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The DAPSI(W)R(M) problem-structuring framework applied to the Venice Lagoon

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ABSTRACT

Using the DAPSI(W)R(M) environmental framework, the multiple links between anthropogenic activities and environmental degradation within the Venice Lagoon have been qualitatively defined. This model aims to organise the available information according to a rigorous cause-and-effect scheme, so as to more easily reach a multitude of stakeholders, environmental management bodies, the scientific community and the public. DAPSI(W)R(M) is therefore characterized by a strong multidisciplinary, analysing the different aspects of environmental management (research, monitoring, policies ...) to evaluate and direct its work. It consists of 5 elements. Starting from the Drivers (D), in form of human needs, are inserted, discussed and compared various human Activities (A) that take place within the Lagoon borders, with a specific focus on sectors with a high "environmental impact". They consequently produce a multitude of Pressures (P) on the natural environment, which, synergically or not, produce State changes (S), negatively modifying ecosystem services, and therefore creating Impacts (on human Welfare) (I(W)). To conclude the process, a series of Responses (as Measures) (R(M)) are produced, which aim to improve the territory by acting on one or more other components, underlining the many feedback loops existing in the framework. Due to the high diversity and therefore complexity of the territory, the work primarily aims to introduce the DAPSI(W)R(M) framework as an approach methodology for managing the coastal lagoon environment, rather than exhaustively defining each single element. Although it is not a detailed approach, the most exhaustive description and analysis has been carried out, collecting as much informative material as possible. This working methodology could become fundamental in the future, to define the guidelines for the management of complex environmental systems, taking into account all the social, economic and environmental aspects in a single reference framework.

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1. INTRODUCTION

The world is changing, and with it, its natural environment. Coastal waters, supporting most of human population, are currently facing high degradation, due to the extremely complex relations between inland and open seas: acting as ecotones, they receive waters from every human settlement, mediating them offshore.

To correctly manage those delicate territories, many attempts have been done. From academia, private holdings and governments, have been carried out innumerate monitoring and consequent measures to enhance the so-called ecosystem services, and restore the natural environment to its maximum ecological state. Unfortunately, those actions have had a limited effect, because often too specific without consider the entire environmental and socio-economic patterns, therefore not reaching the governance. To cope with an uncertain future (e.g. climate change consequences), it is critical to understand holistically how anthroposphere can affect ecosystem processes and functions, and how ecosystems provides services and benefits to human societies. To do so, have been created many frameworks to solve the puzzle. PSR (Pressures - States – Responses) was the pioneer of them (Rapport & Friend, 1979), while later in the 1990s has been universally adopted DPSIR (Drivers – Pressures – State – Impacts – Responses), popular among the scientific community since the recommendations of OECD (1993), EPA (1994), EEA (1999), and EC (1999) for its application.

Because of many critics to this framework (e.g. Patricio et al., 2016), especially regarding some common misunderstanding, has been introduced a new concept for coastal environments: DAPSI(W)R(M) (pronounced dapsi-worm) (Elliott et al., 2017). In this new framework, it has been unified all the previous knowledge to solve the misunderstandings and finally use a linear cause-effect chain to describe the natural environment, including its socio-economic sphere. It is composed by 6 elements named Drivers, Activities, Pressures, State Change, Impacts (on human Welfare), Responses (as Measures), and each of those creates a cascade event on the others as displayed in fig. 1. The framework has been here applied on Venice Lagoon (fig. 3).

Venice Lagoon is a microtidal transitional water ecosystem, with tides up to 1 m of excursion, characterised by wide extensions of shallow brackish water interrupted by a network of channels and saltmarshes habitats (Ravera, 2000; MAV, 2010). It is a semi-enclosed basin which is inserted as UNESCO world heritage site, but currently threatened by many anthropogenic disturbances (Guerzoni & Tagliapietra, 2006). Through the centuries, but especially in the contemporary era, the city urbanization and industrialization has induced many complex environmental changes (e.g. Bevilacqua, 1998), which have heavily modified the geomorphological and ecological structure. To cope with this metamorphosis, have been adopted some measures to enhance the Lagoon ecosystem,

such as the here described LIFE+ projects and the compensation plan (Consorzio Venezia Nuova, 2016). This study will also describe some of the main processes impacting the Lagoon.

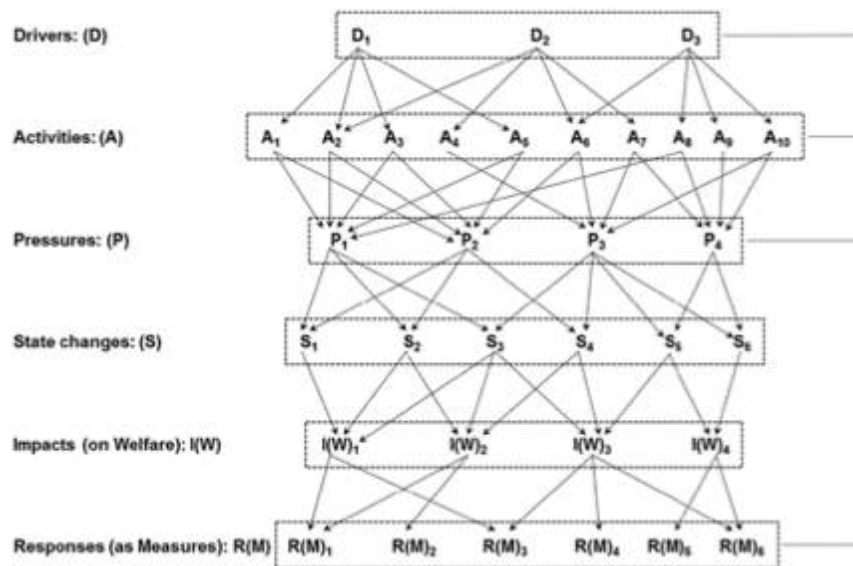


Fig. 1. Illustration of the multiple interactions between the framework elements, including the feedback loops coming from R(M). Modified from Elliott et al. (2017).

Similar attempts available in the literature to apply frameworks in such a wide area has been done by MAV (1990), MAV (2010), Solidoro et al. (2010), Pastres & Solidoro (2012). Those studies, together with the work by Provveditorato interregionale OO. PP. (2016), have been extremely useful to set up the entire analysis. According to Pastres & Solidoro (2012), even though “the Lagoon of Venice has been deeply investigated and extensively monitored, a framework like DPSIR could fill the result gaps and improving the monitoring and management strategy, often fragmented by the governance structure”. As per this study, DAPSI(W)R(M) could add to the previous attempts many other updated information and distribute them in a more linear cause-effect chain.

1.1 THE NEED OF A NEW FRAMEWORK

After the 1970s-environmental movement and the late century environmental-related issues, worldwide governments have started to deal with Integrated Water Resources Management (IWRM), in order to effectively and efficiently manage water resources (Rahaman et.al., 2004; Elliott, 2014; Glaeser, 2019). This has led to the creation in the 1990s of many important “holistic” legislation applied in the coastal environments, after 30 years of water legislation dealing with individual issues (Boyes & Elliott, 2014; Giakoumis & Voulvoulis, 2018b) such as the Water Framework Directive (WFD) (Directive 2000/60/EC; Decreto 260/2010), the Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC, Decreto 190/2010), or more recently in the Mediterranean Sea, the

the old PSR has been substituted. The policy-oriented DPSIR framework, largely promoted by the OECD (Organization for Economic Cooperation and Development) (OECD, 1993) and soon adopted by several international organizations as US EPA (Environmental Protection Agency) (EPA, 1994), UNEP (1994), has been also adopted by European Union, at the time considered the most appropriate way to structure environmental information (EC, 1999).

To implement many other policy-based decisions, several DPSIR-based frameworks are born, leading to stronger social applications such as EBM-DPSER (Kelble et al., 2013), or human health frameworks (DPSEEA) (von Schirnding, 2002). Still many publications pointed out some limitations of the canonical DPSIR applied on coastal management (Eastwood et al., 2007; Atkins et al., 2011; Martins et al., 2012; Gari et al., 2015; Lewison et al., 2016; Patricio et al., 2016). Common critics were in relation to differences in the use, terminology and misinterpretation by many authors of various components, particularly P, S, and I. The term “Pressure” is often interchangeable with “Activity” or “Driving force”, while State change and Impact has been commonly used as Impacts on the environment or Impacts on society due to environmental State changes. But P-S-I elements are not mutually exclusive, despite being commonly treated as such.

According to Patricio et al. (2016), S and I definition misunderstandings had led to the “modified DPSIR” (mDPSIR) of the ELME EU FP6 project, where Impact categories were restricted to Impacts on human systems. This has led to the DPSWR framework (Cooper, 2013) in the KNOWSEAS FP7 project, where Impacts has been changed in Welfare, even tough should be called “Impact on human Welfare” rather than “Welfare” *per se*, thus leading to the most recent DAPSI(W)R(M) derivative (Scharin et al., 2016; Patricio et al., 2016).

An important target of this new DAPSI(W)R(M) framework has been unification of natural and social sciences to solve the many issues created by human Activities and spreading in the seas (Gregory et al., 2013). Then for the first time has been illustrated a clear cause-effect relationship, linking Activities to both the D and P components (Patricio et al., 2016). In the methods paragraph (3) the framework will be better discussed.

1.2 STUDY AIMS AND OBJECTIVES

The DAPSI(W)R(M) approach focus on the relationships between the anthroposphere and the natural environment, considering all the aspects of human development together (societal, economic and environmental). It is designed to cross disciplines, addressing different aspects of environmental management (research, monitoring, mitigation, policy, and society) and better reach scientific community, environmental managers, policy-makers and the public. All the society could therefore

benefit from this approach, which could be used in this complex environment as a guideline for future management projects or as a tool for enhancing environmental awareness.

The full product of this analysis (Annex 1) mirror the image represented in fig. 1, where each element creates a cascade impacting other elements, creating many feedback loops starting from R.

In order to apply the DAPSI(W)R(M) framework to the Venice Lagoon social-ecological system, it has been gathered here as much published and unpublished information currently available to outline an extensive (not exhaustive) picture of the territory. The strong complexity and diversity of the area has been then organised and described, following the cause-effects scheme of the framework (Elliott et al., 2017), to show how this methodological model could be applied here and the relationships between the elements (Drivers, Activities, Pressures, State changes, Impacts on human Welfare, Responses as Measures). Therefore, this work primary aim to implement the Venice Lagoon system management and not extensively describe each element, even though it has been performed the more comprehensive description and analysis as possible.

2. STUDY AREA

The Lagoon of Venice is a complex economic, social, and environmental system (Rinaldo, 2001), with peculiarities both on the surface and subsurface environments. Covering an area of 550 Km² it is considered one of the widest in Europe and the Mediterranean Sea (Aspden et al., 2004; Libralato et al., 2004). Geomorphologically it can be described as a restricted lagoon type, due to its high impact of tidal circulation and water movement (mainly caused by the wind). Here spring and fall are the wettest seasons, while winter and partially the summer, the driest; water and air temperatures (monthly average from 3°C to 24°C) have a seasonal cycle, with minimal values in January, and maximal in July (Solidoro et al., 2010)

The territory (Fig 3), which contains numerous inhabited islands (45 Km² per Solidoro et al., 2010) such as Murano, Mazzorbo, Burano, Sant'Erasmo, is delimited and separated from the Adriatic Sea by three long and narrow pieces of lands: Cavallino peninsula (North), Lido (centre) and Pellestrina (south) island. Far south lies Chioggia, with its own archipelago including big islands such as Sottomarina. The city is not part of Venice Municipality, but forms a municipality of its own under the Venice County, and is included in the UNESCO world heritage site, which covers the entire lagoon.

According to Comune di Venezia (2019), Venice Municipality has reached a population of 259,297 residents. The biggest conglomerate of Islands in the centre host the famous city of Venice, (52,143 people), while around 27,578 residents live on other islands and the bulk of residents inland (179,576) (Comune di Venezia, 2019). The city centre population reached its peak in 1951 with

174,808 residents but as the tourism has increased, its resident population has fallen (Grydehøj & Casagrande, 2019).

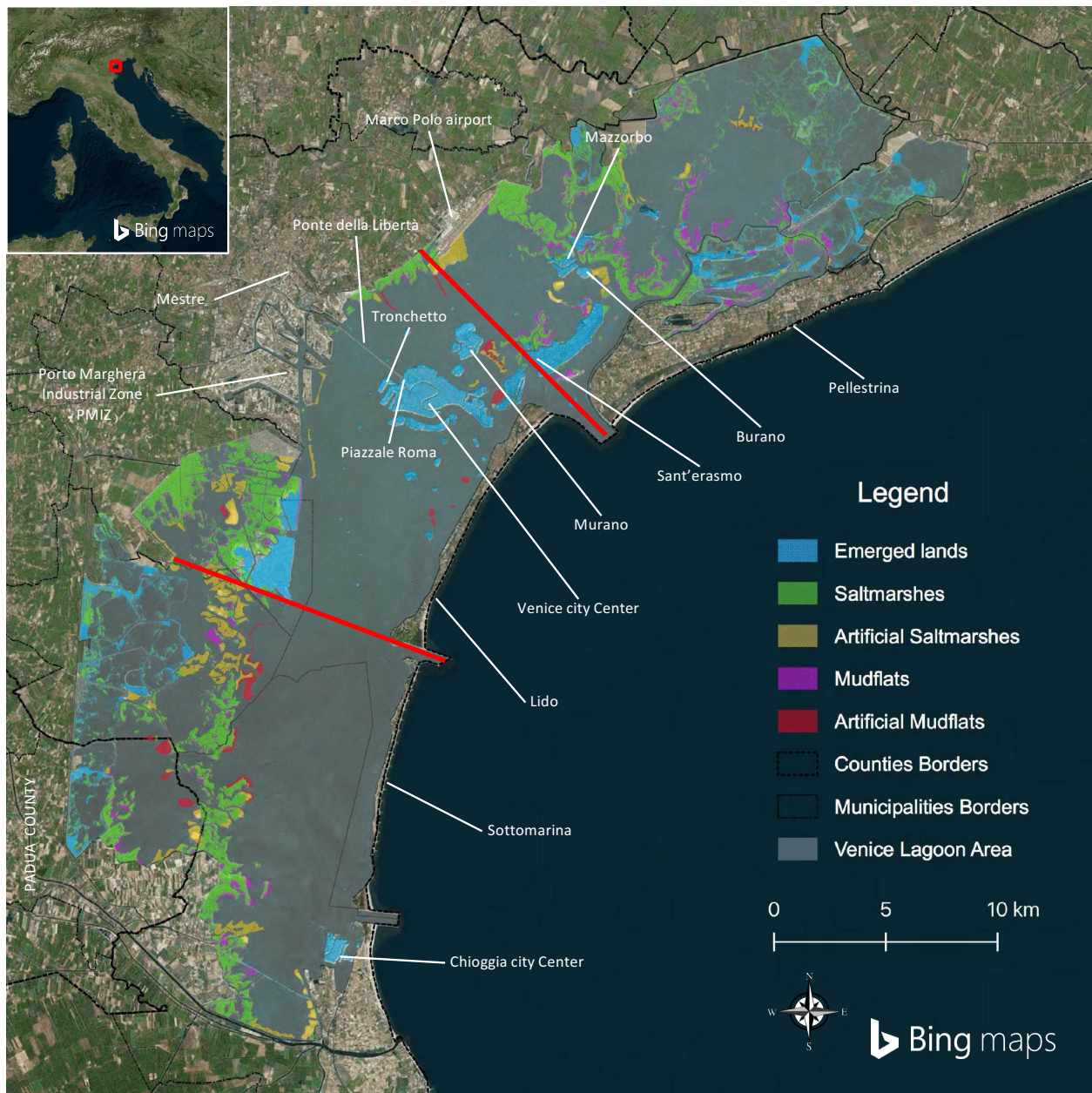


Fig. 3. Study area representing the Venice Lagoon, divided by the red lines between the northern, southern and central part. The localization of artificial and natural saltmarshes/mudflats, emerged lands (inside the lagoon areas) has been retrieved from Atlante della Laguna, based on the MAV campaign in 2013. Produced using QGIS on Microsoft Bing Maps.

The lagoon system is composed of shallow water of 1 m in average, with tidal flows reaching more than 1 m. It exchanges $1.5 \cdot 10^8 \text{ m}^3$ in each tidal cycle with open seas and receives freshwater from 27 tributaries (maximum discharge of $100 \text{ m}^3/\text{s}$) (Malavasi et al., 2004, Libralato et al., 2004). The dominant winds, blowing up to 10 m/s, are Sirocco from southeast and Bora from northeast. Those winds, together with tidal cycles and river discharges, contribute to the large clockwise eddy made by currents around the Venice islands, with a net southward flux of water driven from the many

discharges in the northern section (Solidoro et al., 2010). Per Cucco et al. (2009), the average water residence values for the inner part could be higher than a month, while it is a few days for seaward areas.

Hydrologically the lagoon can be divided in three main sub-basins: northern, central and southern (Solidoro et al., 2004; Zucchetto et al., 2016) (fig. 3). The main discharge points (fig. 11) are:

- Dese river, Silone channel, Marzenego-Osellino channel in the north lagoon;
- Naviglio Brenta channel and Lova channel within the central part;
- Taglio Nuovissimo channel, Montalbano channel, channel of Trezze in the south lagoon.

