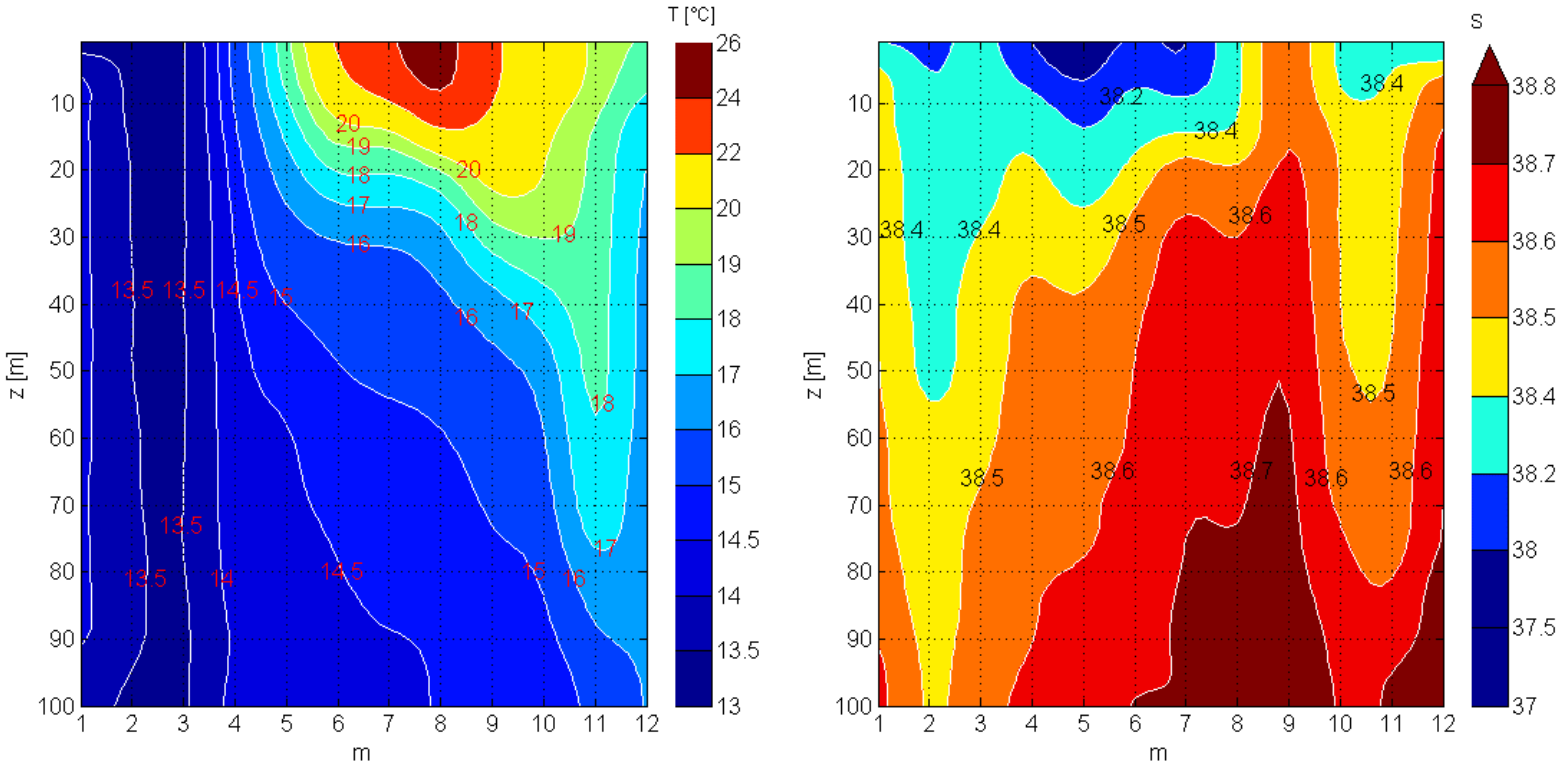
Implementation of the ecosystem approach
in the Adriatic through marine spatial planning

Towards a Marine Good Environmental Status (GES) in Montenegro

Assessment of Hydrography (EO7)



Mediterranean Action Plan
Barcelona Convention

Montenegro
Ministry of Ecology,
Spatial Planning and Urbanism

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Cover image:	Mean annual cycles of sea temperature and salinity for the Central Adriatic Sea, 1998-2010 (Grbec *et al.*, 2010)

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Foreword

This document provides assessment of good environmental status (GES) of marine areas of Montenegro regarding Hydrography (Ecological Objective 7 of the Integrated Monitoring and Assessment Programme (IMAP); Marine Strategy Framework Directive (MSFD) Descriptor 7).

The document is a part of the project “Implementation of ecosystem approach in the Adriatic Sea through marine spatial planning” (GEF Adriatic) co-financed by the Global Environment Facility (GEF), and is directly related to Outputs 1.1 (Updated assessment of the characteristics of a Good Environmental Status (GES) in the Adriatic Sea), and 1.2 (Proposal of the measures to achieve a Good Environmental Status) of the Project. When it was possible the topics in this document consider knowledge on hydrographic parameters and changes for the whole Adriatic basin, since reaching good environmental status (GES) does not rely solely on national efforts.

Special emphasis was placed on the specific dynamics of the Adriatic Sea, primarily due to the fact that the Adriatic Sea is sensitive to climate change. The impact of climate change is considered to be a significant pressure on other ecological objectives in the process of achieving good environmental status.

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1 Introduction

The Ecosystem Approach (EcAp) in the Mediterranean is integrated into the MAP and Barcelona Convention framework and the decisions of the Convention on Biological Diversity (CBD) regarding the ecosystem approach. Monitoring changes in hydrographic conditions is carried out through ecological objective EO7, i.e. its Common Indicator 15.

Ecological Objective: EO7 Hydrography (IMAP) – Alteration of hydrographic conditions does not adversely affect coastal and marine ecosystems

Common Indicator 15: Location and extent of the habitats impacted directly by hydrographic alterations (EO7)

MSFD Descriptor

D7 Commission Decision (EU) 2017/848 of 17 May 2017

Permanent alteration of hydrographical conditions does not adversely affect marine ecosystems

Criteria

D7C1 – Secondary: Spatial extent and distribution of permanent alteration of hydrographical conditions (e.g. changes in wave action, currents, salinity, temperature) to the seabed and water column, associated in particular with physical loss (1) of the natural seabed.

D7C2 – Secondary: Spatial extent of each benthic habitat type adversely affected (physical and hydrographical characteristics and associated biological communities) due to permanent alteration of hydrographical conditions. Member States shall establish threshold values for the adverse effects of permanent alterations of hydrographical conditions, through regional or sub-regional cooperation.

Permanent hydrographical changes can occur due to changes in the thermal or salinity regimes, changes in the tidal regime, sediment and freshwater transport, current or wave action and changes in turbidity. The degree of change and the period over which such change occurs varies considerably, depending on the type of modification. Assessment of the degree of change can be related to both the water column and the sea-floor, and consequently to their biological communities. These types of change are normally triggered by building activities, such as extensions or alterations to the coast, or the building of artificial islands and other infrastructural works in the marine environment (such as outfalls from power stations, bridges and causeways to islands, and offshore installations). This Descriptor addresses all such developments (existing and new infrastructures) including both large- and small-scale structures. The cumulative pressure of 'localized activities' will have to be considered to assess the significance of the aggregated effect of many small-scale changes. Specific importance is given to new planning activities that will have to fulfil Environmental Impacts Assessments (EIA).

Changes, such as altered erosion patterns or residence time can modify local conditions in a way that negatively impact sensitive species and habitats and can therefore compromise the achievement of the biodiversity and eutrophication Descriptors (D1, D4, D5 and D6). Consequently, the cumulative impact on the ecosystem from pressures resulting from the alteration of hydrographical conditions is therefore intimately linked to the assessments of these other Descriptors.

2 Potential pressures, impacts and climate sensitivity

About 28% of Europe's coastline is affected by permanent hydrographical changes, including from seawater movement, salinity and sea temperature changes, as a result of human activities such as dredging, infrastructural development, sand extraction or desalination (Report on the implementation of the Marine Strategy Framework Directive Directive, 2020). The MSFD information about trends and environmental status with respect to hydrographical conditions is, however, too scarce and scattered to allow for a suitable assessment on a large scale. The criteria and methods used are not harmonised. Direct and indirect changes in hydrographic variables caused by human actions, as well as their impacts on seabed and water column habitats, are not always well understood or reported under MSFD. As a large part of human activities directly responsible for hydrographical pressures take place in coastal waters, this problem is closely linked to the Water Framework Directive (WFD).

Permanent hydrographic changes due to infrastructural maintenance and development, maritime transport, sand extraction, tourism and recreation, have been observed in several locations along the coast of the Adriatic Sea. Therefore, the first step in achieving and preserving GES is to pay attention to such interventions at the local level. Their impact must be controlled by environmental impact studies, which are prescribed by local or state authorities. This reduces the cumulative effect of the intervention.

