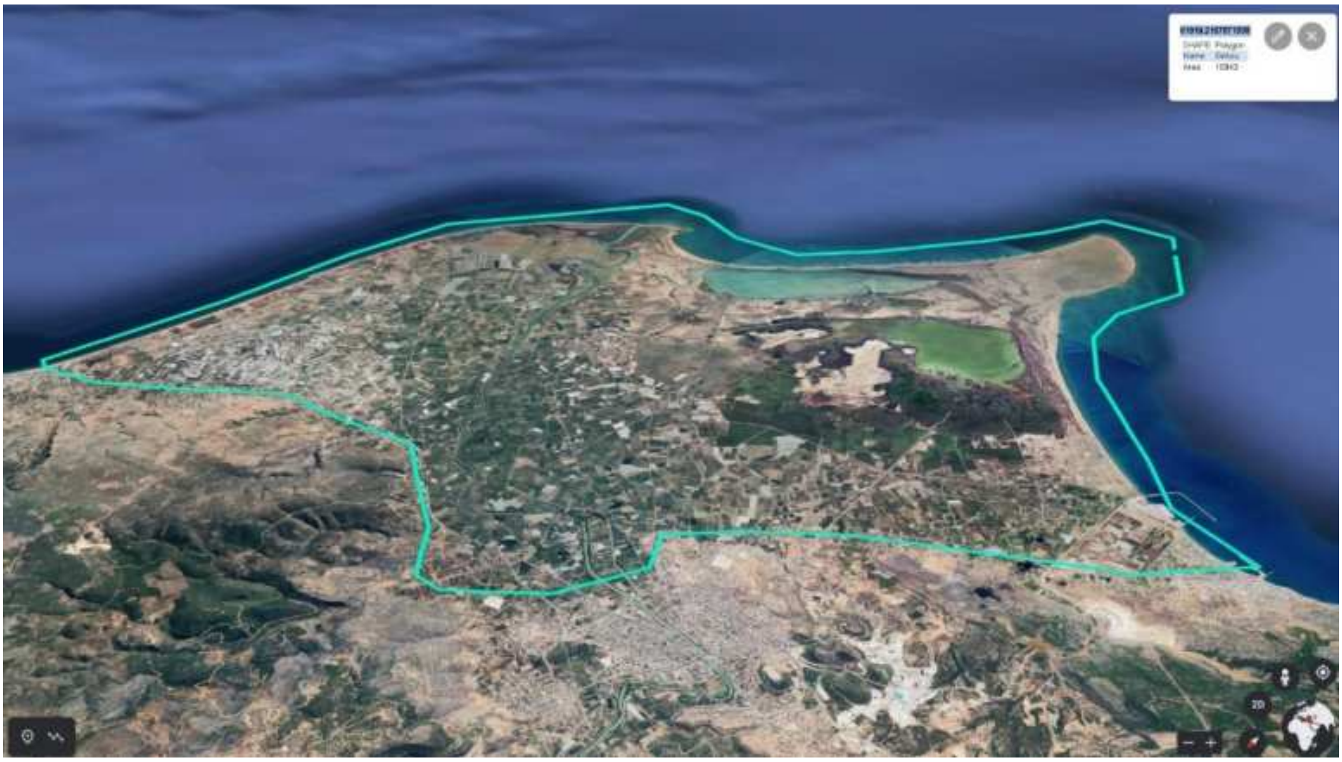
The Nile Delta is easily visible from space, forming a unique green agricultural production area within the desert. The Nile River is a human cultural lifeline of global importance. Nevertheless, up to 90% of Nile discharge is used for irrigation to maintain agricultural production (Google Earth 2023).

In some deltas, it is hard to recognise the river and even small remnants such as lagoons (Google Earth 2023).



The Syhan-Cyhan double delta in Turkey is among the largest in the Mediterranean and still hosts precious natural features. However, hydropower dams have heavily affected the catchment over the past 4-5 decades (Google Earth 2023).

The plains of this double delta spread over 50 km (in the background, the first hydropower impoundments are visible (Google Earth 2023).



Several protected areas can be found in deltas. However, despite protection levels, their spatial dimension often covers only small parts of deltas, like, in this case, only the lagoons (Google Earth 2023).

Again, glass houses cover several deltas more or less entirely. Along with the total removal of natural deltaic features, pollution, i.e. due to excessive use of fertilisers and pesticides, highly impacts the water quality (Google Earth 2023).

Touristic use and golf courses are another threat to deltas in general. Apart from France and Italy, Turkey is mainly affected (Google Earth 2023).

In some deltas, at least buffer areas of deltas remain. However, in this example, hinterland swamps associated with the delta will become disconnected from the delta (Google Earth 2023).