The nutrient loads coming from those sources should sustain a primary production and food web processes when delivered moderately. The annual average freshwater discharge is 40 m³/s, even though could reach 340 m³/s (Collavini et al., 2005). Those watercourses originate far away from the study area, which is confined to the lagoon borders (as expressed from WFD guidelines), but they will be considered during the discussion of agricultural/pastoral Activities, threatening the whole drainage basin as a black box, from which the negative outcomes derive. The drainage basin includes the counties of Venice, Padua, Treviso, and Vicenza with a total of 108 municipalities covering an area of approximately 2038 km² with more than 2500 km of discharges (Soccio et al., 2018)

While in past (D'Alpaos, 2010) the lagoon was subjected to higher sediment burial compared to its erosion (due to higher contribution of river flows), since the Serenissima Republic (far back many centuries ago), many rivers have been diverted into the sea, jetties have been built at the lagoon inlets during the period 1808–1927 and many channels has been dredged for navigation in 1926 and 1970 (Guerzoni & Tagliapietra, 2006). In the same time spam, urbanization and land reclamation for agriculture, aquaculture, and industry, have reduced the total surface of the lagoon by 3280 ha (Ravera 2000). Those modifications altogether have shifted the original sediment dynamics controlled by wave energy, river flow and coastal currents (Aspden et al., 2004), into a new equilibrium accompanied by salinization and higher erosion rate (D'Alpaos & Carniello, 2010). The average salinity values range indeed today from 23.7 PSU in the north (Valli Laguna Nord) to 31.3 PSU of the south (Val di Brenta) while average pH from 8.0 to 8.3 unit and dissolved oxygen close to the saturation limit (ARPAV, 2016).

As a transitional water, the system's ecology can be considered with riverine and marine influences, but because of its heterogeneous morphological and physicochemical parameters, the Lagoon experience strong spatio-temporal differences depending on the area, with its habitats suitable for different organisms (Aspden et al., 2004; Malavasi et al., 2004; Zucchetto et al., 2016). As per Franco et al. 2006, the Lagoon (particularly the northern basin), can present 5 main types of aquatic habitats within 2 types: “structuring” habitats, like seagrasses and saltmarsh creeks, with specialized

fauna; “transition” habitats (sandy bottoms, mudflats and sparsely vegetated habitats), with variable organism assemblages, strongly influenced by adjacent habitats.

Saltmarshes are the areas situated above mean sea-level which not fall into the island category, therefore partially influenced from the seawater influence. Tidal flats (here mostly mudflats) remain below mean sea-level close to the saltmarshes, and can be classified as intertidal or subtidal flats (depth between 0.75 and 2 m), depending on whether they are above or below the mean low water spring tide value of 0.50 m. In addition to that, as displayed in fig. 4, besides the artificial channel themselves, it is possible to find some other peculiar deeper elements such as tidal channels and tidal

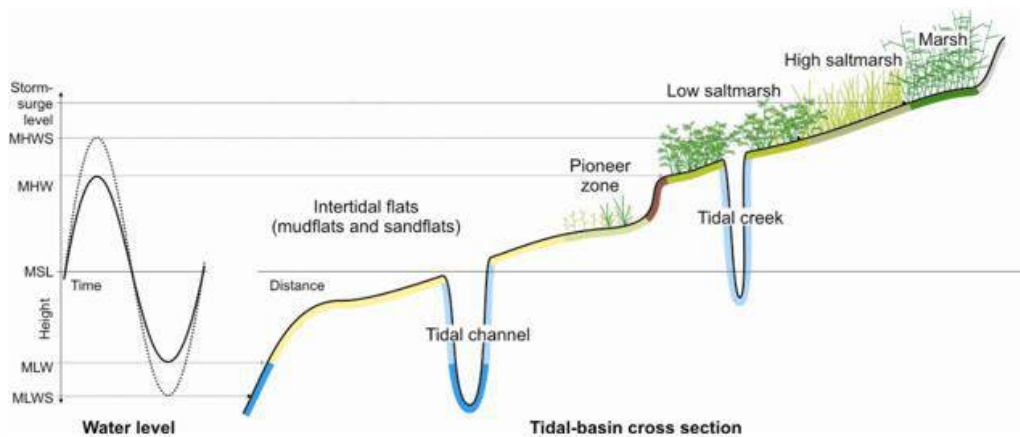


Fig. 4. Zonation in saltmarshes relative to the tidal frame. Retrieved from Gotie et al. (2007).

creeks (D’Alpaos et al., 2005). Among them the most peculiar and endangered habitat are undoubtedly saltmarshes, with their creeks hosting the highest fish density because are located farther from the sea inlets in the internal areas of the lagoon, present more resources and act as a refuge from predators (Desmond et al., 2000; Rountree & Able, 2007). Unfortunately, these systems are disappearing because of the many anthropogenic interventions. For example, the construction of the breakwaters to defend the inlets has led to the reduction of both riverine and coarse marine sediment (Day et al., 1998), creating erosion and subsidence (extensively explained in Carbognin et al., 2005), which have in turn caused a reduction around saltmarshes in the Venice Lagoon to about 35 km² in the last century.

Following the European biodiversity directives “Habitat” (Council directive 92/43/EEC) and Birds” (Directive 2009/147/EC, 2010), within the territory are located many SPA (Special Protected areas) and SCI (Sites of communal importance). Particularly, there are:

- SPA IT3250046 Venice lagoon;
- SCI IT3250030 Mid-lower Venice Lagoon;
- SCI IT3250031 Upper Venice Lagoon.

Those areas (Buffa & Lasen, 2010), part of “Natura 2000 net”, should help to maintain their long-term conservation efforts due to their high ecological importance. Indeed, per Franzoi et al. (2010), as a whole the lagoon areas sustain at least 80 fish species, grouped into lagoon residents, marine migrants, marine stragglers, anadromous migrants and freshwater species (other assessments in Malavasi et al., 2004; Franco et al., 2009). Seagrasses could be seen as the major primary producers, while a total of 300 species of macroalgae have been recorded in the Venice Lagoon (Sfriso & Curiel, 2007). Benthos (e.g. Tagliapietra et al., 2016), phytoplankton (Socal et al., 2006) and zooplankton communities (e.g. Aciri et al., 2004; Camatti et al., 2006) are strongly represented as well, together with wintering aquatic birds (Scarton & Bon, 2009).

3. METHODS: THE DAPSI(W)R(M) FRAMEWORK

As a conceptual model, this tool will be used to “collate, visualize, understand and explain the issues and problems relating to actual or predicted situations and how they might be solved” (Patricio et al., 2016). All the information here gathered, has been extensively summarized in a standardized, logical and hierarchical way, with the final aim to reach and assess current policy maker decisions.

As for the first element, it has been proposed in Elliott et al. (2017) the utilisation of a five-tier hierarchical structure created by Maslow (1943), in the role of Drivers to assess human needs (fig. 5). Each of the societal needs, structured in a pyramidal and hierarchical structure, represents the urgency of human development. In every personal decision made, everyone escalates this pyramid trying to fulfil first their basic needs, then psychological needs and subsequently self-fulfilment needs. The same groups have been created here to evaluate the Drivers essential to pursue each socio-economic Activity. Five Driver classes have been in this way created: self-actualization, esteem needs, love and belonging needs, safety needs, biological and physiological needs.

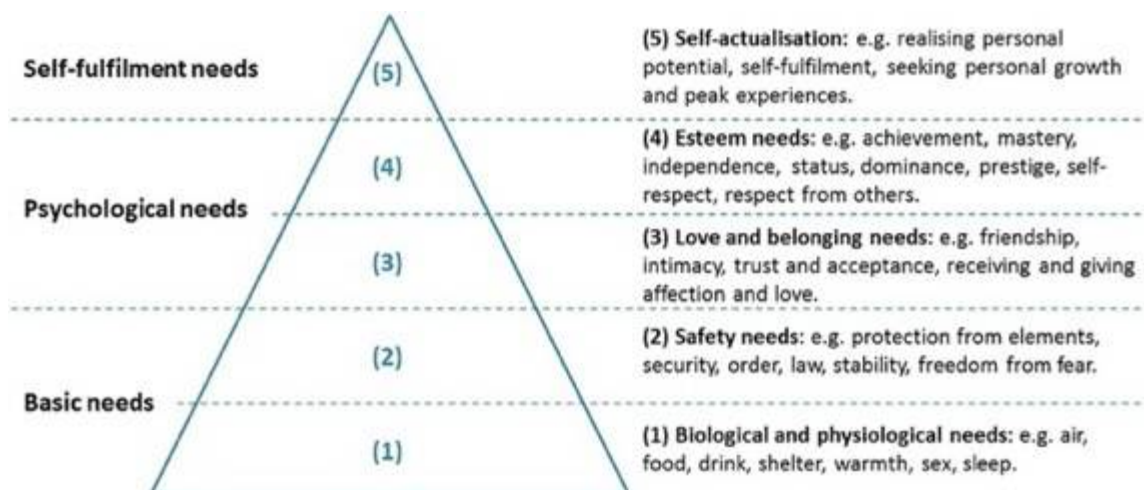


Fig. 5. Maslow's hierarchy of needs and human welfare. Retrieved from Elliott et al. (2017).

For every D correspond in turn many Activities carried out to achieve a specific need. Therefore, it has been listed all the Activities (with their respective macro-fields) carried out in all the basin and coupled with the correct Driver. It has been included some agricultural Activities within the river basin (and outside the proper study area) only because of its marked effects (Pressures) in the Lagoon. Together with the later described Responses element, the section put attention to human interactions on the environment.

Pressures indicate all the “environmental impacts” of short/long term Activities, which have the potential to alter to different extent the lagoon system. A division between “Endogenic Managed Pressures” (EnMP) (all the Pressures acting from inside the system and managed to different extent) and “Exogenic Unmanaged Pressures” (ExUP) (meaning unmanageable or not directly manageable Pressures which come from outside the system) has been made. (Elliott, 2011; Patricio et al., 2016). This decision has permitted the introduction of some issues regarding climate change and species invasion. EnMP and ExUP are then combined together to form common Pressures elements. In fig. 6 has been represented this division together with the whole problem structuring framework.

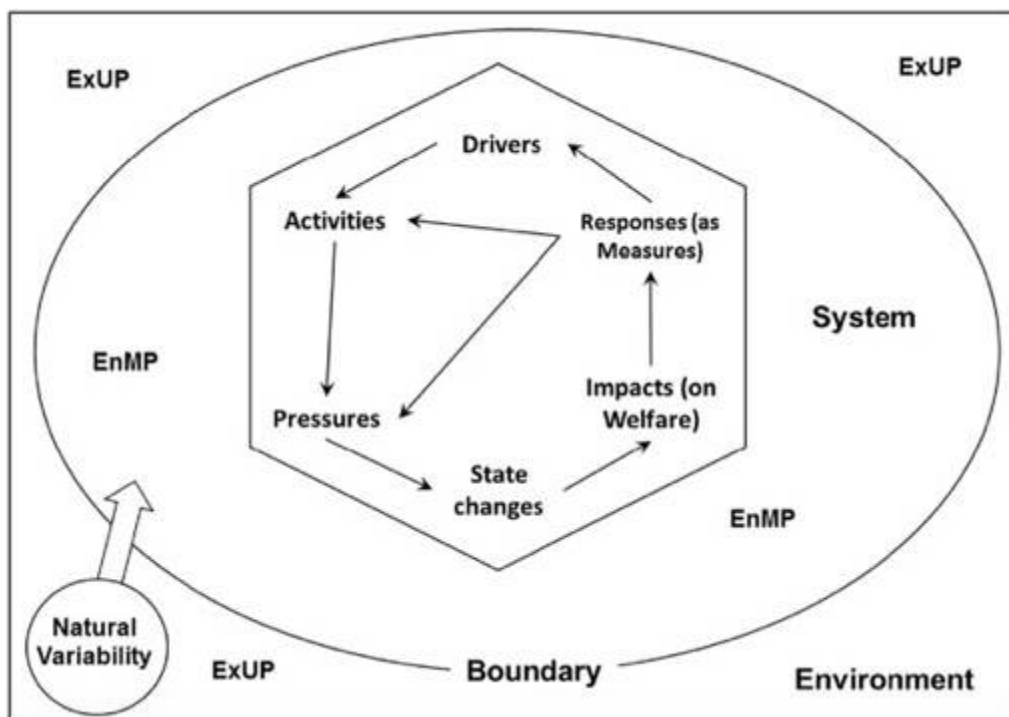


Fig. 6. The DAPSI(W)R(M) problem-structuring framework displaying the boundaries between the system and environment, and the natural variability. Key: ExUP: Exogenic Unmanaged Pressures; EnMP: Endogenic Managed Pressures. Retrieved from Elliott et al. (2017).

State change shows the environmental modifications in the system, underlining which Pressures are conveyed together to produce similar effects. Clearly some of them are interchangeable because often acting synergically and enhancing each other; nevertheless, each-one has the potential to

produce many different Impacts on human Welfare. To better represent these linkages, Haines-Young & Potschin (2010), have introduced the “service cascade” conceptual model: a link between ecological structure (here State change) and elements of human well-being, using intermediate stages between them. This cascade will be here represented using the conceptual framework set out by Fisher et al. (2009), which distinguishes between ecosystem structure and basic processes (relative to the marine ecosystem), intermediate services, final services and goods/benefits (fig. 7). Even though the present study take place in a transitional ecosystem, it has been decided to use the original name “marine ecosystem” for the first step of the State changes.

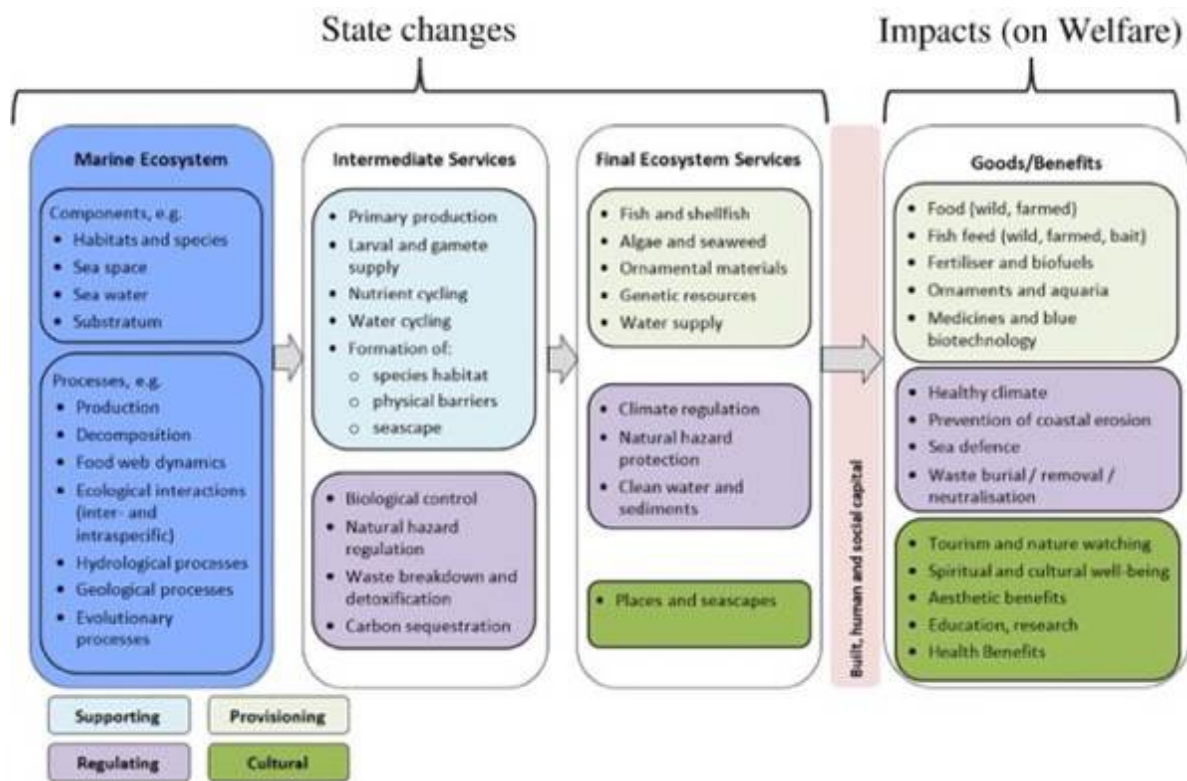


Fig. 7. State changes to the natural system reflected by changes in the “marine ecosystem”, intermediate and final ecosystem services (left hand side), and Impacts (on human Welfare) reflected by changes to the provision of societal goods and benefits (right hand side). Retrieved from Elliott et al. (2017).

Similarly to the DPSIR analysis of Müller & Burkhard (2012) (where the biophysical structures, processes, and functions have been placed in the state change step, whereas the changes of ES provision in the Impacts section), here the “marine ecosystem” (fig. 7) will be discussed in the State change section, while the “ecosystem services cascade” will be placed in the Impacts section. This approach aims to follow a better linear discussion and to better represent ecosystem services as a major tool for policy development (i.e. WFD) (Vlachopoulou et al., 2014; Grizzetti et al., 2016; Voulvoulis et al., 2017; Giakoumis & Voulvoulis, 2018a).