Changes in hydrographical conditions caused by natural processes and anthropogenic activities, and their cumulative impact on maintaining GES, should be such that they do not harm the marine ecosystem. The impact of human activities on the local and regional scale must be carried out in such a way that all significant changes and shifts in hydrographic properties, caused by natural and anthropogenic interventions, are minimized. The pressures on the seabed and water column caused by the mentioned interventions, including the pressure due to climate change, in the Adriatic Sea are evident in the changes in the regime of temperature, salinity, waves and currents and transparency. Therefore, spatial and temporal changes of temperature, salinity and transparency are the key parameters that determine dynamics of ecosystems. This dynamic is also controlled by processes at the spatial scale larger than the Adriatic, which is closely connected to different water masses present in the Adriatic.

Water masses specific to the Adriatic are a result of permanent and sudden climate changes over the northern hemisphere which results in a change of thermohaline circulation and water exchanges with the Mediterranean (Matić *et al.*, 2011). These changes can have permanent effects on the ecosystem by changing the composition and inter-relationships in the marine food web (Šolić *et al.*, 2018). The consequences of these changes are different along the coast and on the open seas because the hydrographic conditions are different.

As the other MSDF descriptors and EOs indicators, descriptor D7 and EO7 are based on the so-called DPSIR cycle (Figure 1): **D**rivers, **P**ressure, changes in **S**tates, **I**mpact and Response.

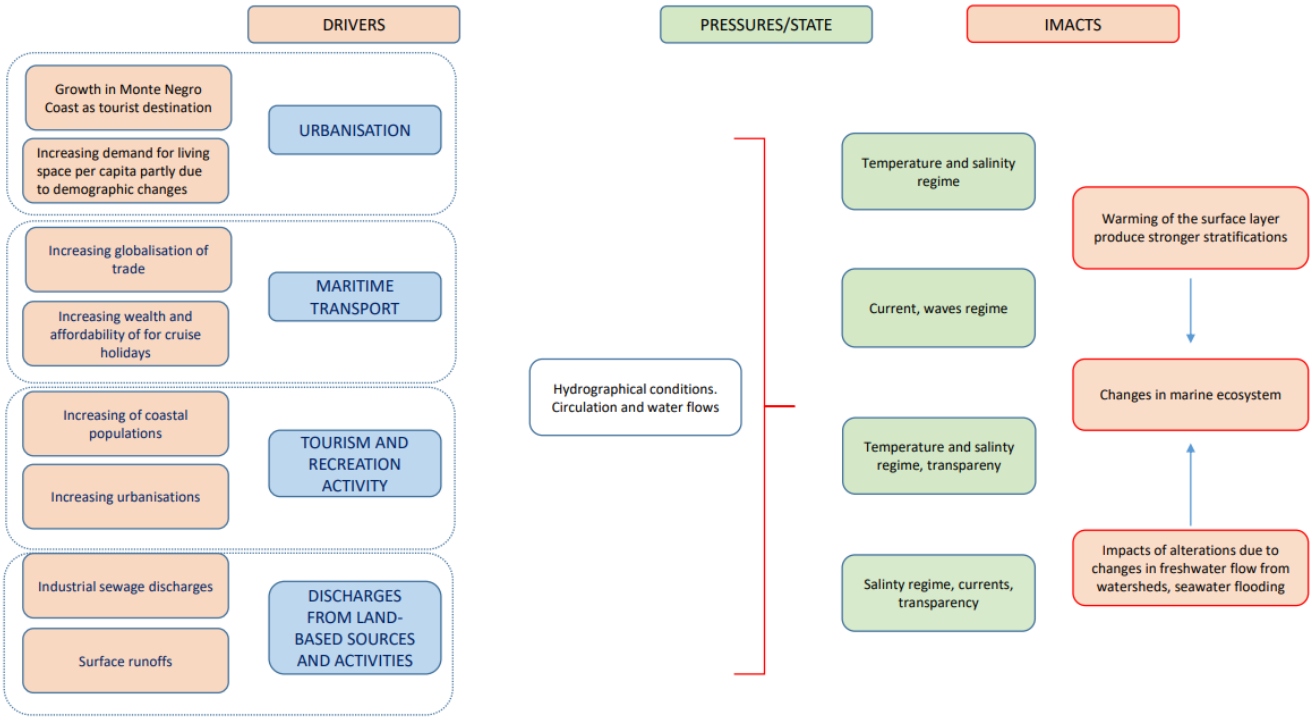

Figure 1. Map of key relations between Drivers-Pressure-State-Impact for hydrography

DPSIR cycle is based on the fact that human activities (drivers) exercise pressure on the marine environment, which may produce changes in the status of the environment, having negative impacts that could be prevented or mitigated through relevant measures that lead to a change to the activities (responses). Any of these five stages in the model can be observed, categorised and measured using specific parameters leading to achieve GES. In the framework of DPSIR model, various type of human response can be introduced. Under the hydrographical condition main drivers which produce pressure exercised on sea bed and/or in the water column can be those connected with climate changes and those activities which change the infrastructure in coastal and offshore waters.

Along the eastern Adriatic Sea, the main activities which cause (or can cause) changes in sea bed integrity are those connected with locally limited infrastructural interventions whose cumulative effect can permanently change hydrographic features. Interventions in a limited area are subject to environmental impact studies prescribed by national law. But their cumulative effect is subject of D7 under the MSFD and the IMAP's EO7. Changes in heat and salt (temperature and salinity regime changes), and transparency, and waves and sea currents are recognized as main hydrographic conditions which suffer the consequences of the human pressure exercised (impact) in the water body. To prevent any lasting changes, the response to anthropogenic action must strictly follow an ecological approach. Link between human impacts and hydrology in the Adriatic and Montenegrins waters is recognised through several drivers (Figure 1). Some of these drivers have strong impact most of the time during summer due to increasing pressures by tourism activities during summer season.

Climate sensitivity

Adriatic is very sensitive to climate changes and hence, under this era of strong climate changes, we can expect significant response in hydrographic conditions.

Various climatic scenarios for the Adriatic region show changes in the frequency and intensity of bora events, which cause changes in the intensity of vertical convection, changes in the structure of temperature and salinity and the formation of water mass.

As increase of salinity and temperature of the south Adriatic water should occur under such climate changes condition; in the future climate we can expect increase in density and consequently changes in vertical stability of water column. In the southern Adriatic Sea, two possible states of the oceanographic conditions: periods of stronger Mediterranean intrusions in the intermediate layer (i.e., ingression) and periods of weaker intrusions (i.e., non-ingression) (Bulljan et Zore-Armanda, 1976), have been recently explained by bimodal circulation (Civitarese *et al.*, 2010). This is associated with the atmospheric processes on a scale larger than the Adriatic basin, i.e. with variations in air pressure in the northern hemisphere (NH) (Zore-Armanda, 1969; Grbec *et al.*, 1998, Supić *et al.*, 2004). Due to the recent more frequent and stronger changes in the atmosphere, the established paradigm between ingressional/non-ingressional states in the Adriatic Sea (introduced by Buljan, 1953), which implies increase/decrease in salinity (and density) due to the strengthening/weakening of Levantine Intermediate Water (LIW) intrusions to the Adriatic Sea, should be revised as suggested by Civitarese *et al.* (2010). Changes in nutrients and production and pelagic ecosystem are not simply a consequence of intensification of the Eastern Mediterranean water inflow in the Adriatic, since these cannot explain transient Adriatic thermohaline conditions observed in the recent decades. Establishing anti-cyclonic and cyclonic circulation in the Ionian Sea (Bimodal Oscillating System; BiOS) salinity in the southern Adriatic is oscillating between the periods of reduced and enhanced salinity. In the central Adriatic, the thermohaline states are also oscillatory and more or less synchronous with Ionian salinity fluctuations, depending on the stronger/weaker intrusions from the Mediterranean, i.e. depending on the established cyclonic/anti-cyclonic circulation in the Ionian Sea (Civitarese *et al.* 2010; Matić *et al.*, 2011). The middle part of the eastern Adriatic is influenced by water intrusions from the Mediterranean (LIW and/or CW). The fluctuations of these intrusions have since long time been related to large scale pressure distribution over the NH. It is indisputable that the changes in pressure distribution over the NH and in the position of large pressure centres that define atmospheric oscillations such as the North Atlantic Oscillation (NAO), Arctic Oscillation (AO) and Mediterranean Oscillation (MO), cause changes in the thermohaline circulation of the Adriatic Sea as well as changes in phytoplankton, zooplankton and pelagic fish biomass (Coll *et al.*, 2009). Large-scale atmospheric pattern affects the marine ecosystem through regional weather pattern and ocean features. Natural modes of atmospheric variability such as the NAO, AO and MO during winter impose changes in the wind stress and heat flux on the ocean causing changes of temperature and salinity (Grbec *et al.*, 2007; Matić *et al.*, 2011), and biotic components (Dulčić *et al.*, 2004, Grbec *et al.*, 2009; Ninčević Gladan *et al.*, 2010) of the Adriatic Sea ecosystem. Jumping from one stable state to another, climate system can produce a shift and establish a new regime in the marine ecosystem. According to Rodionov and Overland (2005) "in the marine environment, regimes may last for several decades and shifts often appear to be associated with changes in the climate system. Most of the shifts in the marine ecosystem were attributed to changes in the sea temperature, salinity and circulation controlled by local atmospheric variations that are partly under the influence of large-scale teleconnections. So, **the drivers (D) and pressures (P) attributed to climate change seem to be crucial for the Adriatic and Montenegrin water.**

Alterations due to human interventions in the environmental such as constructions on the coast, marine installations and seafloor-anchored structures, tourism and recreational activity must be minimized in order to prevent changes in marine ecosystem.