In mountainous coastal areas, delta plains are often a favourable airport location. At least ten examples of deltas in which airports were built can be recorded. The flight noise, traffic, and storage of fuel and other pollutants can seriously affect the sensitive delta ecosystems (Google Earth 2023).

Again, a double delta was built out of two separate rivers and the touristic construction between the most valuable river mouths (Google Earth 2023).

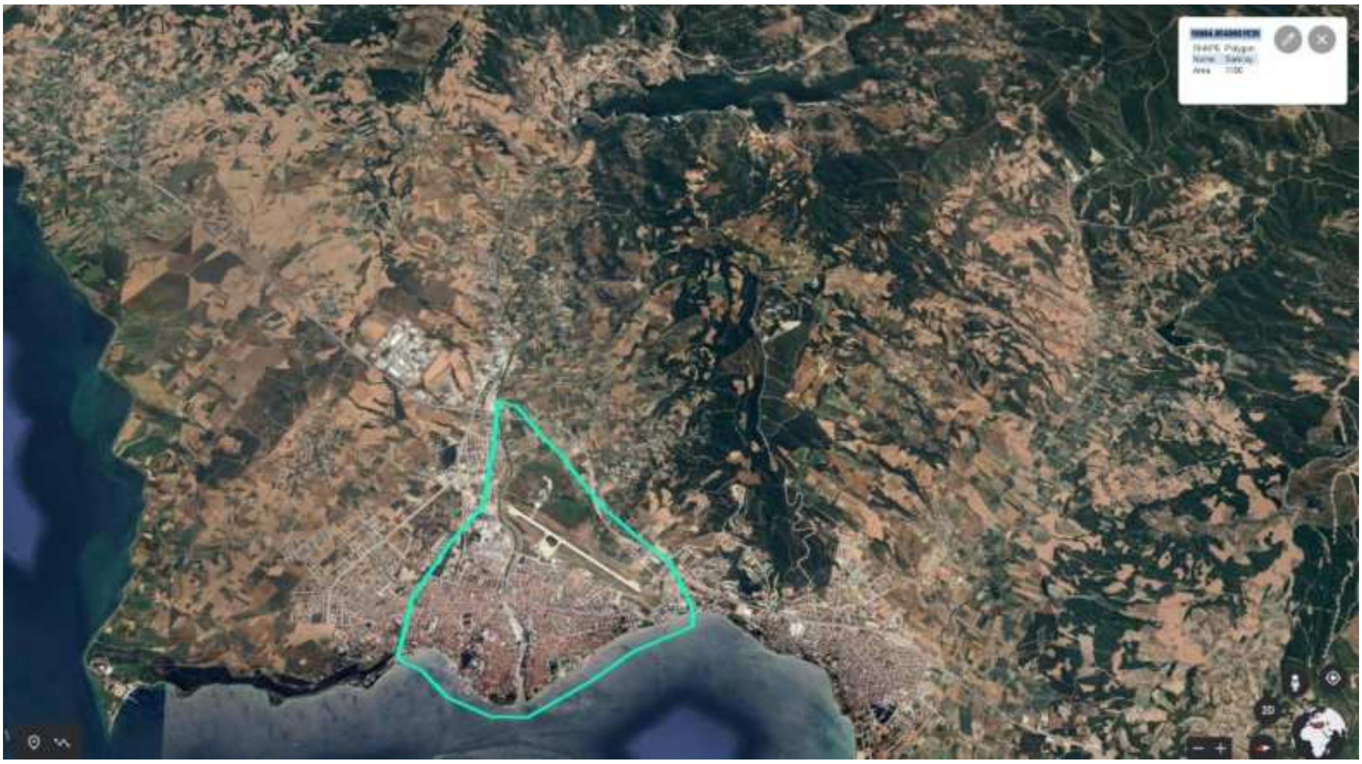
Famous rivers like the “Great Meander” no longer represent the blueprint for meandering rivers. Strong regulation and intensive agriculture allow only a small coastal strip with typical delta habitats (Google Earth 2023).

In some cases, salines cover significant parts of deltas, and their dykes even reach the coastline. Near the urban areas, airports and refineries are built inside the delta area (Google Earth 2023).

New settlements and tourist developments can be observed within the core delta area (Google Earth 2023).

Fully regulated deltas lead to the drying out and total loss of deltaic habitats (Google Earth 2023).

The construction of flood dykes disconnects large delta areas from natural processes of flooding and sediment aggradation, and parallel canals built for irrigation and drainage harm the hydrological regime and increase pollution load in the split channels (Google Earth 2023).