As expressed in Elliott et al. (2017), the operational set of indicators applied in the I(W) paragraph are based upon the discussion of Turner & Schaafsma (2015). Those indicators describe and explain

how the previous elements (D – A – P – S) are contributing to change human lives, producing therefore many ecosystem services/disservices (Shackleton et al., 2016) but especially goods/benefits. Ecosystem services (ES) can be defined as an expression of ecosystem functions which, to different extent, has the potential to affect humans, generating in this way goods and benefits for the society. Those elements are therefore deeply linked with the WFD ecological status in aquatic ecosystems (European Commission, 2000; Boon et al., 2015; Grizzetti et al., 2016), meanwhile this status is a measure defining the distance between the current and desired state, thus defined by Voulvoulis et al. (2017) as an indicator for policy development.

All those described elements require responses (often delineated in EU Directives as Measures) which should modify D and A, preventing P and therefore enhancing positive S and I(W). Therefore, in the last section, it will be discussed some important recent and current Measures, with a focus on ecological restoration practices. Because of its circularity, all the Measures will be assessed considering its P, S and I produced. The R(M) element should indeed prevention and mitigation strategies which need to cover the so-called 10-tenets (Elliott, 2013): sustainable, economically viable, technologically feasible, socially desirable/tolerable, legally permissible, administratively achievable, politically expedient, ethically defensible (morally correct), culturally inclusive and effectively communicable. The tenets should be equally applied to A and P as discussed by Barnard & Elliott (2015).

In this way, the framework here presented consider all the governance of the marine environments, distinguishing, as per Jentoft (2007), the ‘system to be governed’ (D, A and P affecting the state of the ecosystem) and the ‘governing system’, guided by the Impacts (on human Welfare) to improve its Responses. In a wise way, the ecosystem and its resources match with institutions preserving or improving the state of the ecosystem.

Another interesting division can be made covering all the aspects of the sustainable development as per as officially expressed from the Brundtland Commission in 1987 (WCED, 1987), even though there is often an obvious occurrence and repercussion of the three pillars in each DAPSI(W)R(M) element and in the framework as a whole. Nonetheless, D and A are contained in the socio-economic sphere, P and S cover purely the natural environment while the latter (I(W) and R(M)) could be seen as a solid and accurate union of the 3 pillars.

In addition to that, has been created GIS maps using QGIS software (QGIS Development Team, 2009) to display the location of the different elements. For each couple (D and A – A and P – P and S – S and I(W) – I(W) and R(M)) are produced diagrams showing their connections, which have been unified together to produce the map in Annex 1. Colours on diagrams reflects the cause/effect of each element, with the black borders addressing the colour’s provenience.

4. RESULTS AND DISCUSSION

4.1 DRIVERS

Every Driver raised from the human needs as described in Maslow (1943) hierarchical structure. Therefore, is it clear that, in a wide and well-structured society included in the Venice-Chioggia municipalities, every need is fulfilled by many Activities. Fig. 8 represent the connection between those needs and the macro category of Activities (sectors).

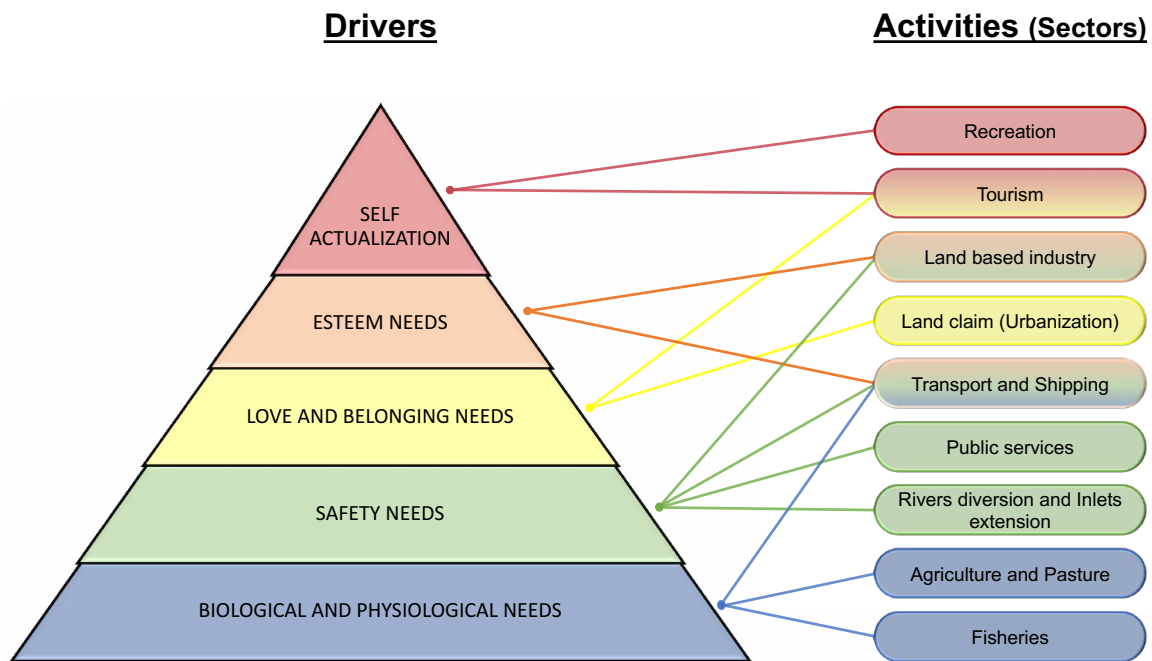


Fig. 8. Connections between Drivers (in the form of Maslow pyramid) and the respective activities (sectors).

Starting from the bottom line of the pyramid, we can distinguish:

- Biological and physiological needs which contribute to the basic life needs regarding the food industry (agriculture and pasture, fisheries). To certain extent, shipping can be included as a direct effect when carried out to import edible materials.
- Safety needs, bringing together land claim (urbanization), particularly important in Venice due to the on-water peculiar location, requiring perennial management. In this category, under the public services field, it has been distributed transport services (shared with transport and shipping, which is partially counted as safety need), waste management facilities, wastewater treatment plants, energy plants, pipelines and electric lines. Because most of those essential services are in the same area of other industries, in order to unify them in a single area to better assess their later on framework elements, land based industry has been connected not only to the esteem needs, but also to the safety ones.

- Considering the deeply rooted consideration of Venice as a “city for lovers”, tourism will undoubtedly fall in the category “love and belonging needs”, even though it should be a purely self-actualization product. In this category rely also partially the urbanization (as well as in the previous section) due to the need of having a roof for families.
- Esteem needs, which include all the industrial production, shipyards, transportation system and every small to large commercial Activities not related to the basic needs supply.
- Finally, the self-actualization category which add the recreational Activities and contain the bulk of the touristic industry.

4.2 ACTIVITIES

Each human Activity can generate Pressures, which may in turn lead to several direct or indirect disturbances to the whole coastal ecosystem. To correctly assess these Activities, fundamental for this study aim is to locate them, and therefore understand how many people can be potentially involved. The results of the analysis will define for each Activity, depending on the type and extent, a different representation on a georeferenced map. The main Activities carried out in the system, with their field groups, are listed in tab. 1.

Tab. 1. List of sectors and related Activities.

Sector	Activity
Recreation	Private boats
Tourism	Cruises
	Tourist infrastructure
Land Based Industry	Marghera Industrial pole
	Murano glass
Land claim (Urbanization)	
Transport and shipping	Docks management
	Marine Commerce
Public Services	Transport system
	Energy facilities
	Wastewater treatment plants
Waste management	
River diversion and inlets extension	
Agriculture and Pasture	Small scale agriculture
	Pasture
	Intensive agriculture (basin)
Fisheries	Artisanal fisheries
	Dragging and Mechanical clam harvesting
	Aquaculture

Per Grydehøj & Casagrande (2019), apart from Sant'Erasmo (population 669) and Vignole (56), which are primarily agricultural communities, all the Venetian islands rely to different extent on tourism, even though agriculture and traditional industries remain significant to the local economies. Mazzorbo (population 277), Torcello (20) and Pellestrina (2,587), hosts small-scale but deeply rooted agriculture communities, with Pellestrina relying also on fishing and craft industry. Another important centre of fisheries, but especially aquaculture, is Chioggia and Sottomarina (50,000), even though the area is also an important cultural and seaside tourism hub.

However, to lead the islands tourism ranks there are Murano (population 4,335), Burano (population 2,459), and Lido (population 14,564) (Grydehøj & Casagrande, 2019). Each of these islands is accompanied by their own particularities attracting in turn many tourists. Murano is known for its famous glassworks industry, Burano for its lacemaking industry and the exclusive colourful village landscapes, while Lido, the second most populous island (after Venice city centre), hosts the Film Festival in September and is crowded in summer due to regional seaside tourism.

4.2.1 Tourism

With 12.1 million tourists per year, Venice receives 2.8% of the Italian tourists (ISTAT, 2018), and as soon as tourism has grown, the whole city and surrounding areas has become dependent on it. The city centre local economy is almost entirely composed by souvenir shops, Venetian and regional craft (such as Murano glasses) or international luxury brands.

The city and the surrounding areas have always been one of the main Italian hotspots for tourism, but only since the opening of the International Airport Marco Polo (in 1960) and the creation of docks in the artificial island of Tronchetto (1957-1961) (fig. 3), it has boosts its tourism attraction (Zannini et al., 2014). The mass tourism has indeed increase its number as showed in fig. 9, with +5,6% per year in the last 20 years as per Zannini et al. (2014). While rich tourists stay in the city centre, but especially on Lido Island where located the luxury hotels, the bulk of the visitors remain inlands (in Mestre particularly), where there are more affordable hotels and apartments, going back to visit the city centre and its islands daily.

Nonetheless, the most remunerative and therefore important industry in the sector is represented by cruises, which have completely changed the city and the surrounding environment. This industry, which reduce costs to offer a low-cost service for tourists, is creating many big social, environmental but also economic problems: because the ship is a destination itself, it generates almost no impact on the local economy, with the tourists wanting to just sightseeing the city or join excursions (Weeden, 2016; Maršenka et al., 2016; Gonzalez, 2018). Nevertheless, at the present, around 500 cruises ships enter the Lagoon each year (446 in 2017 as per Città di Venezia, assessurato al turismo, 2017),

bringing 1.5 million tourists each year (Città di Venezia, assessorato al turismo, 2017), and this traffic will add to the already intense commercial traffic on the Malamocco-Marghera Industrial channel (MMIC) (fig. 10) (Teatini et al., 2017). According to Valcárcel (2018), the passengers increased by 440% between 1997 and 2010 while the ship's landings growth by 263% in the same time span. Those data clearly indicate the ship size grown. Other touristic boats which brings passengers in the city are riverine ships, ferries and hydrofoil, but their numbers are far less.

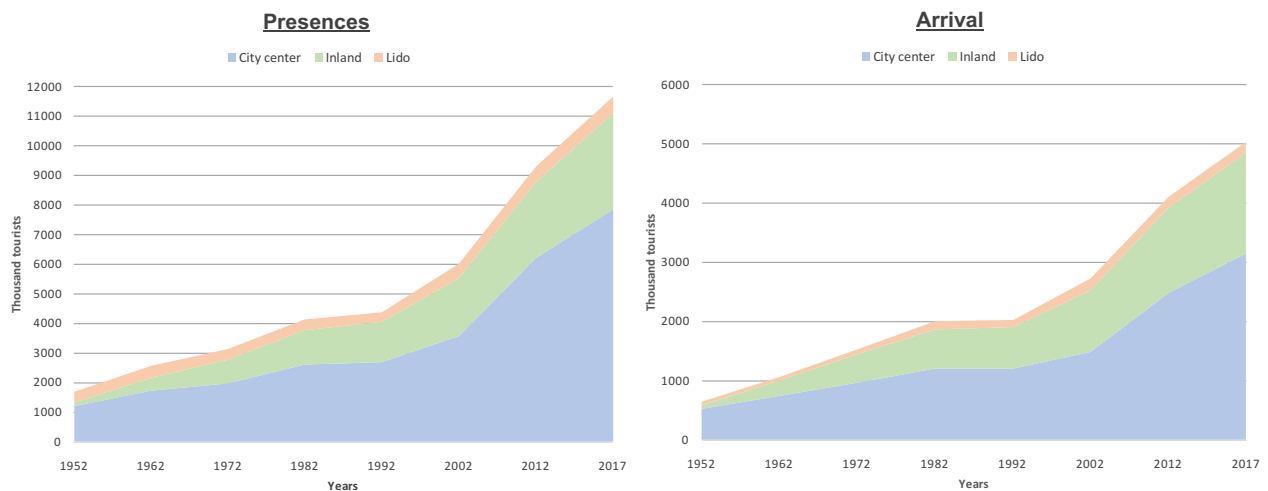


Fig. 9. Historic and recent data about tourism (thousand tourists per year). Arrival and presences in different location of the Lagoon. Data retrieved and combined together from Città di Venezia, assessorato al turismo (2012; 2017) and Zannini (2014).

4.2.2 Public and Commercial Transport System

To reach the city centre of Venice, in 1846 a 4-km rail bridge (Ponte della Libertà) (fig. 3) was built between Marghera and Venice, with the road added in 1933 and the consequent development of parking facilities (Grydehøj & Casagrande, 2019). Most of the parking lots, are situated in the almost completely artificial island of Tronchetto, where it is located the cruise ship terminal as well, close to the near bus, waterbus and taxi terminal (Piazzale Roma). The rest of the Lagoon is road-free (cycling is mostly forbidden) except for the elongated shapes of the Lido and Pellestrina which also have land transport (cars and buses), served by roll-on/roll-off ferries to transport road vehicles. Elsewhere, transportation and public services takes place by water buses, water taxis, private boats, cargo vessels, waste-collection vessels etc., all powered by diesel engines, which in turn contribute to noise and atmospheric pollution, requiring its own set of hard infrastructures (harbours, channels, etc.). Venice's Marco Polo airport is located on the mainland, on the coast to the north-east of Marghera-Mestre.

The fleet for public transportation in Venice is operated by the municipal company ACTV and consists of 160 water buses, which dock in 150 floating piers along the channels and transport over 100 million passengers a year (Morandin et al., 2015). The most common water buses are "vaporetto"

(small steamer), a 24-m long, 4.22-m wide hull, which displaces 37 tons and can accommodate 200 passengers each one, in services for 16 hours daily. Their main routes are represented in fig. 12.

Besides the huge disturbance of underwater noise and pollution, the main issue related to the transport, rely on the channels themselves (fig. 10). A typical intervention in coastal systems is indeed the dredging of canals and inlets, which are performed to increase the water volume exchanged with the sea (Gong et al., 2008), as filling material for upland development and land reclamation (López et al., 2013) or for navigation purposes (Healy et al., 1996; Fortunato & Oliveira, 2007).

The extent of channels net here is about 718 Km throughout the entire lagoon (Brighenti et al., 2003) (Tab. 2; Fig. 10), and since its born, the reclaimed land has been impounded for constructing solid ground on the lagoon's mudflat, urban expansion and industrial settlement (Balletti, 2006; D'Alpaos, 2010; Grydehøj & Casagrande, 2019). Nonetheless many speed limits (in knots) exist, together with some restricted traffic areas (blue areas) to better preserve sensible areas (fig. 10) (MAV, 2007).

Tab. 2: Type of channels, length and extension. Data retrieved from Brighenti et al. (2003).

Type of channel	Length (km)	Extension (Km ²)
Principal channels	171,4	35,4
Docks channels	18,69	2,7
Secondary channels	165,61	10,7
Minor channels	109,88	3,7
Saltmarshes creeks	140,07	8,3
Urban principal channels	46,27	1,8
Secondary urban channels	67	1,51
Tot	718	64,21

Every channel serve to many purposes essential for the city life: urban mobility, city services (e.g. Ambulance, Police, waste collectors), but especially commerce. The last major navigable canal, the Malamocco-Marghera Industrial Canal (MMIC) (fig. 10), excavated in the 1960s, has been created to connect the Porto Marghera Industrial Zone (PMIZ) on the mainland with the Adriatic Sea through the Malamocco inlet. In accordance with Sarretta et al. (2010), this process has removed a total 40 Mm³ of the dredged material than disposed on lands, mainly on structures called “casse di colmata” (fig. 10).