3 Current state of the hydrographic parameters

Permanent hydrographical changes can occur due to changes in the thermal or salinity regimes, changes in the tidal regime, sediment and freshwater transport, current or wave action and changes in turbidity. The degree of change and the period over which such change occurs varies considerably, depending on the type of modification. Assessment of the degree of change can be related to both the water column and the sea-floor, and consequently to their biological communities. Therefore, the knowledge of the current state of physical and hydrographic conditions is one of the important prerequisites for achieving and/or maintaining a good environmental status. In the era of climate change, the established current state should be observed through its variability, which is especially observed in the Adriatic Sea. The known oscillatory states of the Adriatic (Bimodal Oscillating System / BIOS), despite the fact they represent a statistically significant difference between the mean values of basic physical parameters, are the result of natural processes. In this light, current state of the hydrographic parameters of the marine environment of Montenegro and also of the Adriatic as whole, are presented.

The Adriatic Sea is a small, semi-enclosed sea of the Mediterranean connected to the Eastern Mediterranean via the Otranto Strait. According to its topography, it is divided into the northern, central and southern Adriatic. The northernmost part is very shallow overlaying the continental shelf. This area is under the strong influence of the north Italian rivers, especially the Po River. The central Adriatic is deeper, reaching 280 m in the Jabuka Pit. It is separated from the southern Adriatic by the Palagruža Sill (180 m depth). The southern Adriatic is much deeper, with the deepest part in the south Adriatic Pit, reaching 1,233 m.

The earliest oceanographic research of the Adriatic Sea started already in the past century. However, systematic oceanographic measurements began in the 1950's (Zore-Armanda, 1991). The transect Split-Gargano in the central Adriatic is a region with a strong temporal variability of thermohaline structure caused by seasonally dependent circulation in the surface and intermediary layer. This area is exposed to the influences both from the northern and southern Adriatic. The dynamics on the investigated transect is controlled also by the topographic effect on the Palagruža Sill. A comprehensive review paper on the dynamics of the Adriatic Sea is given in the work by Orlić *et al.* (1992). Generally, the current flows from the Adriatic into the Mediterranean in the surface and bottom layer, while the Mediterranean water enters the Adriatic in the intermediate layer (Figure 2). Surface circulation in the Adriatic is cyclonic and mainly follows the isobaths. The topographic barrier of the Palagruža Sill causes disturbances in the flow pattern and is also reflected in the thermohaline structure In winter, in the northern Adriatic, very cold dense water is formed, which sinks to the deep layers of the Jabuka Pit, and from time to time is advected across the Palagruža Sill. The transect area is also under the influence of advection of saltier water from the southern Adriatic which reflects the Mediterranean influence. Advection of the Mediterranean waters, called "ingression" (Buljan, 1957), carries Mediterranean saltier water into the Adriatic (Buljan, 1953). Buljan and Zore-Armanda (1976) have observed temperature and salinity increase in "ingressional" years. The region of the Split-Gargano transect in the middle Adriatic, which is under a number of different influences, is suitable for the analysis of thermohaline fluctuations in the Adriatic. Due to its intensive seasonal and long-term dynamics, and large spatial and temporal differences in a variety of different parameters, the Adriatic has become a test basin for modelling different phenomena like circulation, deep water formation, remote sensing, etc. The most distinguished characteristics of the Adriatic are strong annual and year-to-year fluctuations of its basic oceanographic properties, giving the sea clearly a continental aspect. The extremes of the surface temperature embrace a large range, from 6 °C to 29 °C. The salinity ranges are equally important, though minima are difficult to define due to the influences of rivers in the estuary regions. Currents have generally low speed and variable directions. The fluctuations of different parameters depend, mostly on certain climatic factors over the Mediterranean and therefore on the level of the water exchange between the Adriatic and the eastern Mediterranean. Strong year-to-year fluctuations of basic oceanographic properties influence the level of secondary production as well as the fish catch.

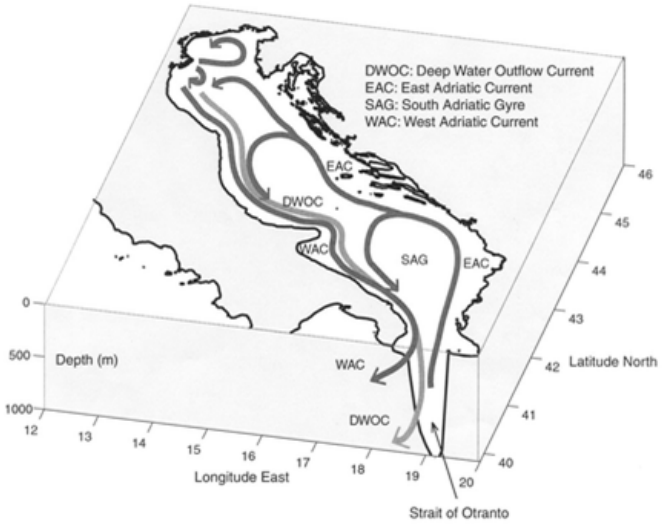

Figure 2. Scheme of general circulation of the Adriatic (according to Zore-Armanda 1963; Vilibić and Supić, 2005)

In order to describe the current state of the oceanographic conditions in the southern Adriatic and in the waters of Montenegro, parameters with an adequate set of data were selected: sea temperature, salinity and transparency.

Sea temperature and salinity

The thermohaline properties of the Adriatic Sea are determined mainly by air-sea interaction, water exchange through the Otranto Strait, river discharge, mixing, currents, and topography of the basin. Vertical structure of the open water column has three characteristic layers. In the upper layer processes are balanced between incoming heat, heat losses through short-wave and long-wave radiation, evaporation and turbulent convention. Temperature of the surface layer lags one month behind the heat flux. The annual temperature range at a surface is 18 °C in the South and 25 °C in the North Adriatic (Zore-Armanda *et al.* 1999).

In the Central Adriatic, temperature in the deeper layers lag four months behind heat flux having two maxima: in May and in the November (Grbec and Morović, 1997). Maximal values in May are the consequence of the fast transport of heat in deep layer as the thermocline layer is not yet formed to prevent vertical mixing process. In the summer when the thermocline is formed, deep layer does not receive heat, and lower temperature was present. The temperature drop, below the thermocline is fully developed, is attribute to the upwelling on the topographic barrier in the Middle Adriatic.

As a hole, the Adriatic is temperate warm sea. Temperature of even the deepest layer are almost above 10 °C. The South Adriatic is 8-10 °C warmer than its central and norther parts during winter. In other seasons the horizontal temperature distributions is more uniform.

Adriatic belongs to those parts of the Mediterranean that have a positive difference between precipitation (including run-off) and evaporation. The influx of saline Mediterranean water through the Strait of Otranto increases, while precipitation and the run-off (the later mostly in the north) decrease salinity of the Adriatic water. Salinity of the Adriatic is relatively high. The largest part of its volume, i.e. its open southern part, has salinity values between 38.4-38.9 (Figure 3).