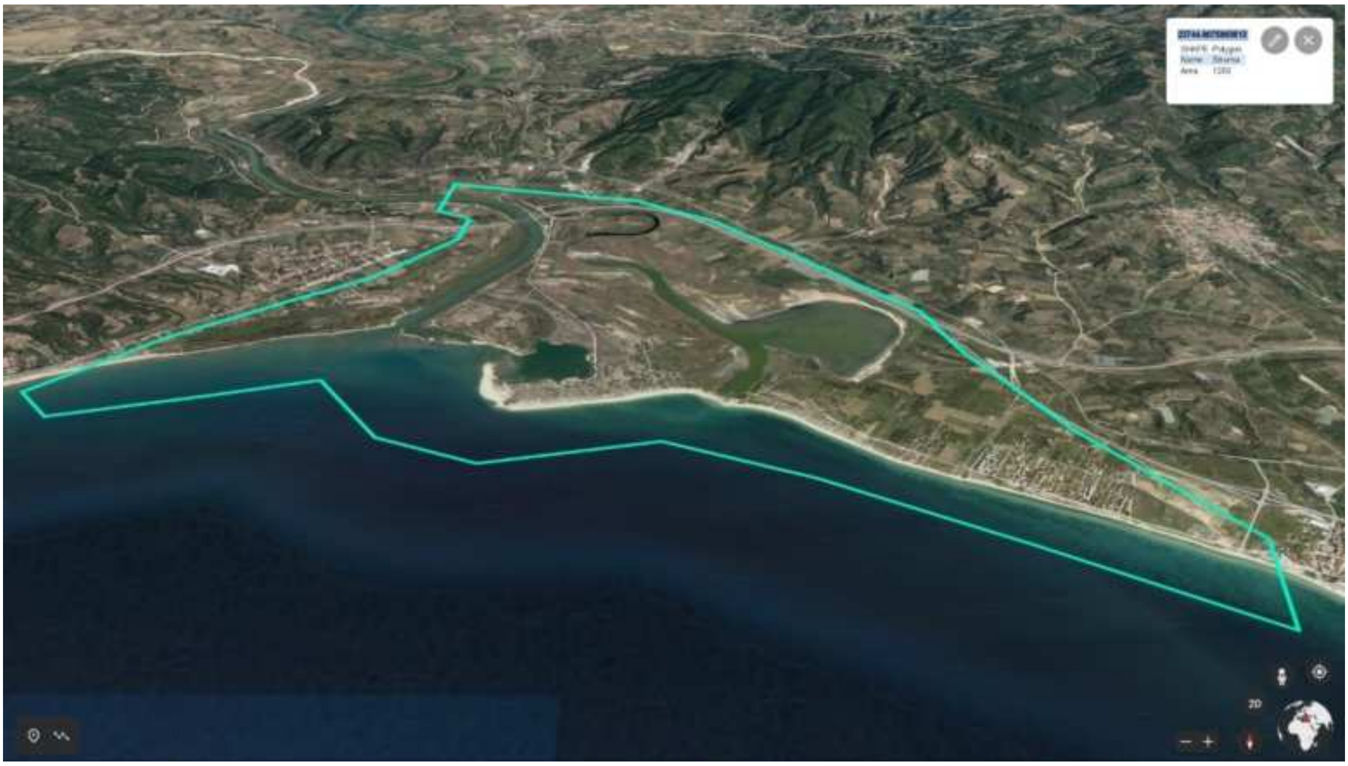


The construction of flood-prone settlements in delta areas is a relatively common development. Due to the remnants of a lagoon close to the airport, this delta was recognised as such and was therefore included in the study. The dam breeches and flooding of Derna in Libya in September 2023 with more than 2,500 casualties are a grim reminder of the painful consequences of constructing towns on river deltas. In this case, the reservoir in the hinterland is visible (Google Earth 2023).

Only small strips at the coastline often remain as natural delta areas (Google Earth 2023).

River regulation affects many deltas, leading to completely changed flood distribution and deltaic development. Changing, even dredging, lower river courses can cause saltwater intrusion and severe problems for agriculture and water supply (Google Earth 2023).

Only a few deltas still host more extensive floodplain forests. One example is the Nestos Delta in Greece (the cover of this study) (Google Earth 2023).