Many studies have already demonstrated how the MMIC for large vessels is the main causes for the morphological deterioration observed in the central lagoon: deepening the tidal flats, marshland

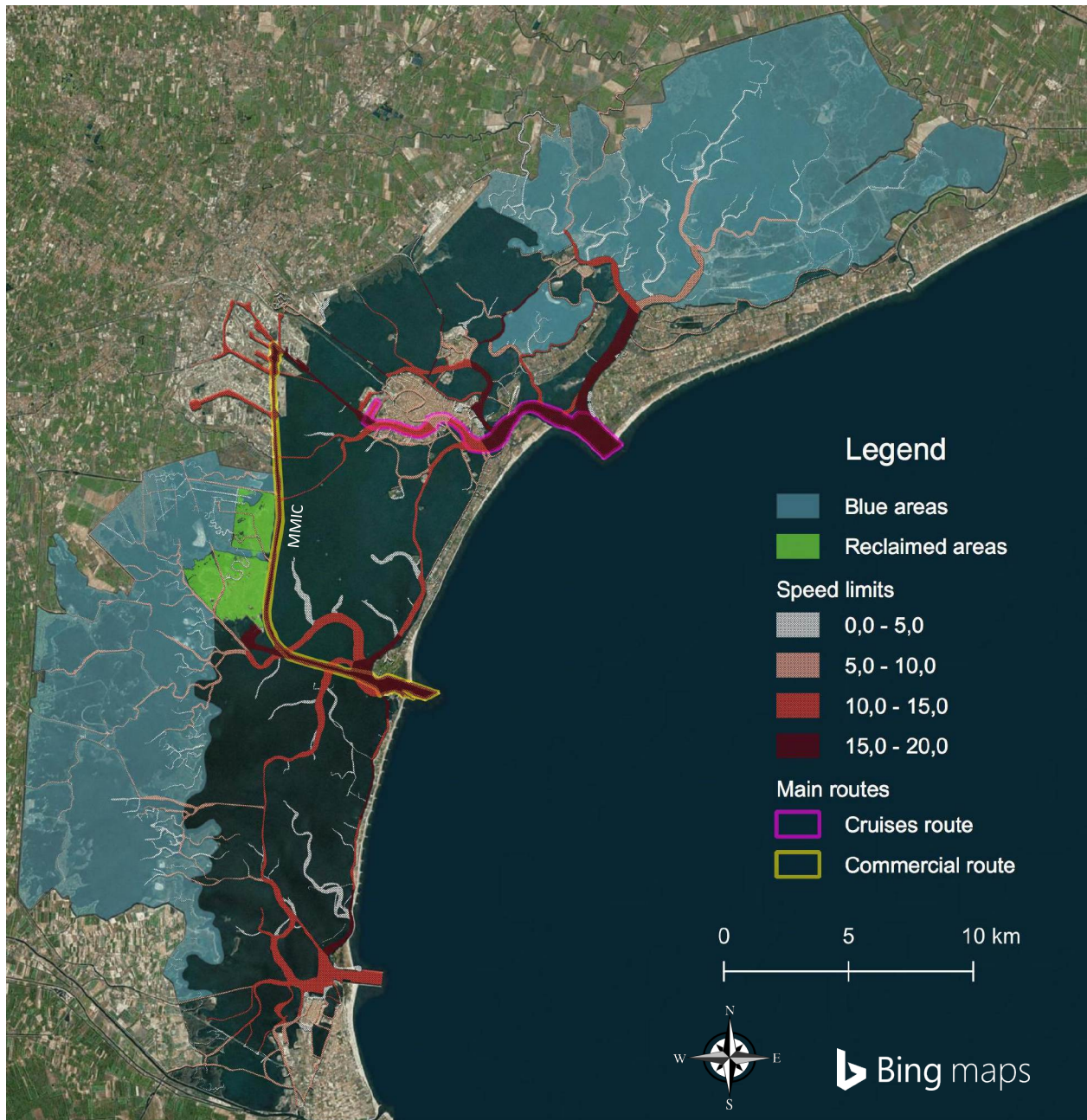


Fig. 10. Representation of channels with their speed limits (knots), limited traffic areas (blue areas), reclaimed areas from dredged materials (casse di colmata), main routes of touristic cruises and commercial ships (through MMIC – Malamocco-Marghera industrial channel) (see text). Data retrieved and adapted from Atlante della laguna. Produced using QGIS on Microsoft Bing Maps.

erosion, sediment loss, texture and grain size changes (e.g. Ravera, 2000; Tambroni & Seminara, 2006; Carniello et al., 2009; Molinaroli et al., 2009; Amos et al., 2010; Marani et al., 2011; Ferrarin et al., 2013). Unfortunately, without it, commerce outside the lagoon could be impossible, especially thinking about the average ships hull size, far bigger than the average channel depth. Tab. 3 shows the channel utilization (in tons transported) of different industrial sectors of the Porto Marghera Industrial Zone (PMIZ).

Tab. 3. Maritime traffic at Porto Marghera Industrial Zone (PMIZ). Data retrieved from Autorità Portuale di Venezia (2013).

Commerce sector	Goods transported (tons/year)
Energy	10.206.699
Containers	4.296.687
Steel	4.083.399
Food	2.113.355
Roll-on/Roll-off	1.235.657
Chemicals	1.176.364
Other dry bulk	1.149.614
Various goods	149.602
Total Traffic	24.411.377

4.2.3 Food Industry

Within food industry are grouped here agriculture, pasture and fisheries Activities. To correctly assess the agricultural Activities within the lagoon, it is important to consider the whole river drainage basin, treating it as a black box (fig. 11).

The basin comprises all the water bodies draining directly into the Lagoon through its 27 river mouths (fig. 11), reaching 1.850 km² without considering resurgence waters (Cassin & Zolin, 2007). Cassin & Zolin (2007) recognised 55 thousand farms in this territory, with high predominance of intensive agriculture in the form of crops with cultures such as wheat, soy, sugar beet and other cereals (plus horticulture in specialized areas close to the coasts). Those cultures have a well-known impact on the surrounding environment (e.g. Tillman et al., 2002), especially when carried out, as happen here, continuously searching maximum productivity per surface unit, using a lot of chemical inputs. The utilised agricultural area (UAA) and total agricultural area (TAA) ratio is high (83%) when compared to the regional average of 71%, meaning an intensive agricultural utilisation of the fields (Cassin & Zolin, 2007). The waters flowing from the fields, from surface (runoff) into rivers and depth (leaching) through the groundwater, can be therefore polluted by fertilizers (nitrogen and phosphorus) or pesticides (herbicides, fungicides, etc.) (Novotny & Olem, 1994). This is a major “driver of change” leading to the current and past eutrophication and heavy pollution. Besides that, many small-scale sustainable farmers are continuously opening new enterprises, due to the growing demand of organic food (e.g. Abitabile et al., 2015; Bartoli, 2015).

Under “fisheries” is then possible to include Activities such as artisanal fishing, benthic trawling, netting and pelagic trawls fisheries. Some of them will be here discussed, but for an extensive

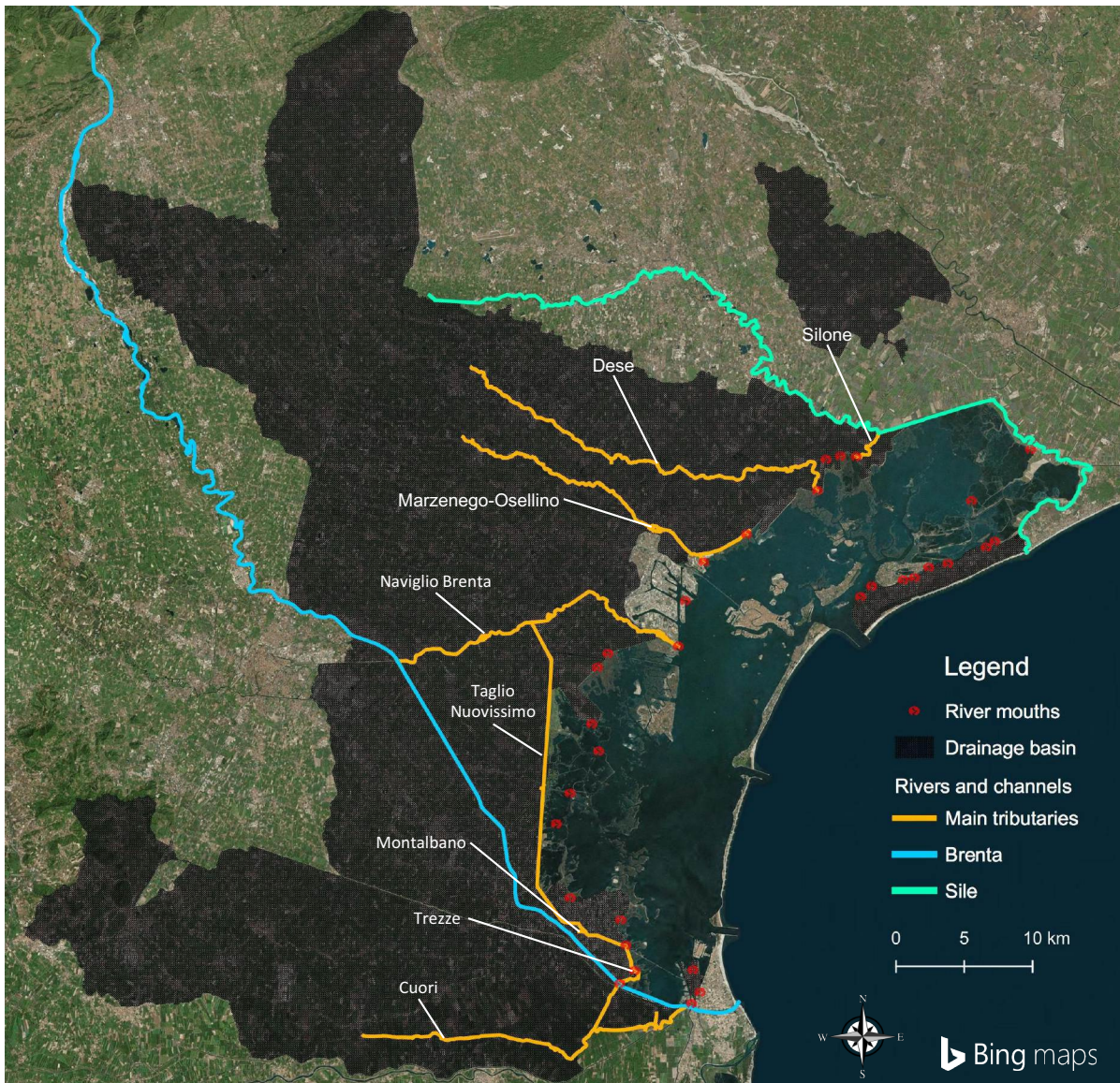


Fig. 11. Drainage basin represented as a black box with the river mouths coming from it. It is possible to see the channels and rivers mentioned in the text and how the river Sile and Brenta have been diverted (see text). Data retrieved and adapted from Geoportale Regione Veneto and Atlante della laguna. Produced using QGIS on Microsoft Bing Maps

discussion it is recommended a look to Provincia di Venezia (1999; 2009; 2014a). Angling (amateur and game fishing) will be not counted, due to its difficulties in assessing it. Anyway, as per Provincia di Venezia (2014b), recreational fishing was practiced by 21.500 people in 2011. Per Veneto agricoltura (2005), in fisheries and aquaculture sector there were 79 local units and 2.620 business location, of which 84% were individual enterprises and only 2% of ltd companies.

Artisanal fishing in the Venice Lagoon is performed using different traditional gears, with fyke nets considered the most important (Granzotto et al., 2001; Libralato et al., 2004; Provincia di Venezia, 2014). This type of fishing activity targets more than 20 different species of fish and benthos, and consists of a barrier which guides the fish towards four cone-shaped, unabated traps (Malavasi et al., 2004; Provincia di Venezia, 2009). Anyway, per Zucchetta et al. (2016), their pressure was less

impacting than other categories, and its effect negligible compared to the past, suggesting therefore that fyke net fishery could be carried out sustainably within the lagoon territory.

Another highly impacting fishing technique is otter trawling (or dragging), now banned (Provincia di venezia, 2009). This practice involves the use of mobile demersal gears (e.g. trawl nets and dredges) which are dragged along the sediment surface behind a towing vessel disturbing up to 120-250 m wide area, spreading the suspended sediment (Schwinghamer et al., 1998). The well-known effects include: alteration of the sediment and water biogeochemistry, change in sediment texture, destroy of bed forms, remove or scatter of non-target species (Watling & Norse, 1998; Pilskaln et al., 1998; Collie et al., 2000; Duplisea et al., 2001; National Research Council, 2002).

In contrast, the mechanical clam harvesting is a single-species fishing Activity, classifiable as a semi-industrial Activity, carried out in the past decades using high impacting equipment which have heavily modified and stressed the whole environment (Pranovi & Giovanardi, 1994; Libralato et al., 2002; 2004; Provincia di Venezia, 1999; 2009). The species exploited in the lagoon has always been the non-native species Manila clam (*Ruditapes philippinarum*), which was introduced in the lagoon in 1983 (Cesari & Pellizzato, 1985). During the mid-1990s, more than 50% (40,000 t) of clam production in Italy came from the Venice Lagoon, where about 600 fishing boats were in operation employing approximately 2500 people (Rosetto, 2000).

Clam harvesting is historically executed using equipments such as suction dredger, vibrating, scrapers, some of them now illegal (Provincia di venezia, 1999; 2009). An example of their impact is given by Pranovi et al., (2004; 2013), where they explain the effects of the widely used small boats equipped with “rusca” (an iron cage with net bag for clams collection) and an additional engine arranged lateral outboard. In shallow areas, the propeller suspended both sediment and clams (as well as other invertebrates), which are then collected by the net, producing in this way a V-shaped tracks which cause a sediment grain size change (loosing fine material) and contribute to suspended much of the previously stabilized heavy metals.

Aquaculture on the other hand, if extensive, is a much more sustainable Activity, but not completely without environmental impacts. (e.g. Sarà et al., 2011; Bouwman et al., 2013). In the lagoon territory it has also been developed the so-called practice of “vallicoltura”, which represents the interface between capture fisheries and common aquaculture: the early life stages are collected from the wild and grown using aquaculture techniques until they reach a marketable size (Provincia di Venezia, 1999; 2009; 2014a; Fortibuoni et al., 2014). There are several types of fish ponds (called here “valli da pesca”), which differ in the level of embankment, but all together refer to the same shallow structure in different ways separated from the open lagoon (Bullo, 1940; Boatto & Signora, 1985; Ardizzone et al., 1988; Ravera, 2000; Granzotto et al., 2001; Cataudella et al., 2001).

According to Mason & Gos (2015) there are 27 Valli covering an area of 12.000 ha (150 Km² as per Solidoro et al., 2010) (fig. 12), with many of them practicing the canonical and remunerative extensive breeding of grey mullets, sea breams and sea basses (plus a limited production of eels and crabs). Those areas are mainly situated between the south-central west part and the far north, while the bulk of clam harvesting concessions lies in the central part and Chioggia surrounding area (fig. 12). The 2005-2015 average production has been estimated by Mason & Gos (2015), of about 23.000 t/year (Philippine clams) and 2.000-2.500 t/year of mussels.

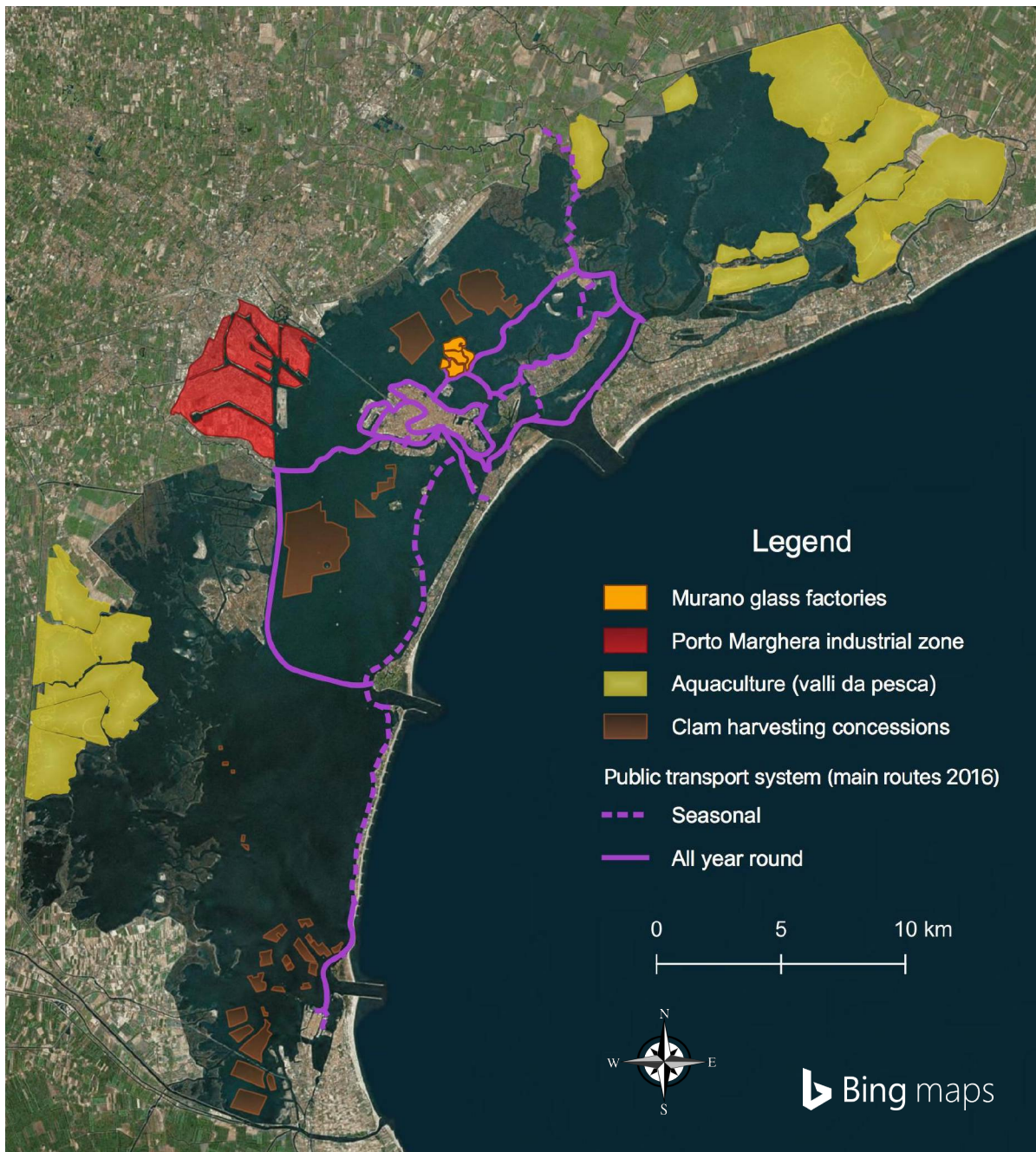


Fig. 12. Representation of Porto Marghera industrial Zone, Murano glass factories, clam harvesting concessions, aquaculture areas and main public transportation routes. Data retrieved and adapted from Geoportale regione Veneto. Produced using QGIS on Microsoft Bing Maps.