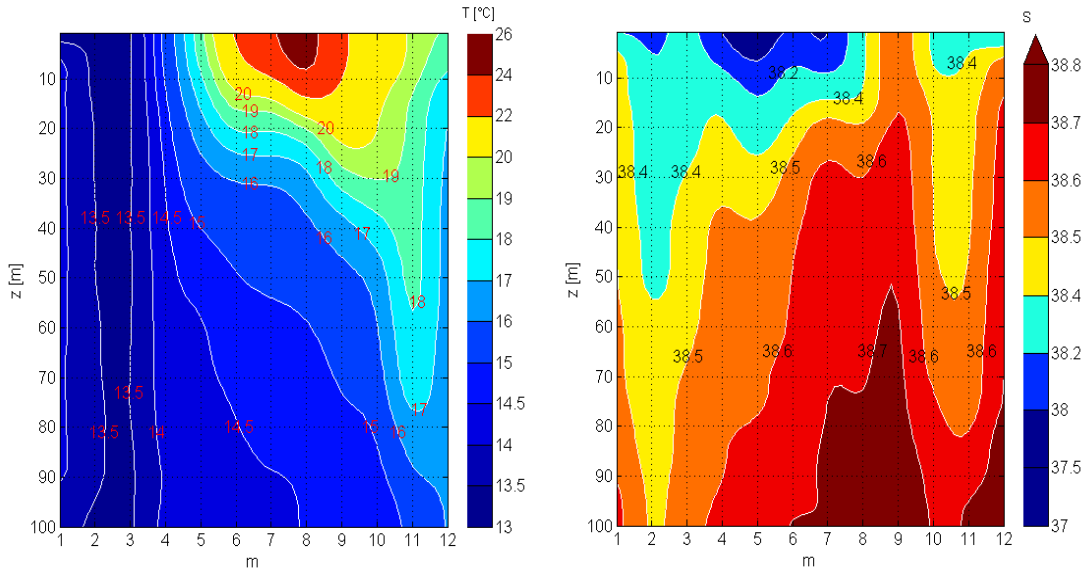

Figure 3. Mean annual cycles of sea temperature and salinity for the Central Adriatic Sea, 1998-2010 (Grbec *et al.*, 2010)

Salinity is lower, and more variable in the shallow northern part, close to the mouth of Po river, and in coastal zone. In the open South Adriatic waters, on the three clearly distinguished layers, the intermediate layer has the highest salinity.

The unavoidable fact is that the Adriatic Sea is very sensitive to climate change. As mentioned earlier (see Chapter 2), the Adriatic-Ionian Sea communication plays an important role. In the recent time, it is important to know the processes on the surface, especially the surface temperature changes due to climate forcing. Therefore, it is very important to know the mean states of thermal processes in the boundary layer of the atmosphere -sea as well as their long-term variability. The last few decades have seen an increase in surface temperatures in the Adriatic and the Mediterranean. In the summer, i.e. in the warm part of the year, this increase is more expressed. Measurements of the surface temperature of the sea in the area of the central Adriatic, from the coastal area to the open sea, show that since 1979 the surface temperature of the sea has been rising, more precisely oscillating around higher values. In the period from 1979 to 2015, the increase was 1.03 °C, which is in line with the trend of warming of the sea surface in other Mediterranean areas (Grbec *et al.*, 2018). The positive trend has been more noticeable in recent decades. In the period 2008-2015 the temperature of the surface layer of the sea increased by 1.25 °C. This trend of strong warming continues, which does not mean that episodes of cooling of the surface layer of the sea do not occur. Warming episodes become more frequent and stronger and longer lasting.

In the **Montenegrin** coast, long-term changes have also recently become more variable and with a more notable trend. Mostly their trend follows the trend observed along the eastern Adriatic coast.

In the period 1984-2017 in the Boka Kotorska Bay, a positive trend of sea surface temperature (SST) of 0.48 °C per decade was recorded (Violić *et al.*, 2019). By analyzing the average annual values of sea surface temperature along the coast of Montenegro, long-term variability was determined, which coincides with the general trends in the Adriatic (Figure 4). For stations in Ulcinj and Bar, with a relatively long series of measurements, the increase is 1.28 °C/40 years (Ulcinj) and 1.38 °C/40 years (Bar), respectively.

Comparing obtained trends it is noticeable that the corresponding linear trends are declining towards the south. This is a consequence not only of the influence of the marine environment but also of the action of the predominant mesoscale atmospheric processes and processes on a scale larger than the Adriatic (Grbec *et al.*, 2009). Due to the geographical position of the Adriatic, much of its atmospheric variability is associated with hemispheric atmospheric processes such as the North Atlantic Oscillation (NAO), North Africa – West Asia (NAWA), Eastern Atlantic (EA) which affect the Adriatic with varying intensity and duration (Matić *et al.* 2011).

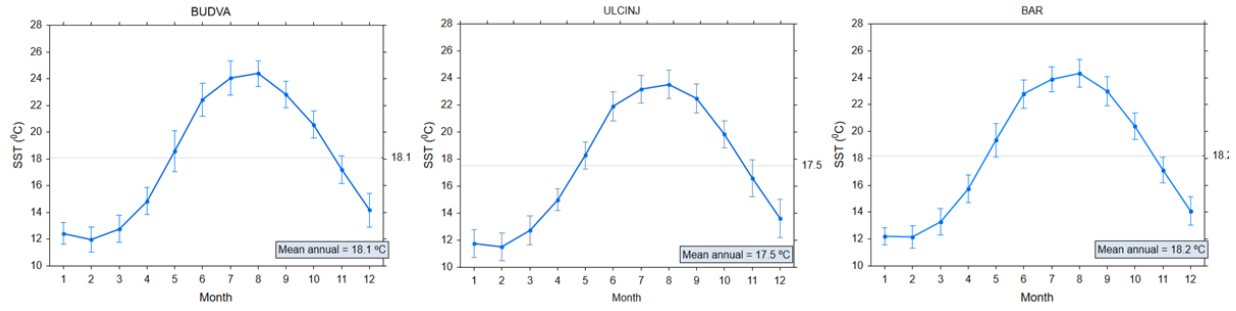

Figure 4. Mean annual SST cycles for selected stations along the Montenegrin coast (Grbec, 2019)

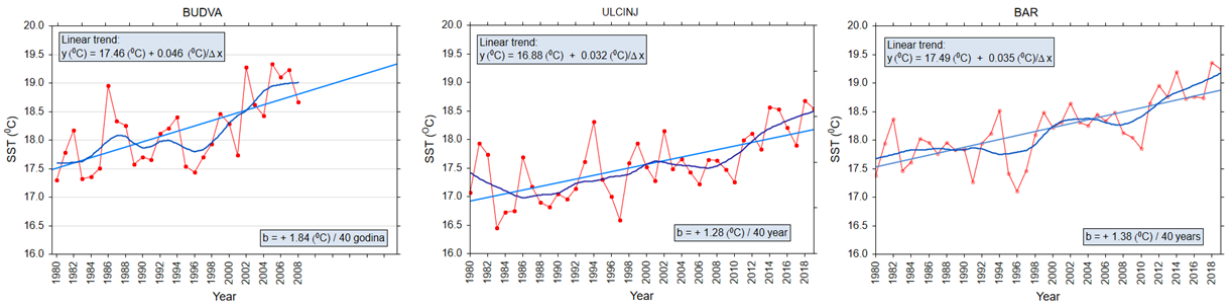

Figure 5. Long-term SST trend for selected stations along the Montenegrin coast (Grbec, 2019)

Recent general climatology for the entire Adriatic made by analysing a large number of data (1911-2009) of temperature, salinity and dissolved oxygen shows that the deepest part of the southern Adriatic becomes much saltier and warmer (Lipizer *et al.*, 2014). Unique termohaline conditions in the Adriatic observed in 2017 with very high salinity values in the entire water column with an 'inverse' salinity profile in August and a maximum in the surface layer, recorded for the first time in the central Adriatic. Surface salinity of 39.02 recorded in August was 2.5 standard deviations above the long-term average (1961–2016). The observed salinity distributions are the result of both local and remote drivers, whereby the North Ionian cyclonic gyre controlled by the Adriatic-Ionian Bimodal Oscillating System has been responsible for the overall above-average salinities since 2011 (Beg Paklar *et al.* 2020). In the future, as the Adriatic is sensitive to climate changes, more such situations can be expected.

Montenegro – recent findings

In the Montenegrin waters there is no systematic long-term thermohaline measurement. In October 2019 a three-day measurement of temperature, salinity and transparency (and also chemical and biological parameters) was performed during the field survey (cruise) in order to gain insight into the hydrographic characteristic of the area (IA, 2019). The measurement was conducted at a total of 17 stations distributed along 5 transects from the Boka Kotorska Bay to the mouth of the river Bojana (Figure 6). The depth at the measuring stations varied from the shallowest station P11 with a depth of 15 m in the mouth of the river Bojana to the deepest station P3 with a depth of 217 m.

Figure 6. Stations map in the study area

Termohaline properties investigated during the cruise show a significantly stratified water column for that time of year (October), as a result of prolonged summer conditions and the absence of the usual mixing of the water column where the temperature and haline vertical gradients weaken (Figure 7). Moving from north to south along the coast of Montenegro, and from the coast to the open sea, the expected autumn characteristics were not observed due to the very specific warm and dry September and October. In 2019 autumn was unusual: warming from the atmosphere continued thanks to prolonged summer conditions, calm weather without strong winds prevailed. Such conditions resulted in the maintenance of the thermocline and the stability of the water column. Thermocline can be observed that starts at a depth of approximately 30m. At stations closer to the coast, the surface layer has uniform values up to a depth of 20-30 m, with a mean temperature of 22.6 ^{0}C and a salinity of 38.84, where the horizontal gradient of temperature and salinity in the surface layer is most notable. In the deeper layers the gradients are of a smaller amount. On the transect bounded by stations 7 and 10 the temperature and salinity are vertically uniform from the surface up to 30 and 40 meters, respectively, depending on the depth of the station. The depth of the surface layer is greater towards the open sea. Below the halocline at stations 8, 9 and 10, water core of reduced salinity is observed as a consequence of the specific conditions of the local thermohaline circulation.