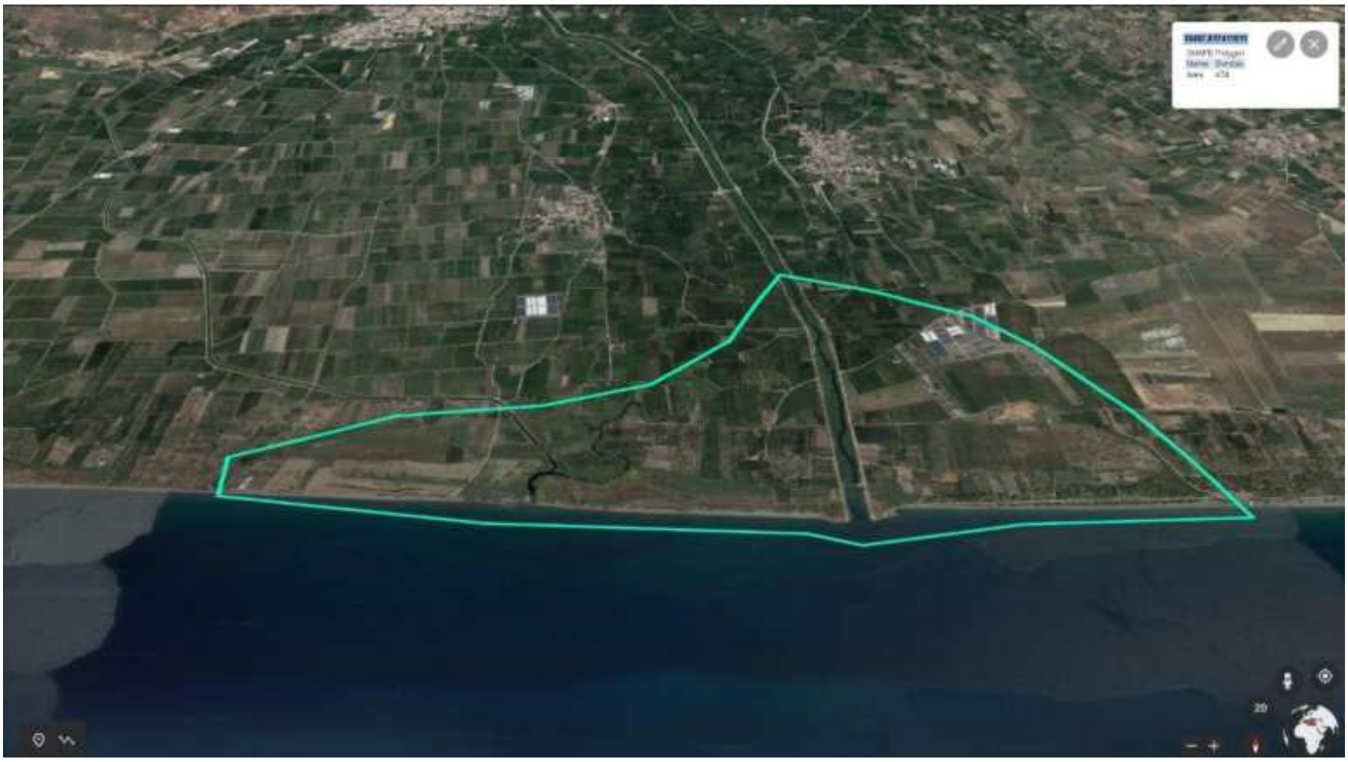
Engineered deltas comprise channel regulation and constructions such as dam and sluice systems to former lagoons, harbours and settlements (Google Earth 2023).

Due to human interaction, the delta type varies, or its behaviour is intensified. In this case, the strongly regulated lower channel increases slope and stream power, generating a crowfoot delta with various small front channels (Google Earth 2023).

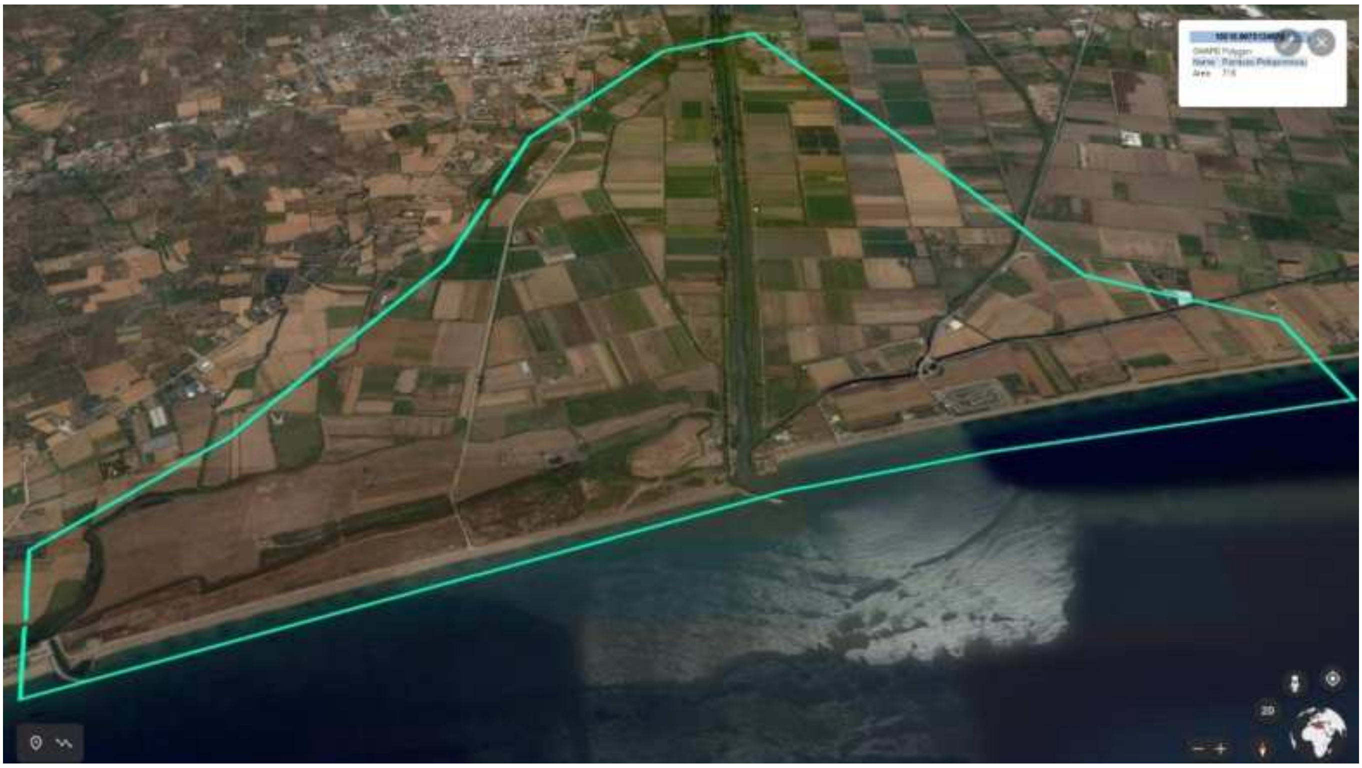
As in previous examples, this double delta covers a vast area. However, the numerous constructions of large hydropower dams in the river's middle course cause a drop of transported sediments, which results in a decreasing delta area as material to “produce” such is missing (Google Earth 2023).