4.2.4 Land-Based Industry and Municipal Services

No analysis can be done without taking in account the outcomes of heavy and manufacture industries. Venice particularly, has a long history of factories which in the 1970s accounted for 80% of the Italian chemical industry (Beretta & Terrenghi, 2016). The most important industry centre is undoubtedly the inland area of Porto Marghera (fig. 12), a site of national interest (SIN) which has in 2018 celebrated its 100-year anniversary. After World War II, many petrochemical companies started in the area and began to dredge channels, re-using the sediments (with its processing waste) to form new territories, raising the land close to the Lagoon. These raised areas have then formed the 8 macro-islands inside Marghera industrial pole (Osservatorio Porto Marghera, 2013). The total extension of the area is about 2000 ha, with 340 ha of water channels, 841 factories hosting 10498 workers in 2017 (Porto Marghera website).

Displayed in tab. 4, the predominant sectors are nowadays manufacture and advanced tertiary. Recently has been noticed the growing presence of the logistic and transportation services as well as new enterprises connected to the green economy (e.g. Green refinery promoted by Eni). These more sustainable industries, account nowadays for 80 companies.

Tab. 4. Sectors, companies and number of employees in 2016 in Porto Marghera. Data retrieved from Regione del Veneto (2014).

Sector	Number of companies (2016)	Employees (2016)
Mineral extraction	1	5
Manufacture	114	3976
Energy, water, wastes	26	862
Construction	55	360
Commerce	94	368
Transportation and Logistics	184	1773
Advanced tertiary	290	2359
Services	75	793
n. d.	2	2
TOTAL	841	10498

As Explained by Interreg Central Europe (2016), the main Activities involved in the waste collection and treatment are in Porto Marghera. Here there is an environmental platform called “SG31”, which include a treatment chemo-physical-biological plant (TAS) and a sludge incinerator (suspended since 2012), both receiving the wastes from petrochemical plants (Arkema, Versalis, Solvay, SAPIO). With a small dock connecting the waste boats coming from the lagoon, Ecoprogetto Venezia S.r.l. direct the “Stazione di Travaso del Polo Integrato di Fusina” (11.100 m²) where wastes are stoked before being sent to the plants. There are 2 plants of combustible production from wastes

named “CDR1” (in activity since 2002) and “CDR2” (since 2010), both working on a maximum load capacity of 267000 t /annum. Interreg Central Europe (2016) continue to reveal that 53% of the remaining materials is then send to the Enel thermoelectric plant “Andrea Palladio” situated in Fusina, substituting in this way 5% of the coal utilized for energy production, with an energy efficiency of 38%. This process avoids the overload of landfills in Venice (fig. 13). Another waste facility is the “RTN – VERITAS wastes plant of Fusina”, which is permitted to discharge many, special, dangerous or non-dangerous materials, such as the polluted soils dredged in the lagoon. Veritas group (the public society for environmental management) manage also the city’s wastewater treatment plants, fig. 13.

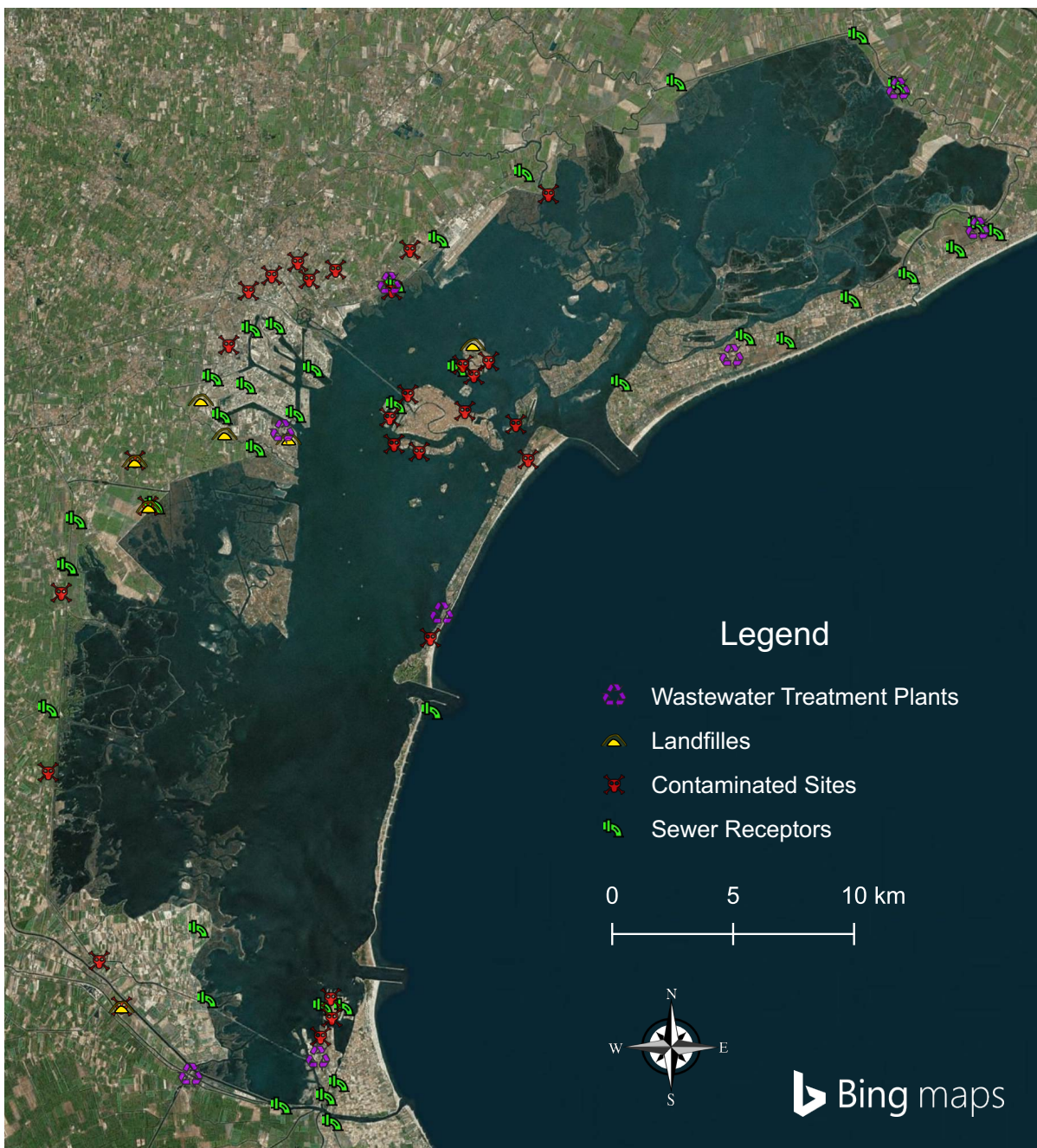


Fig. 13. Venice lagoon with its wastewater treatment plants, landfills, many contaminated sites and many sewer receptors displayed. Data retrieved and adapted from Geoportale regione Veneto. Produced using QGIS on Microsoft Bing Maps.

Moving northward, another important land based industry is on Murano island (fig. 12). This industry account for 81,8% of the total island activities in 2005 (Murano glass district website) and according to Rossini et al. (2010), there were here between 80 to 100 glass factories while about 200 involved in secondary activities such as glass-blowing, engraving, decoration and trade. Artistic glass manufacture entails exposure to complex mixtures of pollutants (Apostoli et al., 1998; Scalet et al., 2006) coming from the utilized raw materials such as silica sand, borax, carbonates, nitrates or oxides (Rossini et al., 2010). Within the lagoon territory, Giusti & Zhang (2002) found high levels of trace elements in marine waters, sediments and mussels, probably influenced from Murano's atmospheric emissions (Rampazzo et al., 2008). Other contaminated sites are displayed in fig. 13.

4.3 PRESSURES

Many disturbances will be here listed and discussed, splitting them in Endogenic Managed Pressures (EnMP) and Exogenic Unmanaged Pressures (ExUP) as suggested in Elliott (2011). Those indicators are then conveyed within common categories of Pressures. Natural phenomena and hazards (such as floods, erosion patterns or subsidence) will be considered to different extent in both sections, sometimes exacerbated by human Activities while others enhanced by global environmental changes. In fig. 14 are listed the Activities responsible for each EnMP and ExUP (and therefore for each Pressure) described in this chapter.

4.3.1 Endogenic Managed Pressures (EnMP)

In the last century the lagoon system has been exposed to many anthropogenic disturbances. discharge of pollutants and nutrients from industrial and urban areas or agricultural Activities carried out in the basin have not always been regulated as now (Cossu & De Fraja Frangipane, 1985). Aggressive fishing methods (e.g. mechanical clam harvesting) has furthermore caused a trophic chain modification, with the side effect of further spreading pollutants previously submerged and stabilized under the anoxic sediment layer, which when dragged, are subsequently suspended (e.g. Libralato et al., 2004; MAV, 2010; Solidoro et al., 2010). Similar outcomes have been noticed by the excavation of channels or maritime traffic, which impacts the lagoon morphology by creating sediment resuspension, erosion and currents modifications (e.g. D'Alpaos, 2013; Rapaglia et al., 2015; Cavraro et al., 2017). Other pressures here discussed concern land based Activities or agriculture Activities, which often influence the basin water quality (e.g. Carrer & Leardi, 2006; Zonta et al., 2007; Gieskes et al., 2015; Teatini et al., 2017) as happen with the fallout of air pollutants miles away from their original source (e.g. Guerzoni et al., 2007; Rossini et al., 2010).

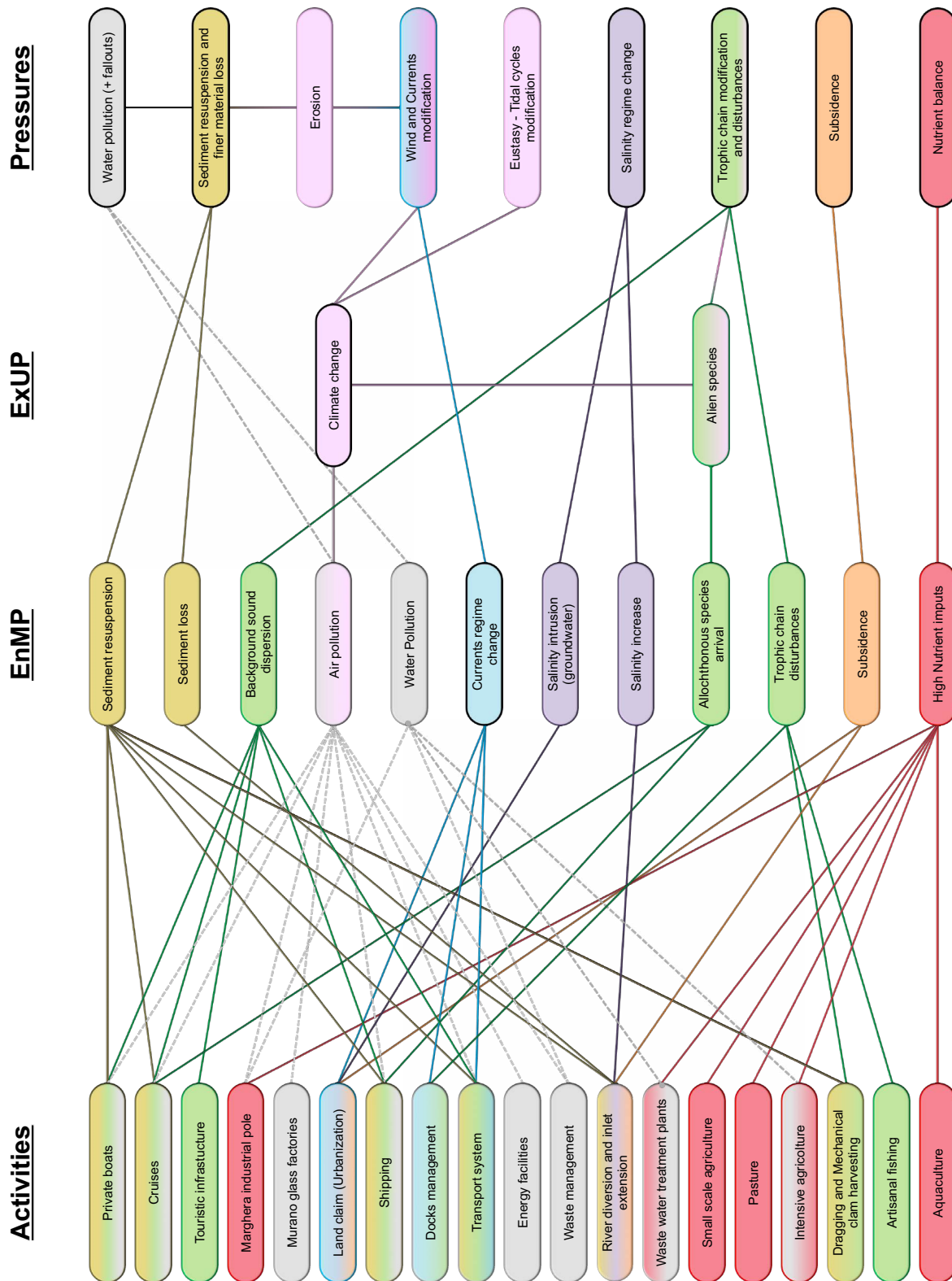


Fig. 14. Connections between Activities, EnMP, ExUP and pressures. Colors represent categories falling under the same type of pressure, while the grey dotted line represent water and air pollution connections.

4.3.1.1 Fishing Disturbances

When fishing efforts increase, if not carried out sustainably, it is mostly likely to produce a trophic chain disturbance. The main global effect is described as Fishing Down the Food Web (FDFW) (Christensen, 1996; Pauly et al., 1998), meaning a top predators and susceptible species

diminishment, which in turn change the fish community composition in favour of faster growing and smaller sized species. Consequently, species which belong to lower trophic levels become target of the fishing activities, impacting every other ecosystem process. In the Lagoon this modification has been noticed by Libralato et al. (2004), but their findings suggest an exclusion of overfishing as a trigger.

In accordance with them, the reason behind the landings variation could be some background changes of the fishing industry (e.g. fishing grounds, fishing gears, market-driven shifts). It has been considered, above all, the indirect effects of the mechanical clam harvesting, which have produced a great impact on the benthic community structure, producing in the medium-term a loss of more fragile species (Pranovi et al., 2004). Coupled with the constant fishing boats passage, those techniques affect the resistance of the surface sediments to erosion, reducing the bed shear strength and modifying the lagoon morphology. This could also have happened indirectly by disturbing or removing biological components (and in general the establishment and succession of biological communities), therefore influencing sediment biostabilisation (Aspden et al., 2004; Sfriso et al., 2005). The removal of the oxidised surface sediment could also have been an obstacle for suspended infaunal organisms, which after the passage of the gear try to penetrate underground.

Nevertheless, the main issue of those techniques is undoubtedly the redistribution of organic carbon buried into the sediments, followed by the further spreading of suspended particulate matter (SPM), which have the potential to change the sediment grain size and all the biogeochemical processes (e.g. Provincia di Venezia, 1999, 2009). Nutrients and pollutants, previously buried, can then increase contamination, promote phytoplankton blooms and hypoxic events (Newell et al., 1998). As explained in Pranovi et al. (2004), within the Lagoon water turbidity has increased since the 1990s, affecting primary production (both in the water column and sea bottom) and erosion rates.

4.3.1.2 Dredging and Excavation Impacts on Morphology

Channel dredging and excavation practices has led to a strong and wide environmental deterioration, by changing the flushing efficiency of the channel systems and aggravating salinity stratification (e.g. Teatini et al., 2018). Additionally, the re-suspension of fine sediments (Carniello et al., 2016), have synergically contributed with the ship traffic (e.g. Scarpa et al., 2019) and the mechanical clam harvesting of the 1995-2010 (Provincia di Venezia, 2014a), to the pollution spreading and eutrophication.