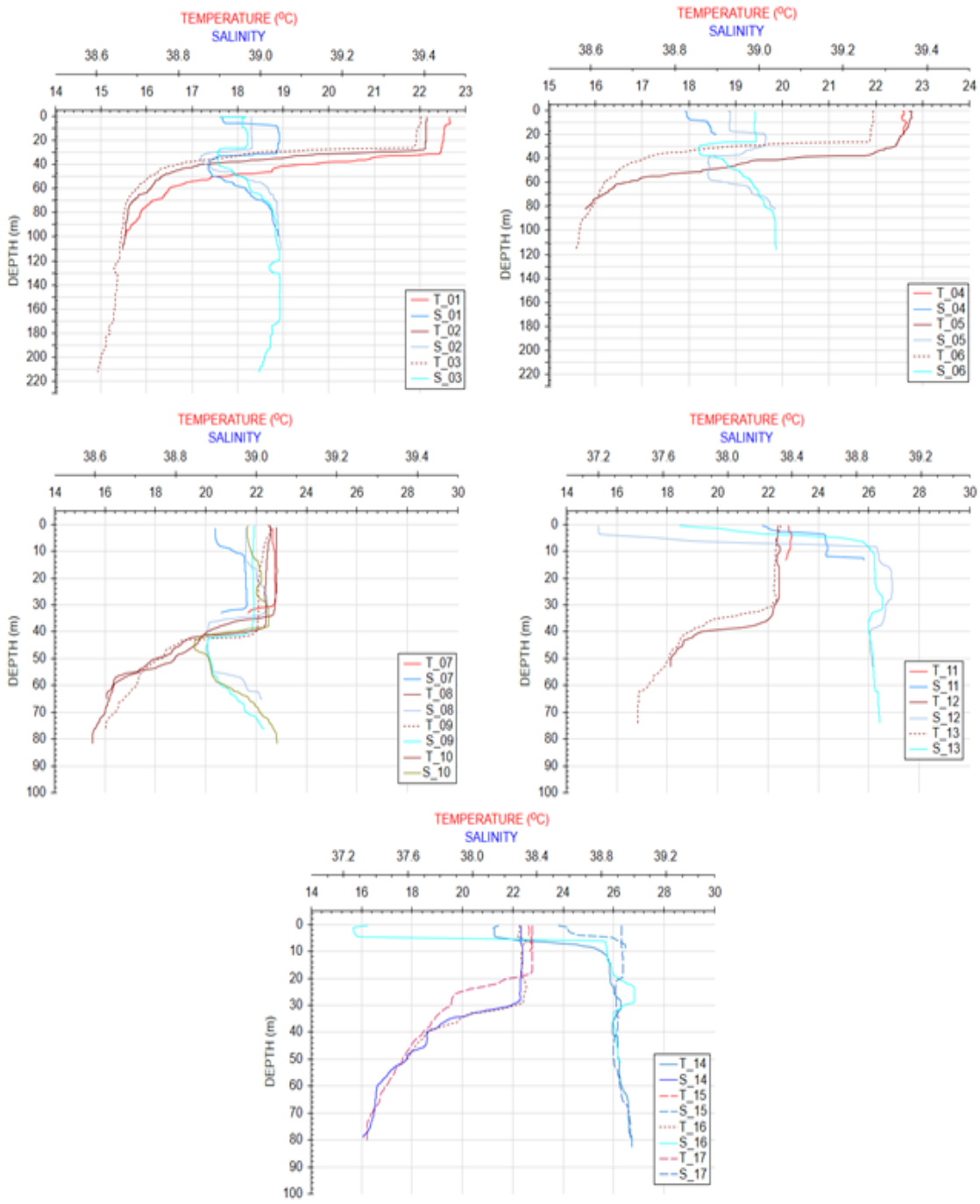

Figure 7. Vertical temperature and salinity profiles at stations 01-17 (Grbec, 2019)

The core of this water is also of lower density as a result of reduced temperature values in this layer. The front line between the surface and deeper layer is (20-22) ^{0}C and salinity value is 38.9. Relatively high salinity values, even in the surface layer, originate in the previously established state of the Adriatic when occasionally due to local conditions and/or supported by non-Adriatic processes, salinity increases (Beg Paklar *et al.*, 2020). Changes in salinity along the eastern Adriatic coast have recently shown a positive trend in the entire water column (http://baltazar.izor.hr/azo/azoindex).

Transparency

Long term changes in transparency analysed from previous measurements in the southern Adriatic (Morović *et al.*, 2010) indicate that transparency is highest during the summer and lowest during the winter months. Transparency has high spatial variability depending on the influence of natural and/or anthropogenic factors. By moving away from the coast, transparency in the southern Adriatic, otherwise the most transparent area of the Adriatic, is increasing. The area of the southern Adriatic encompasses a wide range of optical types, but in the open sea it is mostly optical type I water characteristic of oligotrophic areas. In areas where the impact of rivers is significant, the waters are more turbid, and if the circulation is weaker, these waters, due to their strong anthropogenic influence, have a small depth of light penetration. They belong to coastal turbid waters of type IV-VII (Morović *et al.*, 2008).

Along the coast, the depth of light penetration into the sea depends on local specific conditions (location of the site, freshwater input from the land, proximity to anthropogenic and/or natural sources of fresh water, circulation,). Relying on many years of research, it is possible to obtain a general picture of the annual course of transparency along the coastal area of Montenegro. Due to the anthropogenic impact at some measuring stations, the transparency along the coast does not have a notable annual course. Mean monthly values range from 6m to 15.5m with considerable variability. The lowest transparency in the area of the Bay of Kotor was determined at the locations OS-1 in the Bay of Kotor and IG-1 in the Bay of Herceg Novi, where the median transparency for the entire research period was about 8 m (IA, 2019). However, from the range of values for transparency in almost the entire investigated area of the Bay of Kotor it is evident that transparency occasionally falls below 4 m (OS-3) which are extremely low values and it is quite certain that this is not solely due to the increase in phytoplankton biomass, but freshwater inflows and land leaching are also likely to contribute to such low values.

3.1.1 Montenegro – recent findings

During the cruise performed in autumn 2019 along the Montenegrin coast at 17 stations across 5 transects (see Figure 8) show a minimum value in the area of station 15, while the highest values were recorded at stations 1 and 10. The mean transparency of this area is 17.2 m with a standard deviation of 4.51 m and a range of (7-25) m. The box diagram additionally shows the variability of this parameter, and one value (7m) can be considered extreme. Of course, for a complete picture of the penetration of light into the sea in this area, significantly more measurements are needed.

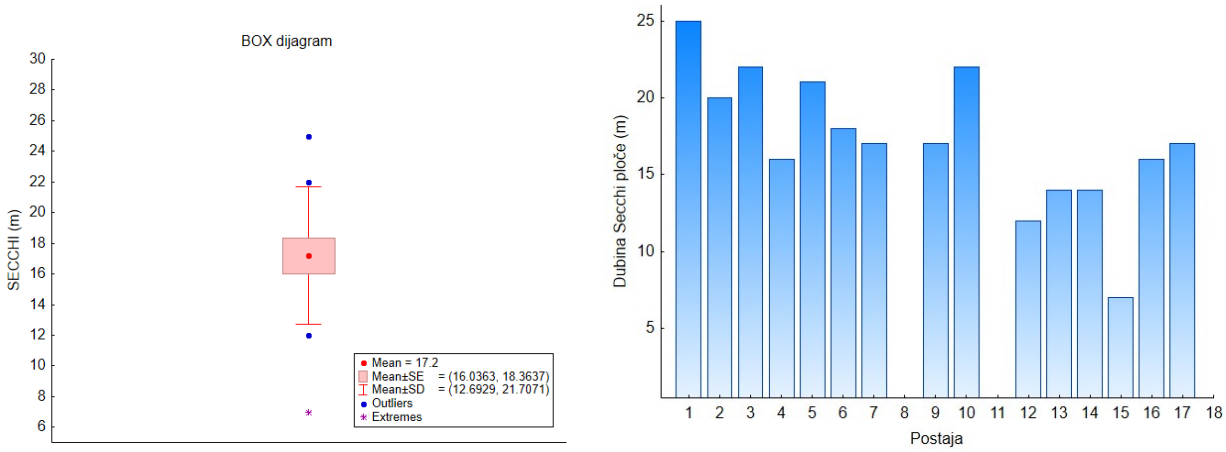

Figure 8. Transparency measured during the cruise in October 2019

Boka Kotorska Bay

Boka Kotorska Bay is an eutrophic shallow closed basin in the southern Adriatic Sea, which differs significantly from the open sea due to its climate, geomorphological and physicochemical characteristics (Campanelli_*et_al.*, 2009). This fact explains the large annual, seasonal, monthly, and daily changes in the physical and chemical parameters of seawater, which is significantly influenced by specific atmospheric processes. Oceanographic processes in the basin are very complex, which requires the establishment of systematic measurements of high spatial-temporal resolution.