Several examples show the construction of settlements within deltas during the past decades, reducing natural habitats and increasing flood risk (Google Earth 2023).

Pictured is another example of a completely regulated lower river course and intensively used delta plains for agriculture (Google Earth 2023).

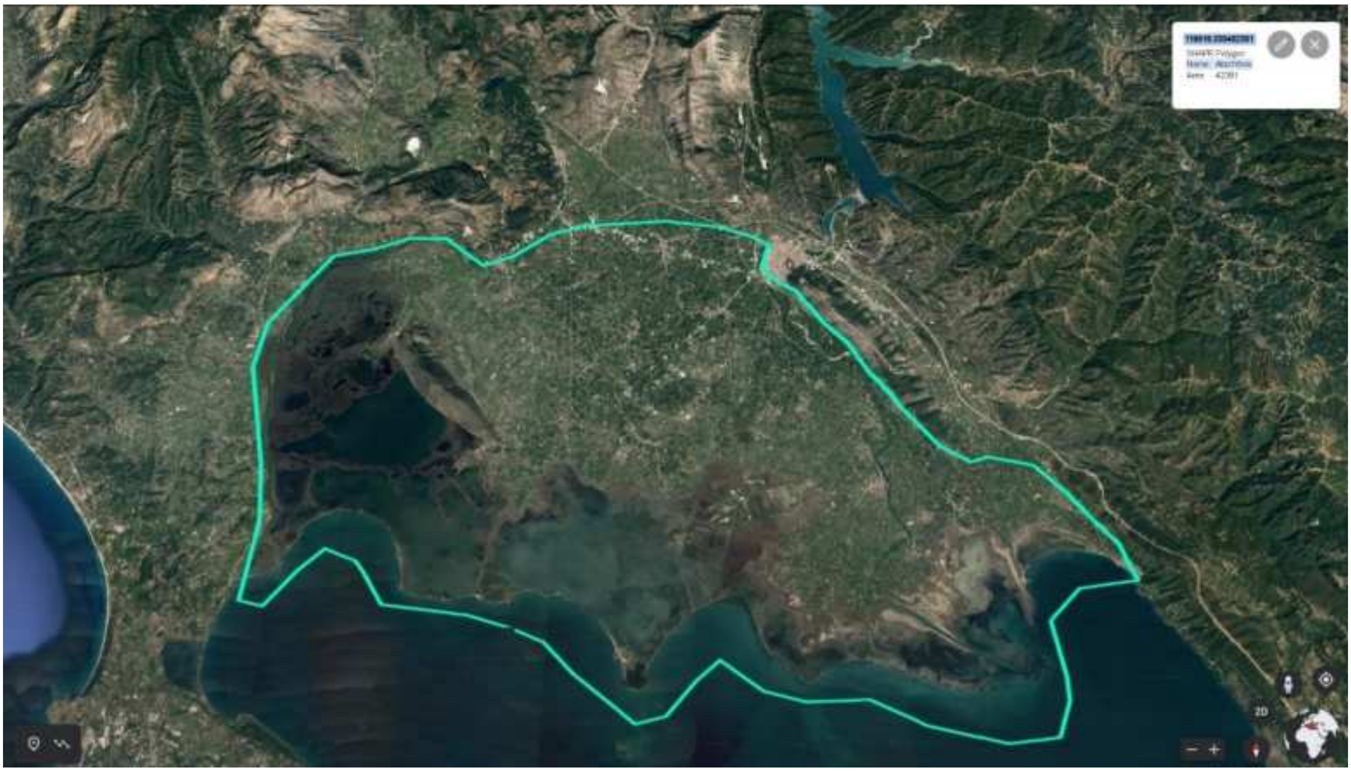


Regulation of the main course of the river enables the adverse development of settlements and intensive agriculture in delta areas, both prone to be flooded sooner or later (Google Earth 2023).