Channels excavation and maintenance, especially regarding the Malamocco-Marghera channel, as explained by Molinaroli et al., (2009), has heavily modified the hydrodynamic conditions, completely changing saltmarsh distribution and bottom features such as texture, grain size, depth, and erosion rates (Ferrarin et al., 2012). To allow the passage of larger vessels (Bellafiore et al., 2018),

the average depth of the mouths has been extended since 1901 from 7.5 to 12 m in Lido, from 9.5 to 17 m in Malamocco and from 4 to 9 m in Chioggia (Testa, 2011). This modification has increased the amount of seawater entering the Lagoon, which coupled with the diversion of many rivers (e.g. the river Sile in the northern basin represented in fig. 11) (Grydehøj & Casagrande, 2019), it has further enhanced the salinization process and erosion rates. The additional sediments one time available to counter the erosion phenomenon is in this way disappeared (di Silvio et al., 2011).

The industrialization era increased the need for water, therefore many wells were drilled with perforations reaching the deep confined artesian aquifers at 300 m depth. As explained by Beretta & Terrenghi (2016), between 1950 and 1970, withdrawals caused the water table to drop by 13 m in the Porto Marghera area, leading to 14 cm of subsidence. Even though this partially natural phenomenon has been reduced in the 1970s (when Venice Municipality started the construction of a new aqueduct outside of the area, closing the artesian wells) it is still happening (Tosi et al., 2018).

4.3.1.3 Water and Air Pollution

Subsequently the first environmental legislative tools, in the 1970s the Italian chemical company Montedison has been carried out many monitoring activities, focusing especially in the lagoon central part (Pastres & Solidoro, 2012); since then, it has been discovered in many areas, both water and air pollutant values far beyond the legal limits. The high pollutant load exceeds the natural water regeneration (from tidal regime and currents), fundamental to return the concentration levels comparable of sea water (Guerzoni & Raccanelli, 2003; MAV-CVN, 1999).

Marghera industrial area is the main source of soil and water pollution since the 1950s (Zonta et al., 2007), with its pollutants transported long distances seaward even through the groundwater flow (Gieskes et al., 2015). This phenomenon is called submarine groundwater discharge (SGD), and although naturally should provide fresh-water inputs into the coasts (Rapaglia et al., 2005), it is now seen as the main transport system for nutrients and other contaminants even elsewhere (Santos et al., 2008; Rocha et al., 2016). This event is made possible by natural erosion or channel excavations, which implicate the removal of a silty-clayey layer (at 10-40 m) permitting the leakage of salt water and pollutants into groundwater, otherwise blocked (Teatini et al., 2017). The effect is related to ships transit, which not only have the potential to spread pollutants away, but also to produce a depression wake on the order of 1 m (Bellafiore et al., 2018), able to pump out the groundwater from the shallow deposits around the excavation (Rapaglia et al., 2015), thus permitting seawater intrusion. Indeed, it has been already found between Venice and Chioggia groundwater at 5-15 m depth with a salt content similar to marine waters (Teatini et al., 2017), because of the leakages which, according to Beretta & Terrenghi (2016), has contribute to the loosing of about 36% of a total of 58.5 m³/year of potable water. On the other hand, inland territories have experienced seawater intrusion as a natural

phenomenon for many years (Benvenuti et al., 1998), with an advancement of 20 km and 100 m depth (Tosi et al., 2007).

Sediments here act therefore as a sink for hazardous and nutrients, but also as a long-term source being redistributed through groundwater and moved in other environmental compartments. Many authors have outlined the extent of the contamination in both surficial and core sediments of the industrial channels and the Lagoon, relative to heavy and trace metals, polychlorinated biphenyls (PCBs), dibenzo-*p*-dioxins (PCDDs) and dibenzofurans (PCDFs) (Argese et al., 1997; Fattore et al., 1997; di Domenico et al., 1998; Bellucci et al., 2000; Frignani et al., 2001; Wetzel & Van Vleet, 2003; Volpi Ghirardini et al., 2005; Carrer & Leardi, 2006; Zonta et al., 2007). Particularly, while mean dioxin and HCB values were much higher in the channels of the industrial zone, comparable PCB values were found in both industrial and city centre channels, and were three times higher than the general lagoon data (Guerzoni et al., 2007). Since the 1980s, with the closure of many old plants, the improvement of both manufacturing technologies and waste treatment, there has been a strong metal flux reduction (particularly Hg from chloralkaline plants and Ba from production processes), which were discharged in great quantities in the Lusore-Brentelle channel. Other typical contaminants of the 1st Industrial Area (from the 1920s and lasted till the 1970s–1980s) are As, Cd, Pb, and Zn while Ag come from mainly urban inputs (Bellucci et al., 2009).

Another source of pollution it is produced by the drainage basin (Collavini et al., 2005) and its agricultural areas (approximately 185,000 ha), with rivers carrying downward nutrient loads from nearby cultivated fields of 4000 tN/yr and 200 tP/yr (Cossarini et al., 2009). Discharges limits have been then fixed by applying EQSs since 1998, when many monitoring stations located at the mouth of main rivers systematically measure arsenic, cadmium, chrome, mercury, nickel, and lead to meet the regulatory obligations (Soccio et al., 2018). Even when carried out on small-scale, superficial runoff has already been proved to determine an enrichment of chemicals (e.g. pesticides) and nutrients in creeks water coming from the nearby fields (Regione Veneto-ARPAV-MAV, 2013). Despite this, as explained by Solidoro et al. (2010), after the total ban of phosphorus from detergents in 1989 and the construction of wastewater treatment plants, the lagoon has experience a trend reversal of phosphorus load (halved from 1950), besides the still existent pressure on the environment (e.g. Zarra et al., 2008; Hao et al., 2019). Nitrogen loads on the other hand has started decreasing since the 1990s (now comparable to those of the mid-1960s), due to the introduction of nitrification and denitrification processes in the major treatment plants, closure of fertilizer factories and improved agricultural fertilization practices. For a full assessment of the most relevant environmental parameters (including nutrients) and how they have changed since the middle of the last century it is recommended a read to Sfriso et al. (2019) and the references therein.

Besides industrial and agricultural Activities, as explained by Guerzoni et al. (2007), the Lagoon is subjected to other wastewater and several pollutants coming from:

- Venice and Chioggia municipalities, which have an insufficient sewage network (1,500 million m³/year from 2000 to 2008 as per MAV, 2011), and water treatment facilities;
- commercial ships, which directly discharges into the Lagoon wastes deriving from incomplete fuel combustion, including leakage of hydrocarbons and slow release of antifouling paints (Testa, 2011).

In addition to the water quality issues, many authors (e.g. Guerzoni et al., 2007; Rossini, 2010; Morabito et al., 2014) underline the large presence atmospheric pollutants, which after being emitted in atmosphere can be then transmitted to marine biogeochemical cycles following “wet” or “dry” deposition methods (Zannetti, 1990). The industrial area of Porto Marghera (with its oil refining, metallurgy, chemical plants, power generation plants, urban waste incineration), the many urban areas, glass factories, the Marco Polo airport and ship traffic are responsible for this significant anthropogenic emission. Even though the Lagoon has been subjected to further environmental Pressures related to the construction of the MOSE (Modulo Sperimentale Elettromeccanico—Electromechanical Experimental Module) mobile dams, one for each inlet connecting the Lagoon to the Adriatic Sea, its atmospheric depositions appears strictly limited to the construction area (Morabito et al., 2014).

Loadings of metals into the central lagoon (particularly Cd and Pb) has been found in soils around Marghera by Scazzola et al. (2004), while Rossini (2010) further expanded the fall-out deposition zone, outlining two areas of about 78.5 km² around Murano and Porto Marghera. Their findings suggest higher concentration of As, Cd, Sb, Se and Zn in the whole historic city centre of Venice compared to Porto Marghera values, while Cr, Cu, Ni and Pb loadings were similar comparable. Differently from natural ubiquitous elements such as Na, Mg, K, Ca, Si, Al, many other metals can be distinguished depending on their anthropogenic source: emissions by coal combustion typically include As, Se, Cd, Pb, Sb, Se, Cr, Co, Cu, Ga, Mo. V, Ni, Pb on the other hand means oil combustion, with ship traffic emissions traced by V and Ni; Cu, Zn, Pb, and Sb are associated with road traffic emissions (Guerzoni et al., 2007; Morabito et al., 2014) while As and Cd are typical elements released from glass factories (even though today As has been frequently dismissed).

In addition to heavy and trace metals, and the newly discovered fragrances (Vecchiato et al., 2016), there is growing attention to discover persistent organic pollutants (POPs), such as dioxins, polychlorinated biphenyls (PCBs), hexachlorobenzene (HCB), and polycyclic aromatic hydrocarbons (PAHs) (e.g. Cassin et al., 2018). Those classes have been described in other terms as “semivolatile organic compounds” (SOC), because they are transported in the atmosphere and later deposited. It is

well known their bioaccumulation effects in the food web (even though not always representative of the real contamination state as in Ademollo et al., 2017), posing a risk to human health as well as to the whole environment (Radomyski et al., 2016; Giubilato et al., 2016). These compounds are persistent and ubiquitous in the environment because they are always produced mostly during incomplete combustion of fossil fuels and wood from sources like residential heating, open burning, coke and aluminium production, and vehicle exhausts.

Nevertheless, Sommerfreund et al. (2010) found that the bulk of contaminants originated in the lagoon central basin remain in the northern and central sediments, without fully reaching the south, where the pollutants mostly come from local tributaries (e.g Cuori channel as per Soccio et al., 2018).

4.3.2 Exogenic Unmanaged Pressures (ExUP)

4.3.2.1 Climate Change

Coastal ecosystems are worldwide subjected to the heavier consequences of climate change (Harley et al., 2006; IPCC, 2014; Elliott et al., 2019). The projected rise of temperatures, as explained in IPCC (2018), have the potential to raise the sea levels, produce acidification, alter the atmospheric systems, and produce many other cascade outcomes. Besides some uncertainties (Freer et al., 2018), the projected outcomes could modify the whole coupled natural and human systems (e.g. Cheung, 2008).

As for the Venice Lagoon system, this environmental Pressures will produce many detrimental effects, some of them listed in in Pesce et al. (2019), where general trends and uncertainties are described. Due to the groundwater withdrawals, natural subsidence and eustatism (by 1.5 mm/yr between 1972 and 2002 as per Solidoro et al., 2010), right now Venice city centre (similarly to most of the lagoon) has lowered of about 23 cm (3 cm of natural subsidence, 9 cm of anthropogenic subsidence, 11 cm of sea level rise (Carbognin et al., 2005) (fig. 15). As reported by Scarascia &

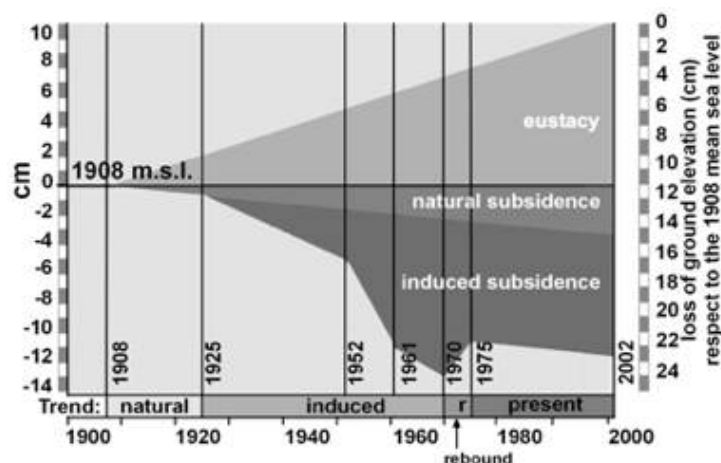


Fig. 15. Graphical representation of the three components causing the lowering of Venice (see text). Retrieved from Carbognin et al. (2005).

Lionello (2013), sea level will rise in the Adriatic Sea further 14–49 cm by the year 2100. This process, however, could differ from the predictions, because of the enclosed lagoon area which behave differently from the Adriatic Sea, which itself differ from the semi-enclosed Mediterranean Sea compared from global predictions (Carbognin et al., 2010). Still, it is predicted a substantial increase in flooding events of 110 cm a.d. or more by 20–250 times per annum (nowadays far less) in a city always been subjected from floods, called “acqua alta”, which result from tides, seiches, and easterly winds.

The main ecological Pressures on coastal ecosystems due to climate change, include the many predicted evidences of the phytoplankton modifications (Cloern & Jassby, 2008; Huertas et al., 2011; Harding et al., 2015; Holt et al., 2016; Pesce et al., 2018) but also related to the bivalve farming (Tan & Zheng, 2020). Furthermore, because of the projected rise in the Mediterranean of surface water temperature by an average of 3.1°C by the end of the 21st century (Somot et al., 2006), is expected a fish assemblages shift northward, with the replacement of temperate and cold species. Pranovi et al. (2013) found that semi-enclosed areas such as the Venetian Lagoon, could act as reservoir for local species or become the northern limit for species that cannot further migrate. This idea underlines how there will be a high vulnerability of artisanal fishery to climate change.

4.3.2.2 Alien Species

Besides being a global leading hotspot for biodiversity, the Mediterranean Sea has experienced many biological invasions (Nunes et al., 2014) since the opening of the Suez Canal (Zenetos et al., 2012; Katsanevakis et al., 2013) and the first effects of climate change (Occhipinti, 2007; Lejeusne et al., 2010; Elliott et al., 2015). In Venice, the central activities related to those pressures are aquaculture, while shipping always plays a central role (Katsanevakis et al., 2014) after the growing intercontinental traffic. Many studies have been carried out in the Venice lagoon trying to assess the extent of such Pressure on the environment (e.g. Occhipinti, 2000; Boudouresque et al., 2011), with its negative (Shiganova et al., 2001; Grosholz, 2002; Wallentinus & Nyberg, 2007; Molnar et al., 2008; Vilà et al., 2010) and positive (Schlaepfer et al., 2011; Simberloff et al., 2013) effects.

The highest number of marine aliens in the lagoon has been found by Occhipinti et al. (2011a; 2011b): 39 species, including 12 algae, 9 molluscs and 9 crustaceans. Out of them the seaweeds *Undaria pinnatifida* and *Sargassum muticum*, invertebrates such as the bryozoan *Tricellaria inopinata* (Occhipinti, 2000) are the species with the highest established populations. Conversely, other species (e.g. the squids *Stoloteuthis leucoptera* and *Cycloteuthis sirventi* in Bello, 2008) have displayed a natural range expansion, therefore has not been listed as alien. An extensive comparison between previous and current seaweed species records has been done by Sfriso et al. (2007).

4.4 STATE CHANGE

All the described pressures on the environment has the potential, to different extents and often acting synergically, to strongly modify the whole lagoon system. These changes are sometimes difficult to be singularly assessed, because many elements can act as pressure for other changes. Nevertheless, it will be discussed this section dividing between abiotic and biotic changes on the “marine” ecosystem. In fig. 16 are then listed the relationships between State changes and Pressures previously described, focusing on the components and processes modified on the natural environment. Pressures related to the pollution, which could have later created negative outputs on society, have been conveyed into the ecological shifts because of the ecological-focus of the framework, the lack of Measures to cope with them and the lack of environmental indicators to assess them. In the next chapter (4.5), the same categories here presented will be further described in an ecosystem services context, adding to the “marine” ecosystem the intermediate and final ecosystem services to follow the discussion proposed by Elliott et al. (2016).