The coast of about 105.5 km long, with the total water surface area of 87.33 km and total volume of 2.4 x 109 m^3 surrounds the Bay of Kotor. Based on its geographical and hydrographical characteristics, the Bay could be divided into 3 parts: Kotor and Risan Bays (the inner part), Tivat Bay (the central part) and Herceg Novi Bay (the outer part) where freshwater input can strongly modify temperature, salinity and sea current.

The average depth of Boka Kotorska Bay is 27.6 m, and its maximum profundity is 64 m (Kotor Bay). Boka Kotorska Bay is surrounded by steep mountains, often causing substantial decrease in air temperature, at times even with ice being formed on the sea surface in wintertime. This is an area of intensive precipitation, resulting in large amounts of fresh water entering the Bay, particularly its inner parts, between November and April (Pilot project on testing EcAp; 2015).

Boka Kotorska bay is a unique coastal ecosystem in the south-eastern Adriatic Sea that has been recently under the increasing influence of human activities. Physical, chemical and biological changes in Boka Kotorska Bay seems to be mainly related to sea water interactions, which significantly depend on natural factors such as the rainfall pattern (Krivokapić *et al.*, 2011). The Boka Kotorska area is the one of the rainiest parts in Europe. Significant amount of fresh water runoff and low average tidal amplitude (28.5 cm) throughout the autumn-spring period generates a pronounced halocline between 2 and 5 m depth. So, minimum salinity values occur in the surface layer, during winter and early spring precipitation events.

The Bay of Kotor in the spring is characterized by a lower surface layer of salinity, and differs significantly from the haline conditions on the open seas. This fact directly affects phytoplankton communities that are different in the bay from those in the open sea. Although similar amounts of phytoflagellates, diatoms and dinoflagellates were observed on the open seas, larger amounts of other species were also observed, probably due to different physical characteristics, primarily due to higher salinity. It is therefore justified to conclude that different salt content in the Bay and on the high seas is responsible for the different composition of the phytoplankton eco-community (Campanelli *et al.*, 2009). In the area furthest from the open sea, the physical and hydrographic conditions are significantly different from the rest of the basin due to the specific conditions of mutual exchange of water within the basin and the open sea basin.

The investigation in terms of dynamics of buoyancy and density flows inside the bay, main circulation patterns and effects of the combined action of forcings (wind, tides, precipitation and river freshwater) in the bay, was conducted under the ADRICOSM-STAR project. Due to the lack of systematic measurements, the dynamic processes within the Bay of Kotor are insufficiently known and considerable efforts should be made to improve current knowledge. This primarily means the establishment of appropriate oceanographic measurements (temperature and salinity, currents and waves). The Boka Kotorska bay can be defined mainly estuarine but evidences from the sea current and thermohaline structures in the straits that connect Kotor-Morinj Bay with Tivat Bay and in the channel linked to Herceg Novi Bay suggest that more complex small scale dynamics can be seen (Bellafiore *et al.*, 2011).

According to hydrodynamic processes in Boka Kotorska Bay classified Kotor Bay differently from the outermost area, Tivat and Herceg Novi Bay. This generally indicates a slow rate of water exchange between Kotor Bay and the open sea reaching a residence time of around 70 days during the period of minimum freshwater discharge. This slow circulation of seawater is characterised by surface outflow and bottom inflow (Bellafiore *et al.* 2011). The other interesting characteristic is the anticyclone circulation in the central bay – Tivat Bay – which has residence time values of 25 days at the surface and 15 days in the deep layers (Bellafiore *et al.*, 2011). Some areas near to the open sea maintain residence time values of 5 days at the surface and lower values in the deep layers (Bellafiore *et al.*, 2011). From the along-channel section in the Verige Strait the

presence of a sill controls the bottom water exchange between Kotor Bay and Tivat Bay. Regular seasonal temperature fluctuations without marked differences among stations and embayments, ranging at the surface from 12.3 ± 1.5 in winter to 24.8 ± 2.6 in summer was found for the one-year period survey from January 2010 to January 2011 (Redžić *et al.*, 2015). For this particular period, thermal stratification of the water column began in June and lasted until September when the isothermal period began. In this shallow area beginning and lasting of stratification strongly depends on prevailing atmospheric-land conditions and by them controlled processes in the air-sea boundary layer. A strong vertical salinity gradient with a flow of fresh water at the surface is seen in the inner part of the bay, where the salinity varied from 0.6 to 36.4 at the surface. Surface salinity depends on the amount of precipitation (vertical processes) and the amount of freshwater (horizontal processes) and is significantly seasonally variable. The lowest values and widest ranges of temperature and salinity in Kotor Bay were recorded mostly due to the influence of the river Škurda and the streams Ljuta and Sopot.

GES assessment approach

Considering the intention of IMAP to prevent significant negative effects on marine ecosystems (habitats and species), the defining of GES for EO7 must be closely linked to GES in ecological objectives EO1, EO2, EO3, EO5, EO8, EO9 and EO10.

Negative effects can produce water column changes and seabed habitats changes. Changes, such as altered erosion patterns, can modify local conditions in a way that negatively impact to habitats and can therefore compromise the achievement GES for Biodiversity and Eutrophication objectives. Consequently, the cumulative impact on the ecosystems from pressures resulting from the alteration of hydrographical conditions should ultimately be assessed in these relevant ecological objectives.

Achieving GES for EO7 primarily refers to the prevention of deterioration of those parameters that directly affect the weakening of the possibility of preserving GES for EO1, EO2, EO3, EO5, EO8, EO9 and EO10. These are primarily temperature and salinity, transparency, and waves and sea currents. Concerning climate change, it is important to mention that if the surface layer becomes warmer, stronger stratification can occur in the future climate.

Human activities undertaken in Montenegrin waters with the potential to permanently change hydrographic conditions mainly near the coast include construction or expansion of ports, marinas, and construction of wastewater treatment plants and sewers. At the present, the situation in the coastal area is quite burdened by unplanned construction, marinas and sewers outflow. For the example, in the Boka Kotorska Bay some parts of its coastal areas is of reduced circulations and hydro-morphological quality which has led to deterioration in ecological quality. Cumulative impacts of these modified areas largely represent locations where substantial coastal infrastructure activity has taken place, resulting in major modifications of the coastline and/or adjacent marine waters. In the open water, there are currently no planned activities that could lead to permanent hydrographical alterations.

Due to the significant impact of urbanization through unplanned construction, increasing the capacity of sewage and increasing the number of berths in marinas (construction or extension), special care should be taken to achieve or maintain good environmental status. The current situation (Figures 9 and 10) is already worrying. The main discharges must be positioned in a such way that the stratification (summer thermocline position) prevents the upwelling of pollution to the surface. An environmental impact study involving measurements thermohaline conditions, currents and hydrodynamic modelling should be performed for all new planned waste water discharges. After construction, control monitoring should be carried out for each wastewater discharge. Out of 6 municipal centers in the coastal area, only four regional centers have wastewater treatment plants: for the municipality of Herceg Novi in Meljine in the Bay of Kotor, for Kotor and Tivat on a joint device in Đuraševići, with the discharge of treated water in the bay of Trašte into the open sea, and for Budva with the surrounding settlements PPOV "Vještica" in the hinterland of Bečići and Rafailovića, which discharges purified water into the open sea through the existing waste water treatment plant on Zavala into Budva Bay. Ulcinj and Bar do not yet have treatment plants, so wastewater is discharged into the open sea only with primary treatment, with long sewage outlets. In addition to the main sewage outlets, there are a large number of local ones, which discharge wastewater at shallow depths.