The complete lack of space for any natural development of deltas is representative of many deltas in regulated landscapes in Greece and Italy (Google Earth 2023).

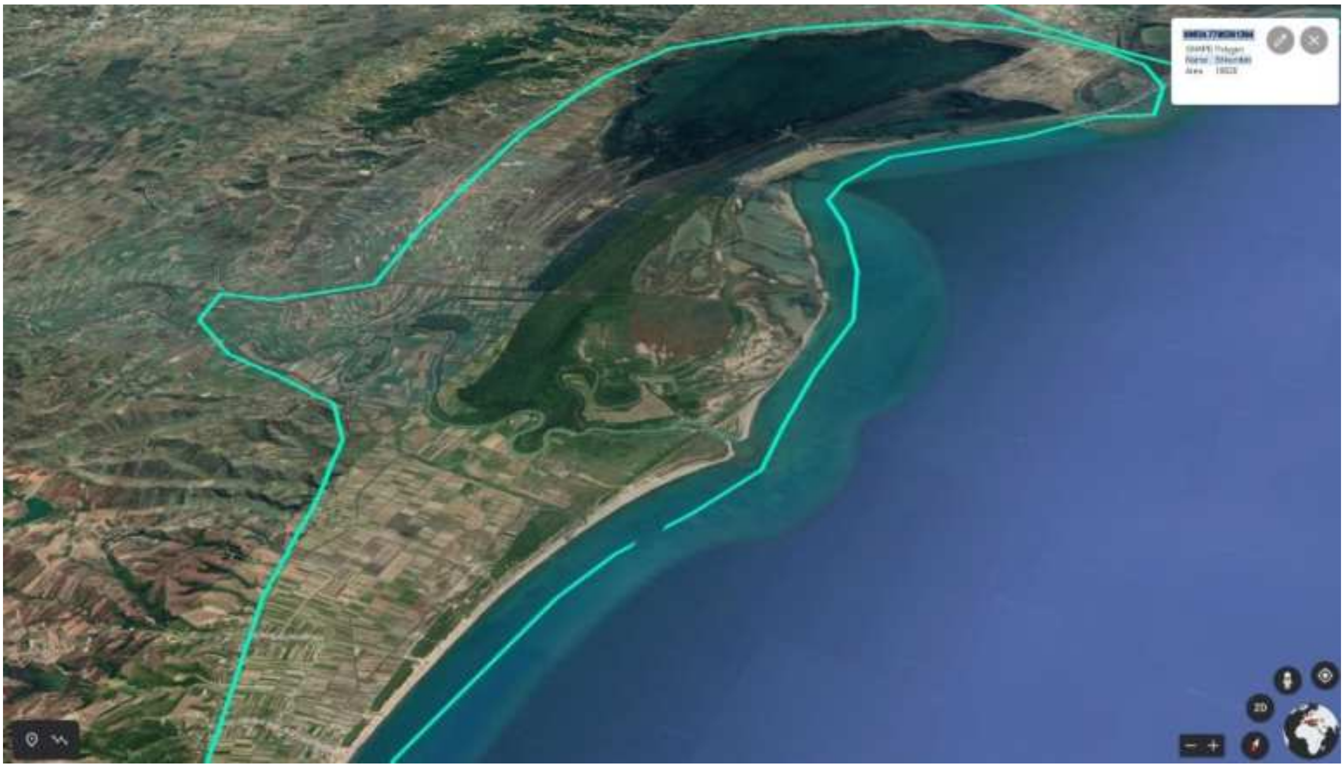
River regulation prevents the natural and regular shift of main delta channels, causing long-term coastline erosion and a decrease in deltas. To protect the coast, construction of dykes and coastal protection measures are needed (Google Earth 2023).



If sediments are caught behind major dams, the fertile delta lowlands become prone to be eroded by waves. Additionally, saltwater intrusion can limit growth conditions and freshwater supply for households (Google Earth 2023).