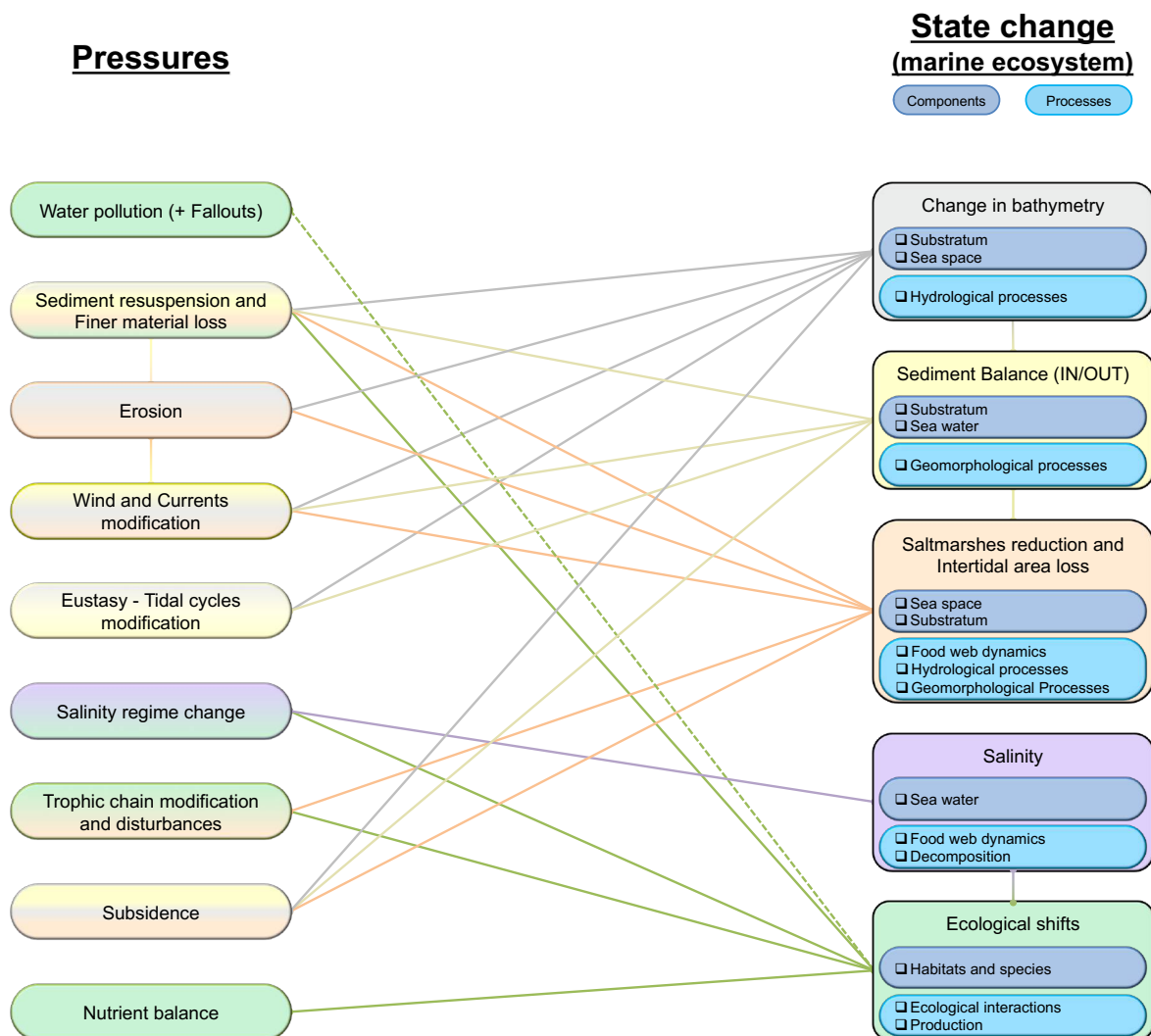


Fig. 16. Connections between Pressures and State changes (on the “marine ecosystem”). The dotted-line represent the outcomes of water pollution, which has been conveyed into the ecological shifts (see text).

4.4.1 Abiotic changes

During the past century, the Lagoon has been heavily modified by all the elements pictured in the above discussion. Thus, the morphologically complex microtidal lagoon of the 1930s, has been modified firstly into a subsidence-dominated and sediment-static lagoon of the 1970s and then into the flatter-bottomed bay-like of today. Nowadays the lagoon morphology, with its high depth of both channels and beds, exchanges too much water with the sea, leading to salinization and weakening the estuarine environment. Furthermore, it will be year by year more subjected to climate change (Day et al., 2019).

During the 20th century, worldwide saltmarshes extent has decreased (Airoldi & Beck, 2007; Fagherazzi, 2013), as happened in Venice from 149 km² in 1912, to 68 km² in 1927 and 37 km² in 2003 (approx. 75% were lost) (Silvestri et al., 2003). As previously explained, saltmarsh habitats in lagoons are fundamental to provide many resources in a competition-limited habitat (Koutsogiannopoulou & Wilson, 2007; Maci & Basset, 2009), due to the high productivity by itself and the limited species specialized to live with variable physio-chemical water characteristics (Elliott et al., 2007).

In accordance with De Nat (2010), their reduction has happened mainly due to land-claim, dredging, pollution, ship traffic, aquaculture, which have cause in turn anthropogenic-induced erosion, subsidence and sea level rise (Rizzetto & Tosi, 2011; Bock et al., 2012; Kirwan & Megonigal, 2013), acting together due to lower income of sediments coming from inland and weakening the saltmarshes margins. D'Alpaos (2013) suggests furthermore that the reduction could be also driven by wind wave-induced resuspension and erosion processes on the bio-morphodynamic evolution of the tidal landscape. The only significant amount of sediment come from the northern basin (e.g. Silone, Dese and Osellino rivers), which account for approx. 46% of the total riverine inputs, but they are insufficient to guarantee a substantial amount of suspended matter to counterbalance the erosion, especially because of their rapid settling (Zonta et al., 2001). Sfriso et al. (2005) estimated in a net loss of 1.2 million tons per year of sediment from the central basin, mainly due to a reduction of macroalgal biomass coverage and the spread of Manila clams which loosen the sediment (Tolomio et al., 1999; Facca et al., 2002).

Sarretta et al. (2010) suggest that this process has led to a progressive deepening of the Lagoon from 0.62 m in 1927 to 0.87 m in 1970 and 0.88 m in 2002, mostly due to the areal expansion of the deepest subtidal flats (0.75 and 2.00 m in depth) from 88 to 206 km² during 1927–2002. Although a compensation effect exists between the erosional southern part and the stable-depositional northern part, Sarretta et al. (2010) have found a net sediment loss of 0.3 Mm³/yr, with 70% of 110 Mm³ occurred during the historical channel dredging and 39 Mm³ lost from the Lagoon to the sea

throughout the inlets, at an annual average rate of 0.5 Mm^3 . The depth increase mainly affect the Malamocco sub-basin (0.64 to 1.75 m), while Chioggia has deepened from 0.39 to 0.88 m, and Lido, from 0.65 to 1.12 m. In Carniello et al. (2009) (fig. 17) those modifications are visualised, together with a prediction of 2050s expected values. They explain also how the degradation process consists of an initial saltmarsh deterioration phase and a subsequent tidal flat erosion phase, slower in the northern lagoon compared to the southern part.

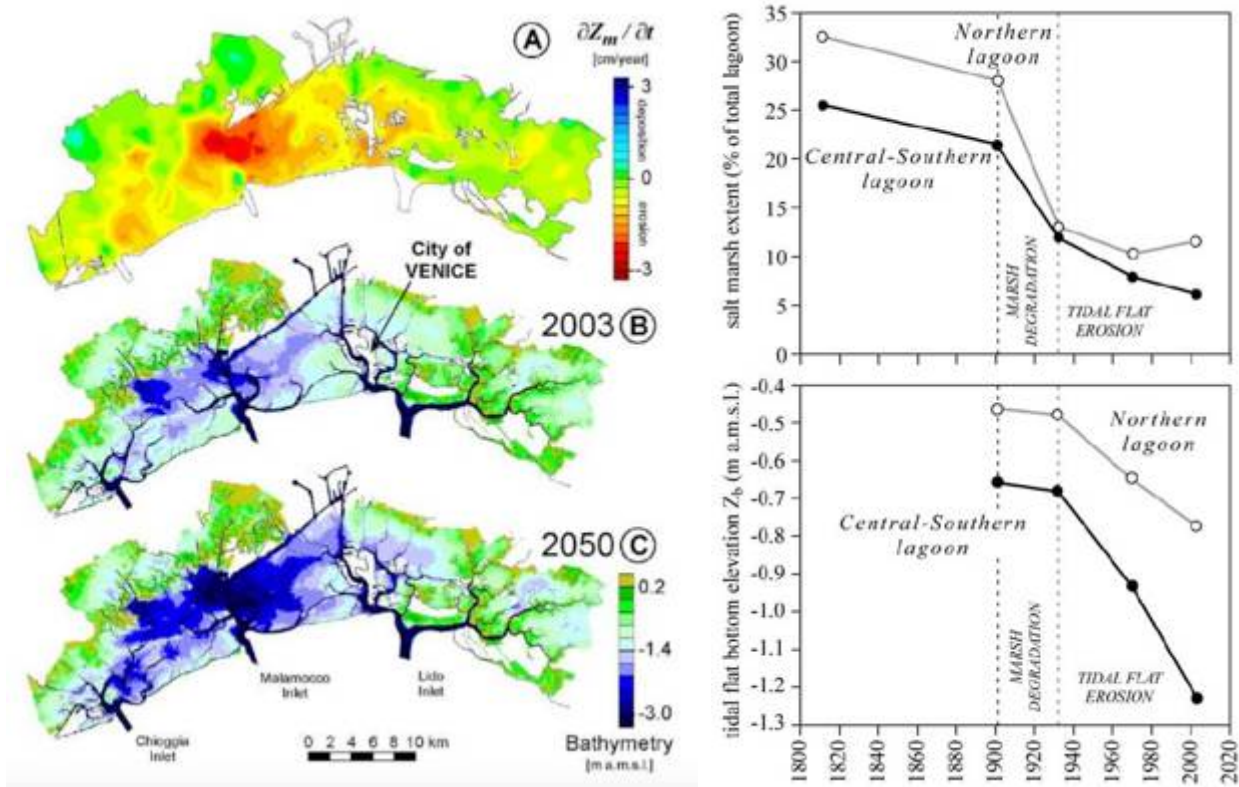


Fig. 17. Rate of bottom evolution for tidal flats (between 1932 and 2003) (A); bathymetry in 2003 (B); bathymetry in 2050 (C). Time variation in northern and southern part of salt marsh extent (top-right) and tidal flats average elevation (bottom-right) during the last two centuries. Retrieved from Carniello et al. (2009).

All these features act simultaneously with the solitary waves (depression wakes or Bernoulli wakes) associated to the passage of the many large vessels and small boats in the navigation channels, completely changing the hydrogeological system (Rapaglia et al., 2015). The current change produced increases every year due to the periodic maintenance of the channels and boats traffic, which have reduced secondary channels and create high degree of pollution and disturbance. Those disturbances (water diversion, deepening of the inlets, building of jetties and digging of new channels) have also resulted in higher intrusion of seawater, expanding the central mudflats habitats. Estuarine-like oligohaline habitats are therefore disappearing as noted by the replacement of brackish species with more marine ones, and a shift toward assemblages that are more tolerant of eutrophic conditions (since Giordani Soika & Perin, 1974).

4.4.2 Biotic changes

All the above morphological modifications have strongly affected the whole ecosystem, with consequences to all the trophic levels. This section indicates the outcomes of the different pressures on phytoplankton, seagrasses, crustaceans, molluscs and fish population. The ecological states are here represented using BQI (biological quality index) as formally expressed by WFD guidelines (Directive 2000/60/EC). Maps in fig. 18 (a-d) (ARPAV, 2018), have been produced from 2014 monitoring in 77 stations as per the zoobenthos index and M-AMBI (Borja et al., 2004; Muxika et al., 2007) (fig. 18a) and BITS (Mistri & Munari, 2008) (fig 18c), in 88 stations as per the MaQI (Macrophyte Quality Index) (Facca & Sfriso, 2009; Sfriso et al., 2009; 2010; 2014) (fig.18b).

Chlorophyll-a (chl-a), which is commonly considered a proxy of total phytoplankton biomass, usually follows seasonal patterns and their blooms mainly depends on nutrient concentrations (so related with rainfall and consequent river discharges). However, in the Venice Lagoon, it has been noted by Facca et al. (2002; 2004) a chl-a and phytoplankton cell abundance impoverishment between 1989 and 1999 (especially in the central part) not related to nutrient availability. Chl-a peak concentrations values decreased by 10–20 times (Sfriso et al., 2003), the mean values by 6 times in the central part of the lagoon (Facca et al., 2002), while it has been noted seasonal shifts in diatoms abundance, which increased 4 times (Sfriso et al., 2003). Solidoro et al. (2010) suggest that their diminishment happened because of a combination of bottom-up (e.g. resource limitation) and top-down (e.g. clam filtration) control, but the main cause was related to a reduction in light transmission, caused by the sediment resuspension (from 65 to 759 kg m² dwt in the central lagoon as per Sfriso et al., 2000) due to the Mechanical clam harvesting (Sfriso et al., 2004). The only temporary increase has been noted during a period with minor clam landings, and before and after *Ulva* blooms (Socal et al., 1999; Bianchi et al., 2000). Since the 1987 ($3.61 \pm 5.62 \mu\text{g}/\text{dm}^3$), nowadays chl-a mean values ($1.32 \pm 1.58 \mu\text{g}/\text{dm}^3$) seem to be highly reduced (Sfriso et al., 2019a)

An important ecological modification is indeed related to macroalgae and seagrasses. The whole area has experienced a massive growth of Ulvacea (mainly *Ulva rigida* but also *Ulva laetevirens*), which slowly replaced seagrass populations until the 1980s when massive blooms (higher density ranging from 10 to 20 kg fwt m⁻²) have been extensively recorded, leading to adverse effects on nutrient cycles in both the bottom sediments and the water column (Solidoro et al., 1997; Sfriso et al., 2003). This condition has subsequently led to many anoxia events, which in early 1990s (Sfriso & Marcomini, 1996) have progressively decreased until they have been no longer recorded (Sfriso & Facca, 2007) and the phanerogams *Cymodocea nodosa* and *Zostera marina* have enlarged their coverage, while *Nanozostera noltii* has strongly reduced it (from 4144 ha to 634 ha) (Solidoro et al., 2010). From the highest mean value biomass in late spring 1987 (4.78 kg fwt m⁻²), it decreased to

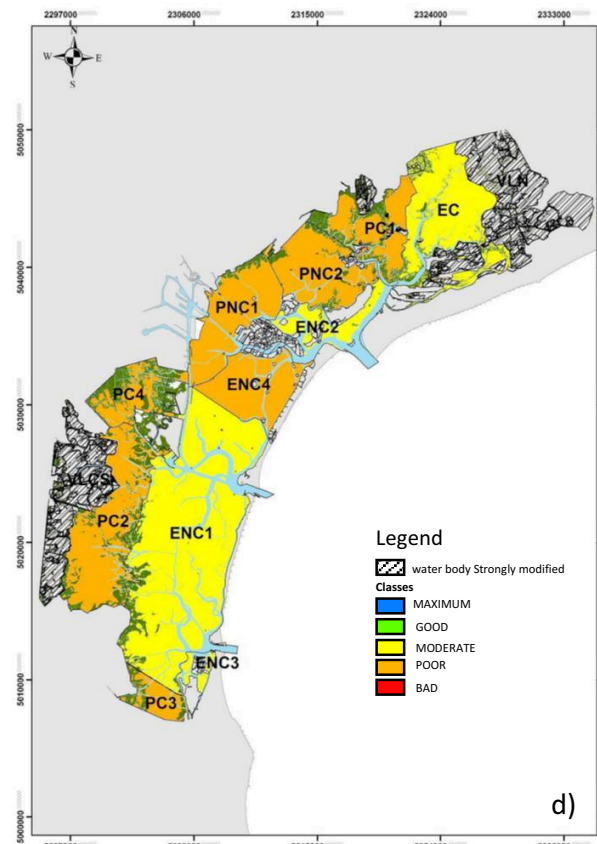
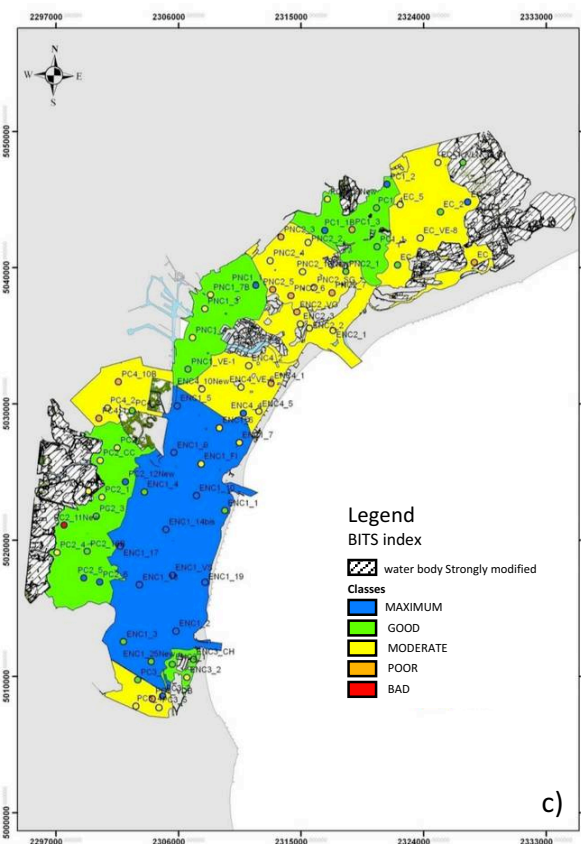
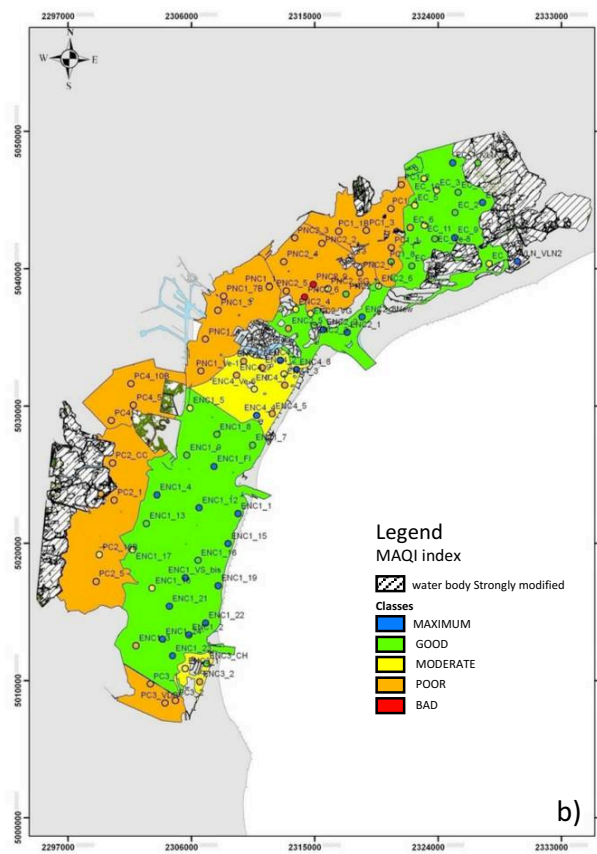
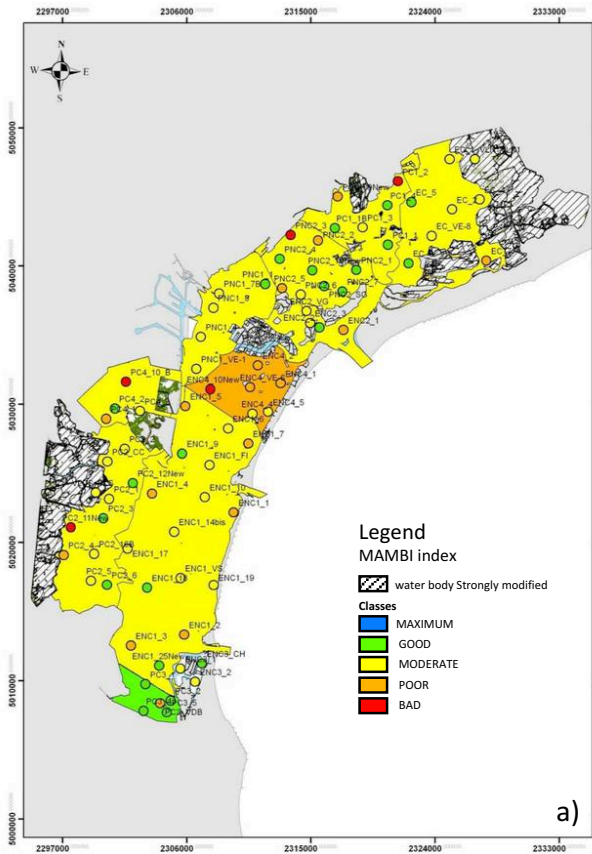


Fig. 18. Ecological states of Venice Lagoon applying MAMBI (a), MAQI (b), BITS(c) index. (d) has been produced using the lowest classes of MAQI and MAMBI, as expressed in WFD. Modified from ARPAV (2018).