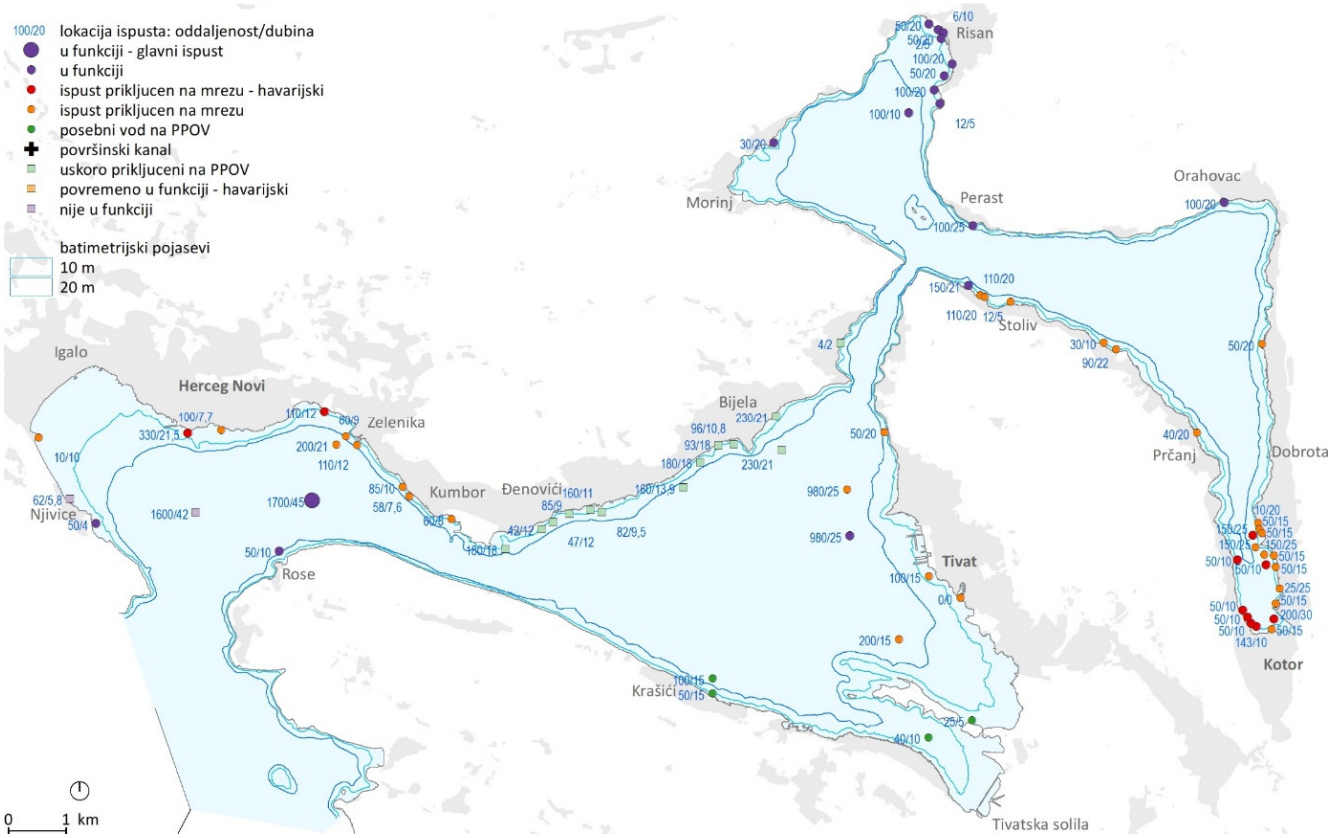

Figure 9. Map of discharge locations in Boka Kotorska Bay

Figure 10. Map of discharge locations along the Montenegrin coast

The cumulative effects of wastewater discharges endanger the marine environment, and their proper remediation should be of great importance for the achievement of GES. Considering all existing and future anthropogenic interventions, only good planning, respecting the ecosystem approach, can leading to achieve GES.

Possible gaps and development needs

Pressures, knowledge and data gaps

In the open Montenegrin waters no long-term sea temperature and salinity data (from surface to the bottom) and water transparencies are available. Only surface temperature (SST) and transparency along the coast for few locations are available. Additionally, there are no instrumental measurement of waves and currents. In the purpose to assessing the relevant criteria for ecological objective EO7, hydrographical monitoring should cover basic hydrographical data (e.g. temperature, salinity, water transparency/Secchi depth), which are required to better understanding ocean processes, especially in the era of global climate change. Due to the fact that Montenegro does not have enough experts in the field of physical oceanography, their education is necessary. This would bridge the knowledge gap. In addition, it would be possible to establish an appropriate measurement of the basic oceanographic parameters, in accordance with the physical processes relevant to the research area. Analysing the available hydrographical data, and knowledge of possible or/and already established various interventions in the coastal and open sea area, that are closely related to achieving GES within EO7, gaps can be divided into three groups:

- *Pressures* – refers to insufficient knowledge of environmental interventions that are being done or planned to be done;
- *Knowledge* – primarily refers to a better knowledge of hydrographic processes that are specific for the waters of Montenegro. It also refers to the education of experts in physical oceanography;
- *Data* – given that data on basic oceanographic parameters are scarce, both spatially and temporally, the need to establish relevant monitoring is necessary.

The meta-analysis of existing literatures on pressure/knowledge/data gaps summarized for the South Mediterranean seas (Crise *et al.*, 2015) gives an insight into the gaps in the waters of Montenegro. The main difficulties are manifested in the inability to separate the impacts resulting from direct anthropogenic influence and those resulting from climate change.

Table 1. Pressures, impacts, and knowledge gaps for open and coastal Montenegrin waters

OPEN SEA		
Pressure	**Impacts**	**Knowledge gaps/research priorities**
Changes in thermohaline properties due to atmospheric influences, and pH of seawater. Changes of thermohaline properties controlled by BIOS influences and climate changes.	Positive trends of temperature in the upper layer of the Mediterranean Sea induce stronger stratification. Potential modification of the primary production of the basins. Changes in the atmosphere (wind system, heat, humidity) on various spatial scales cause changes in circulation and water exchange with Mediterranean. .	The combined effects of thermohaline properties and pH trends on the conditions of MN waters are still unclear. Large uncertainty on the long-term effect of acidification on the whole food web. BIOS oscillations are responsible for different biological answer in the MN waters depending on AC or C oscillations in the Ionian Sea (Gačić, *et al.* 2002; Batistić *et al.*, 2019) – still under investigations.
COASTAL SEA		
Pressure	**Impacts**	**Knowledge gaps/research priorities**
Changes in fresh water and sediment riverine fluxes. Changes in circulations due to infrastructural interventions.	The Bojana river estuary is threatened by increased erosion rates due to reduced sediment fluxes. BK Bay is a dynamically complex area burdened by numerous sewers, marinas and maritime traffic as a result of urbanization.	Impact and resilience of the marine ecosystem to changes in river regimes due to anthropogenic and natural changes. Changes in seawater circulation regime and consequences of dispersion from sewage discharges.

Development needs

Measures and development procedures that can be applied in order to achieve or preserve GES are primarily well-defined measurements of those hydrographic parameters that to a greater extent determine the dynamics of Montenegrin waters. Based on these well-defined follow-ups, it is possible to reduce the gaps identified in the baseline study. The limit values of EO7 are defined in relation to the adverse effects associated with E01 and EO2, EO3, EO5, EO8, EO9 and EO10. During any intervention, for which we can expect permanent changes in hydrographic properties (more than 10 years), the spreading (in km^2) of the negative impact can be estimated using adequate hydrodynamic models for particular case.

Dynamics of the sea are very complex, the status of the ocean at a given moment results from mechanisms ranging from decadal (such as the North Atlantic Oscillation) to shorter time scales (such as wind or river forcing). Therefore, large data sets are required to observe and detect changes in the environmental status. At present, there are no long-term oceanographic data (temperature, salinity, currents, wind-waves statistics) for the open Montenegrin waters. So, implementation of monitoring system can serve as good way to achieve knowledge gaps. In order to achieve GES, it is necessary to create GIS bases of all relevant loads (infrastructure, maritime transport, extension and construction of ports and marinas, geo-morphological and climatic characteristics of the area). Only after such knowledge of current and planned interventions is it possible to define relevant guidelines in achieving GES. Since EO7 has a significant impact on a number of EOs, GES is achieved depending on the prevention of adverse effects on a particular component of the ecosystem.

Hydrography and other ecological objectives

Hydrographical conditions are characterized by the physical characteristics of seawater such as temperature, salinity, depth, currents, waves, turbulence. These characteristics play a crucial role in the dynamics of marine ecosystems and can be altered by human activities, especially in coastal areas. Alterations to hydrographical conditions can occur due to the construction of physical structures (such as ports, marinas) or through sea traffic. Hydrographical condition and its permanent changes (EO7) are in connections with other ecological objectives throughout relevant common indicators. One way of looking at the relationship between EO7 and other EOs is to know the causal link between changes in hydrographic conditions and marine ecosystems. In the Adriatic Sea, more scientific papers and research documented these relationships (see for example Grbec *et al.*,2009; Ninčević-Gladan, 2010; Šolić *et al.*, 2018;). EO7 is, for example, strongly linked with EO5. In addition, hydrographic data are relevant for assessing EO1, EO2, EO3, EO9 and EO10 as hydrographical conditions play an important role in advection and dispersion phenomena. Detailed information on interconnections of EO7 with other EOs in Montenegro is described in Table 6.