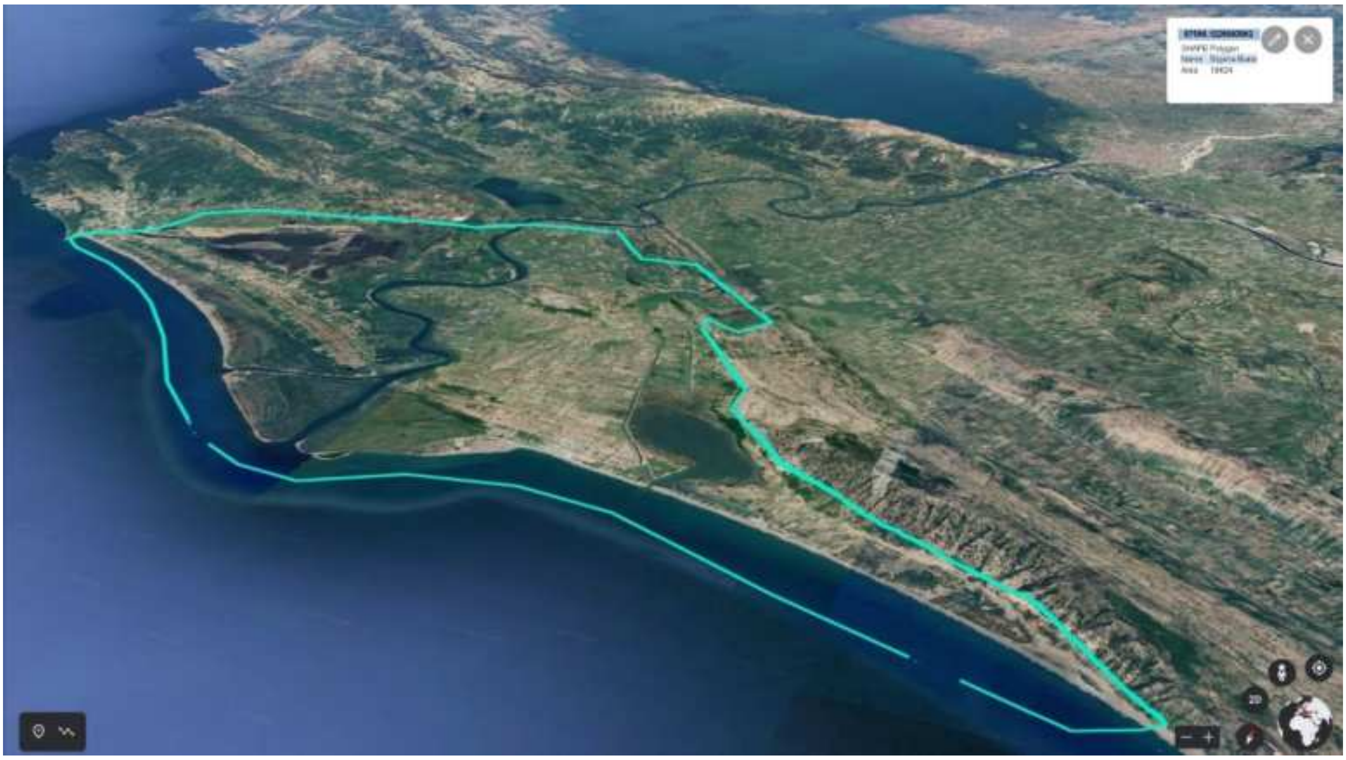
Large intact rivers supplying sufficient sediment load and providing a natural flood dynamic are scarce (Google Earth 2023).

The full set of deltaic habitats created by the fluvial and marine dynamic of sediments and flooding, including wind and wave-induced sea dune scrolls with breakthroughs, backswamps, lagoons of different connectivity and size, remaining floodplain forests and point bars in the last meanders can be observed only in very few places (Google Earth 2023).



Complexes of deltas, including various lagoon complexes, are rich in biodiversity (Google Earth 2023).

Often, deltas are affected by many hydropower plants in the catchment (reservoir in the background) and intensive sediment dredging along the lower courses (where the river enters the plain). But this image also shows the coast's vulnerability and the vital function of deltas for coastal protection. (Google Earth 2023).



Settlements, agriculture, and tourism often develop from both sides of the deltas to the core. Strict spatial development and protection can help to prevent the loss of all valuable habitats (Google Earth 2023).

Sometimes, the usage of deltas can be observed in their close vicinity. These include harbours, industrial zones, and intensive agriculture. Still, remnants of the natural confluence exist (Google Earth 2023).

In some cases, the delta aggradation allows the development of settlements along the seafront, followed in recent decades by extensive tourism development (Google Earth 2023).

In the largest deltas in the Mediterranean, only some lagoons remain as natural features, channels are more or less regulated, and agriculture covers over 70% of the original delta area (Google Earth 2023).

Tourist resorts and marinas in former natural deltas can be observed in many Western European countries (Google Earth 2023).

Developing commercial and industrial areas close to deltas is common (Google Earth 2023).

Complete regulation and overbuilding of deltaic areas are the rule, not the exception (Google Earth 2023).

Urban sprawl eventually leads to a complete urbanisation of delta areas (Google Earth 2023).

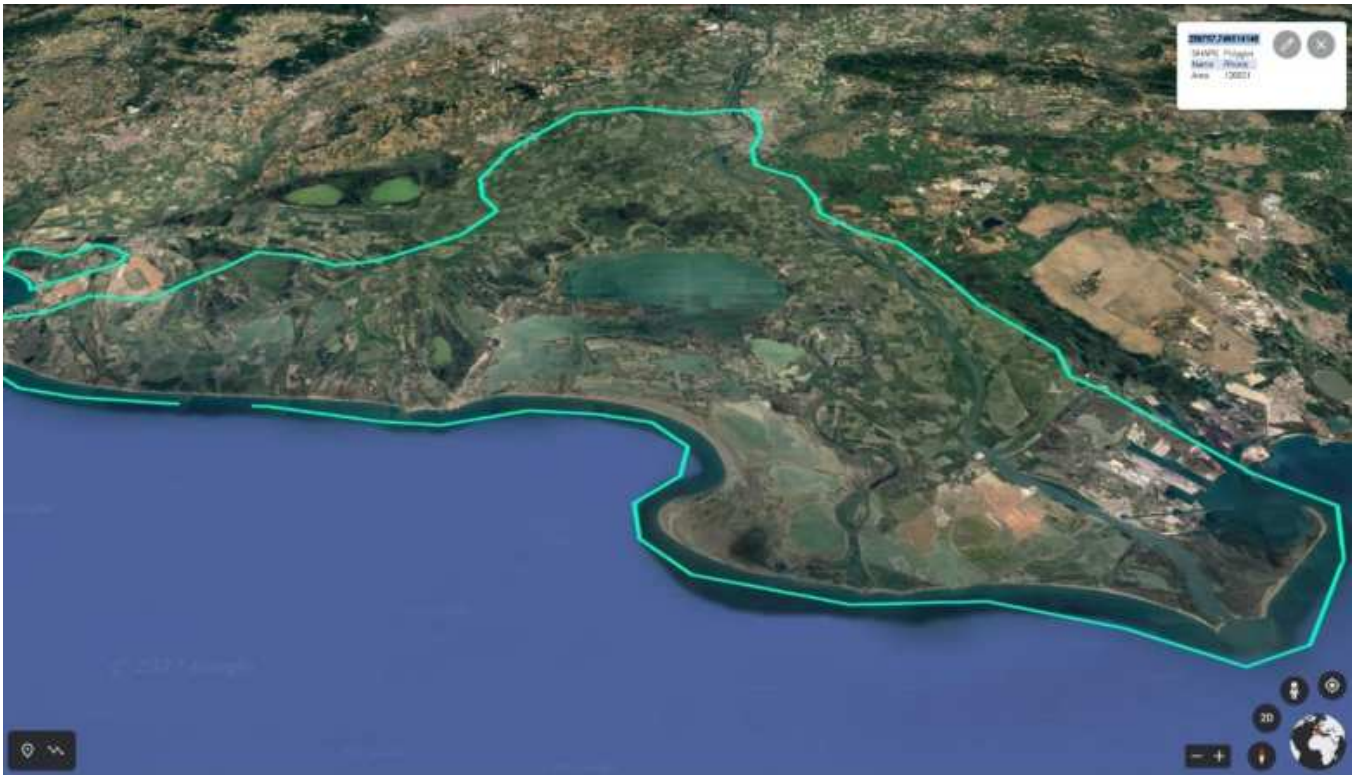
Even protected deltas are subject to considerable changes driven by river regulation, pollution by intensive agriculture and dams in the hinterland (Google Earth 2023).

Deltas are often surrounded by towns and various usages, and the entire channelisation of rivers alters the deltas drastically (Google Earth 2023).

Again, rule, not exemption: The total conversion of river mouths by covering the former delta area and enlarging the area by land reclamation (Google Earth 2023).

Coastal protection measures in the form of groynes go hand in hand with the dense land use in many areas (Google Earth 2023).

Total conversion of a natural delta for touristic use (Google Earth 2023).



In some cases, natural deltaic features remain. However, the main channels are intensely regulated, and the river upstream is modified; large dams in the catchment are frequent (Google Earth 2023).

Only very few deltaic elements remain of the former delta (Google Earth 2023).

Drastic conversion into arable land and major dams in the catchment strongly impact deltas (Google Earth 2023).

Only a minimum of delta-specific habitats remain, as is typical for the Spanish coast (Google Earth 2023).