Table 2. Hydrography and other ecological objectives

	EO1	EO2	EO3	EO5
EO7	Water movement and temperature/salinity regimes directly influence sediment type/ changes. Water movement and temperature/salinity regimes play a significant role in determining species composition of habitats/communities.	Changes in the hydrographic regimes affect occurrence and distribution of non-indigenous species.	Changes in the hydrographic regimes could affect trends in spawning stock biomass.	Information on key hydrographic parameters are relevant for the interpretation of eutrophication results. Typology scheme for the Mediterranean coastal waters is based on the basic hydrographic data (temperature, salinity and density).

	EO8	EO9	EO10
EO7	Physical changes of the coastline, due to man-made structures, could have direct impact on the changes of thy hydrographic conditions.	Contaminants can be redistributed or transported throughout the environment by hydrographic processes. Contaminants remain in the water and especially in the sediment, from which they can be re-suspended depending on the currents, waves and turbulence	Hydrographic conditions, in particular marine currents have significant impacts on marine litter movements.

Studies concerning on long term series on river discharges, oceanographic features, plankton, fish and benthic compartments, collected since the 1970s revealed significant changes of mechanisms and trophic structures in the Northern Adriatic ecosystems (Giani *et al.* 2015). During the 1970s, a gradual increase in eutrophication pressure was recorded, which continued until the mid-1980s. This was followed by a reversal of the trend until 2000. An ecosystem response has been reported: a significant decrease in phytoplankton numbers has been recorded since the mid-1980s, simultaneously with changes in the composition of community species, with an evident shift towards smaller cells or organism sizes. Moreover, changes in the zooplankton community have also been observed. The decline in demersal fish, major predators and small pelagic fish has also been attributed to overfishing and declining eutrophication. Macrozoobenthos communities have been slowly recovering in the last two decades after the events of anoxia in the 1970s and 1980s. In recent decades, an increasing number of non-indigenous species have been recorded, moreover, the increasing seawater temperature has facilitated the spread of thermophilic species. All these changes are in part a response to processes in the atmosphere and also to a reduction in anthropogenic impact. In the area of the central Adriatic, significant changes in the marine ecosystem were also recorded (Grbec *et al.* 2015).

The paper documents synchronous changes in the atmosphere and sea and consequent changes in the marine ecosystem, from the phytoplankton community to the pelagic fish population during significantly different climatic regimes (1963-1986; 1987-1998) that have occurred in the Adriatic in the last 50 years. Only long-term series can allow such research, especially in seas where trends and climate shifts are crucial for ecosystem changes.

Conditions over northern hemisphere (NH) described by middle latitude teleconnections (MLT) patterns co-vary with the winter Adriatic climate and thermohaline circulation in the stratified period, pointing to climatic turning points around 1987 and 1998 that separate relatively stable climate regimes: 1) before 1987 with more frequent Bora wind in the north and Sirocco in the south Adriatic, and 2) after 1987, characterized by the lower frequency of Bora wind present along the whole Adriatic. In the marine environment, the period 1987-1998 was characterized by lower deep layer temperatures, drop of salinity, oxygen and nutrients, confirming lower ventilation of the Adriatic Sea, caused by EMT (Eastern Mediterranean Transient). Atmospheric winter conditions, together with thermohaline circulation are recognized as the forcing parameters for the biological ecosystem, which responded more or less synchronously in all its components (Fig. 10). Recorded shift of phytoplankton biomass can be attributed to low intrusion of the Levantine water during EMT. Conditions of old, unstirred water seem to favour the cyanobacteria Synechococcus spp. growth, which usually appears in the intermediate layer during stratified conditions. A steady increase in summer zooplankton biomass after 1987 could be the reflection of the established underlying physical ecosystem changes. In the time series, sardine and anchovy usually had opposing trends. The fact that small pelagic fish constitute an important part of big pelagic fish diet (such as tunas, including also small tuna species) and demersal fish (such as hake that usually follow anchovy as its preferred prey), could possibly contribute to the lack of their alternations that occurred after 1994. We suppose that the EMT, established in 1987, was responsible for the alternation collapse. Our future research will focus on investigating how climate drives trophic food web under distinctly different environmental conditions. Climate change and oscillations are the main drivers of synchronous changes in the marine ecosystem. The anthropogenic impact in such climate-sensitive areas needs to be further investigated.

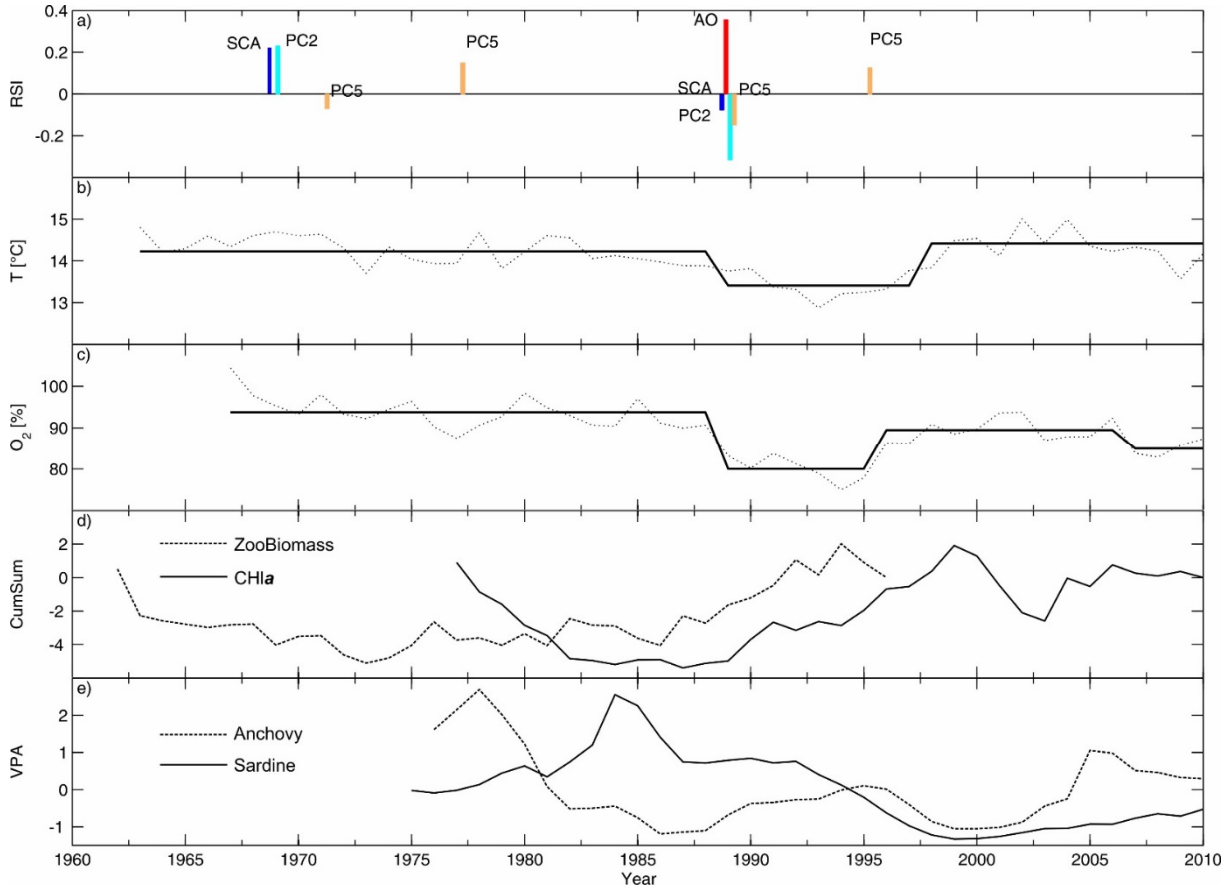

Figure 11. Atmosphere-ocean covariability – Regime shift index (RSI) values for Middle Latitude Teleconnections (MLT) indices and for Adriatic climate proxies a), temporal variations of sea temperature b) and oxygen c) with solid line representing mean states; CumSum of Chl *a* and zooplankton biomass d) and alternations of normalized anchovy and sardine ratio (from Grbec *et al.* 2015).

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Implementation of the ecosystem approach in the Adriatic through marine spatial planning

The GEF-funded project “Implementation of the Ecosystem Approach in the Adriatic Sea through Marine Spatial Planning” (GEF Adriatic) is carried out across the Adriatic-Ionian region with focus on two countries: Albania and Montenegro.

The main objective of the project is to restore the ecological balance of the Adriatic Sea through the use of the ecosystem approach and marine spatial planning. Also, the project aims at accelerating the enforcement of the Integrated Coastal Zone Management Protocol and facilitating the implementation of the Integrated Monitoring and Assessment Program. Eventually, it will contribute to the achievement of the good environmental status of the entire Adriatic. The project is jointly lead by UNEP/MAP, PAP/RAC and SPA/RAC. In Montenegro, the project is being implemented with the coordination of the Ministry of Ecology, Spatial Planning and Urbanism. The project duration is from 2018 to 2021.

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