0.69 kg fwt m⁻² in 1993, 0.11 kg fwt m⁻² in 1998, until 2014 when jumped to 1.05 kg fwt m⁻² (Sfriso et al., 2019a)

The Ulvacea occurrence has been likely favoured by eutrophication and the modification of hydrodynamic and morphological features, which in turn has impacted nutrient cycles and benthos. During the blooms, in late spring and summer, macroalgae beds covered shallow areas with low water movement causing nutrient impoverishment and starting anoxic events. Subsequently the green opportunistic alga *Ulva* mortality due to the oxygen deficit, the amount of decaying organic material increased, adding further oxygen consumption and worsening the anoxia (Sfriso et al., 1992; Solidoro et al., 1997). The decrease in shrimp and crab landings might also be related to this series of changes (Sfriso et al., 1992; Sfriso & Marcomini, 1996), together with a net decline in other seaweeds and phanerogams (Sfriso et al., 1987), with phytoplankton blooms experiencing in areas with low macroalgae and zooplankton density. Then, because of the firsts environmental projects (e.g. harvesting of macroalgae), the introduction of new environmental legislation (e.g. the phosphorus ban in detergents in 1989) and other factors (i.e. morphological works used to reinforce tidal lands or the ongoing oligotrophication of the lagoon), *Ulva* biomass strongly decrease during the 1990s. Thereafter anoxia events became episodic, enabling the zoobenthic community to exert greater control on *Ulva* biomass (Sfriso et al., 2019a).

Other 87 macroalgae taxa (54 Rhodophyceae, 25 Phaeophyceae, and 8 Chlorophyceae) have not been found in the lagoon in recent years, while other new alien species continue to be found replacing native species (Solidoro et al., 2010). Between them, *Sargassum muticum* and *Undaria pinnatifida* (introduced into the lagoon in the early 1990s) have a total biomass limited by the colonization of hard substrates and not soft, with impact on the ecosystem much lower than *Ulva* (Curiel et al., 2010).

An important reduction in benthos has been firstly found by Giordani Soika & Perin (1974) during the late 1950s to 1960s, with a shift in favour of tolerant assemblages and marine forms. With the dystrophic crises in the 1980s, herbivores and detritus feeders accounted for more than 55% of the total macrobenthic community biomass, while later, between 1995 and 2000, the community has shifted in favour of the stress tolerant and fast-spreading Manila clam (on average from 0.2 to 1 kg/m² as per Sfriso et al., 2003) (Pranovi et al., 2007; 2008),

Ruditapes philippinarum, an edible species introduced in the lagoon for economical purposes (Cesari & Pellizzato, 1985), following the reduction of *Ulva*, has spread throughout the area free of macroalgae (Sfriso & Marcomini, 1996; Sfriso & Facca, 2007), while its harvesting has strongly damaged macrophytobenthos, shifting the community toward infaunal species, losing fragile or less mobile species (Pranovi et al., 2007; 2008). Jennings et al. (2001) found that bivalve harvesting decreased infaunal and epifaunal biomass, although the biomass of polychaetes was unaffected,

suggesting that life strategies adversely affect the ability to survive to periodic disturbances, and therefore frequent fishing could select functional groups (Emmerson et al., 2001). Furthermore, because of the disturbance on the sediment beds and the subsequent increase of turbidity, the fishing activity has an adverse effect on light penetration and conditions for biofilm development (Sfriso et al., 2000; Pranovi et al., 2007). This pressure has also impoverished the sediment, because the clams are harvested after having already transferred organic matter from the water column in their tissues (Solidoro et al., 2010).

Nowadays, especially in the central lagoon, filter feeders are still important, with bivalves such as *Ruditapes decussatus* (autochthonous Carpet clam) which seems to have partially replaced the Manila clam areal (Spencer et al., 1997). Other species (e.g. *S. plana*) used to be very abundant, but have declined dramatically due to the freshwater input or the emission of pollutants which bioaccumulate (if bioavailable and bioaccessible) in the food chain (Pavoni et al., 1992; Raccanelli et al., 2004; Dalla Valle et al., 2005; Frignani et al., 2005; Micheletti et al., 2008), compromising metabolic activities and community diversity (Guerzoni & Raccanelli, 2004; Carrer et al., 2005; Guerzoni et al., 2007; Micheletti et al., 2008; Masiol et al., 2014). As a whole, a net increase in benthos has been recorded (Facca et al., 2002; Acri et al., 2004), even though species diversity decreased, with the lowest values recorded in 1999 (Solidoro et al., 2010).

4.5 IMPACTS (ON HUMAN WELFARE)

To understand the provision of goods and benefits for society, it is necessary to identify all ecosystem services (ES) and their interconnections, in order to draw a complete picture of the Impacts of State changes to human well-being (and therefore human Welfare). As expressed in Fisher et al. (2009), the ES can be seen as the link (the path) between ecosystems and services that humans benefit from, not the benefits themselves. In this way “the ecosystem services are the ecological phenomena” while “the good (benefit) is the realisation of the direct impact on human Welfare” (Turner et al., 2015), which can be achieved after adding in complementary assets and human capital such as money, time, energy and skills (Van den Belt & Costanza, 2011; Wolanski & Elliott, 2015). Both ES and goods and benefit can only be assessed by using a set of indicators to analyse the coupled human–environmental systems (Burkhard et al., 2012; Kandziora et al., 2012), in this work provided and extensively explained by Turner et al. (2015); ecosystem processes and functions are therefore here represented by intermediate and final services which lead to the realisation of the direct impact on human welfare (fig. 19).

In this section, all the ecosystem services/disservices and goods/benefits, are divided between provisioning, supporting, cultural and regulating services as suggested in MEA (2005), while the

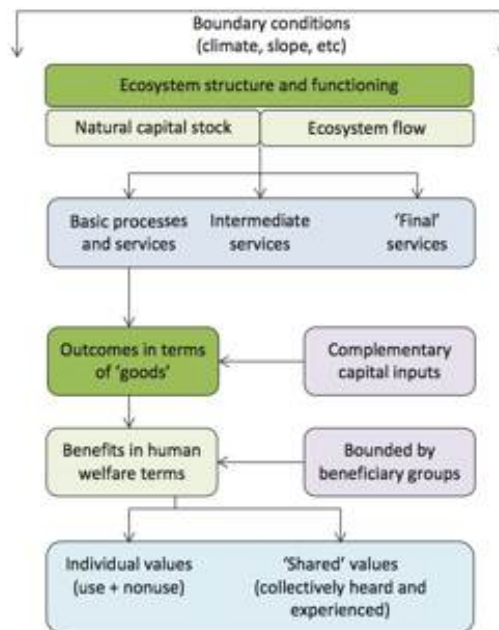


Fig. 19. Ecosystem services conceptual framework. Retrieved from Turner et al. (2015).

supporting services have been already mentioned in the previous section (4.4). The indicators, and therefore their geographical distribution, are based upon the works of Rova et al. (2015; 2019) and Rova & Pranovi (2017). It is important to underline how the ES discussed within the framework are listed as “negative Impacts” to the society and not as benefits gained from the environment; the meaning of each ES indicator does not change, but what happen in the DAPSI(W)R(M) framework is a reduction of the goods and benefits caused by adverse consequences of State changes, and not a provision from them. In the case of the Lagoon of Venice indeed, no benefit from the state changes has been discovered, besides the obvious outcomes (e.g. change in bathymetry) of certain activities (e.g. cruises industry) which have on purpose modified the environment and their ecosystem services to increase their dividends (e.g. by increasing the cruises traffic). Furthermore, no ES related on human health (e.g. Sandifer et al., 2015) has been taken into account. In fig. 20 are displayed State changes (extended to include the ecosystem services chain) and Impacts on human welfare (the detailed definition of the indicators could be found in Turner et al., 2015). Due to vast amount of connection between each element of the cascade, no additional arrow or deep description has been made to connect the single indicators, which have the potential to strongly influence each other because of the ecosystem services flow starting from the same ecosystem structure. In other words, the “ecosystem services cascade” (the path between S and I(W)) can be seen as a black block from where the “Marine ecosystem” directly produce its Impacts. In Turner et al. (2015) it is possible to better understand their complex and often synergic dynamics.

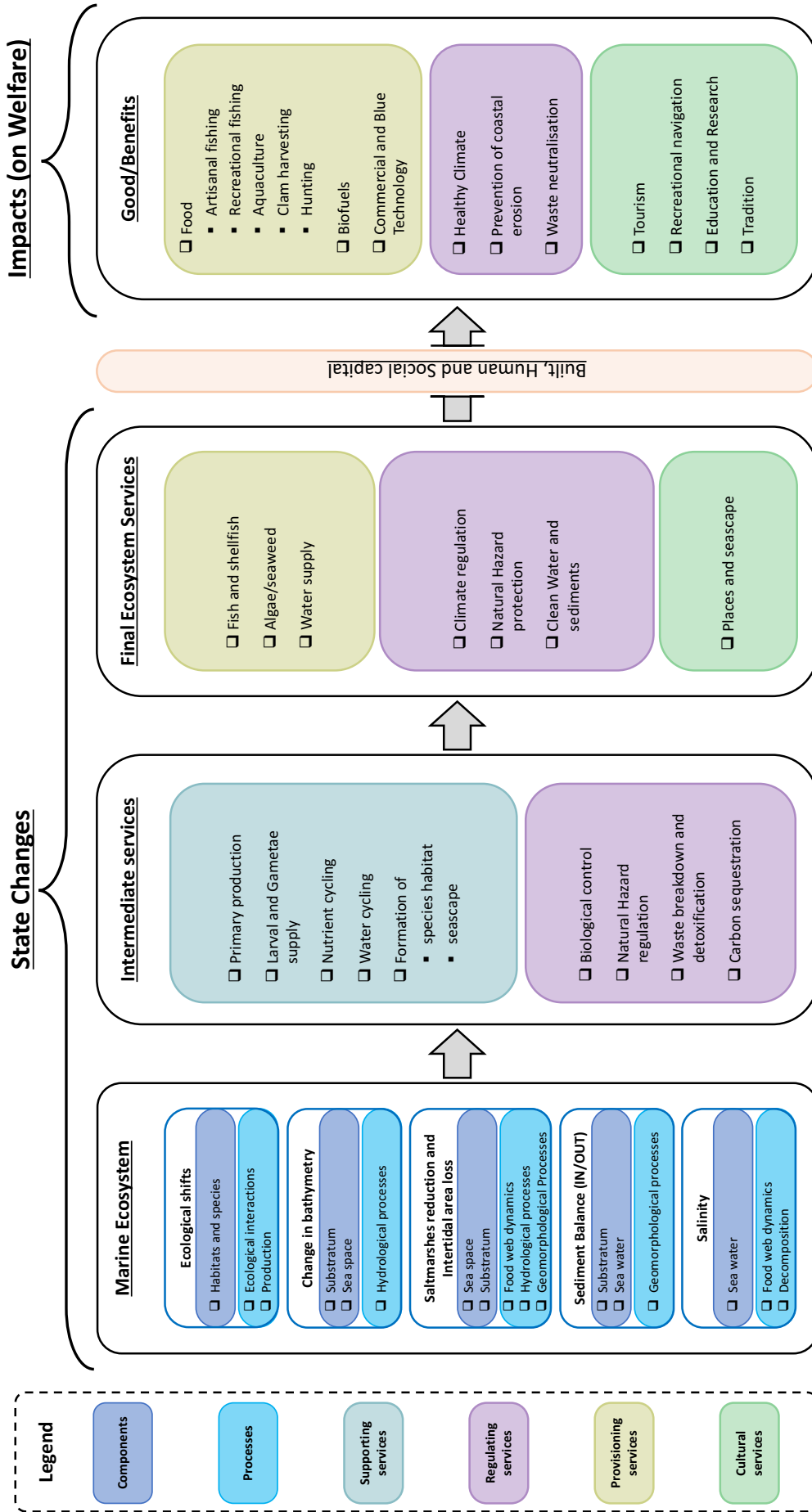


Fig. 20. S related to their (W) using indicators belonging to the original frameworks guidelines, mixed with Rova et al. (2015; 2019). As expressed in Elliott et al. (2017), S are here divided in “marine ecosystem” changes, intermediate services and final ES in order to produce goods and benefit for society by adding the built, human and social capital. Colors represent ecosystem components, processes and the different types of ES (supporting, regulating, provisioning and cultural services).

4.5.1 Provisioning services

All the State changes to different extent provide provisioning services because from every modification to the natural environment, the subsequent services for the food supply (and in general industries based on natural resources) are reduced (4.2.2). It is of note that a positive correlation between the index M-AMBI (Fig. 18a) has been found on the provisioning services by Rova et al. (2019), meaning a “linkage between the ES that directly depend upon fauna and the status of macro-invertebrates”.

In accordance with Pérez-Ruzafa et al. (2007) and Pérez-Ruzafa & Marcos (2012), the main factors explaining fishing assemblage composition are related to geomorphologic features (shallowness, coastline development, inlets extension and the connectivity with the open sea), hydrographic and partially trophic characteristics of the lagoon. Fishing yield on the other hand is strongly related to primary production, favouring the species abundance but not species richness, up to a point beyond which secondary productivity and fishery yields will decline (Oczkowski & Nixon, 2008), as it happened in the lagoon in the dystrophic crises of the 1980s (4.4.2). Therefore, it could be noticed in the provisioning service recreational fishery (fig. 21a) a preferred location close to the inlets, while in artisanal fishing (fig. 21b), how the most used areas stand in more confined areas, where fishermen are more accustomed to find their specific hunted taxa living in more eutrophic conditions. In addition to that, it is equally essential to underline the strong connection between the permitted designed areas, which heavily influence their localisation.

The provision of other services, such as related to the clam harvesting (fig 21e) and aquaculture (fig. 21d) (previously described in the activities section and here mostly overlaying them) are more connected to the governmental setting of the concession than on the proper ecological structure, but their productivity with the surrounding environment (Gaglio et al., 2019). However, Rova et al. (2015) found that they are strongly underused due to their coexistence of other activities (e.g. hunting farms).

Anyway. due to State changes previously described, all those ES could be seen at risk. It is of note that a lack of maintenance of a healthy S poses at risk the coupled land-marine system as well, impacting the presence of different types of seabirds. Hunting in Venice Lagoon is undoubtedly an important source of ecological disturbance, but on the other hand the preservation of games Activities, as often but not always happen (e.g. Knezevic, 2009; Gallo & Pejchar, 2016; Barca et al., 2016), has the potential to help and fund many conservation activities.

Other services have minor impacts, and therefore have not been displayed, but it is important to mention the recent use and growing of algae as biofuels and for commercial purposes, due to the expected role they could have in future. The only known society which have planned to produce

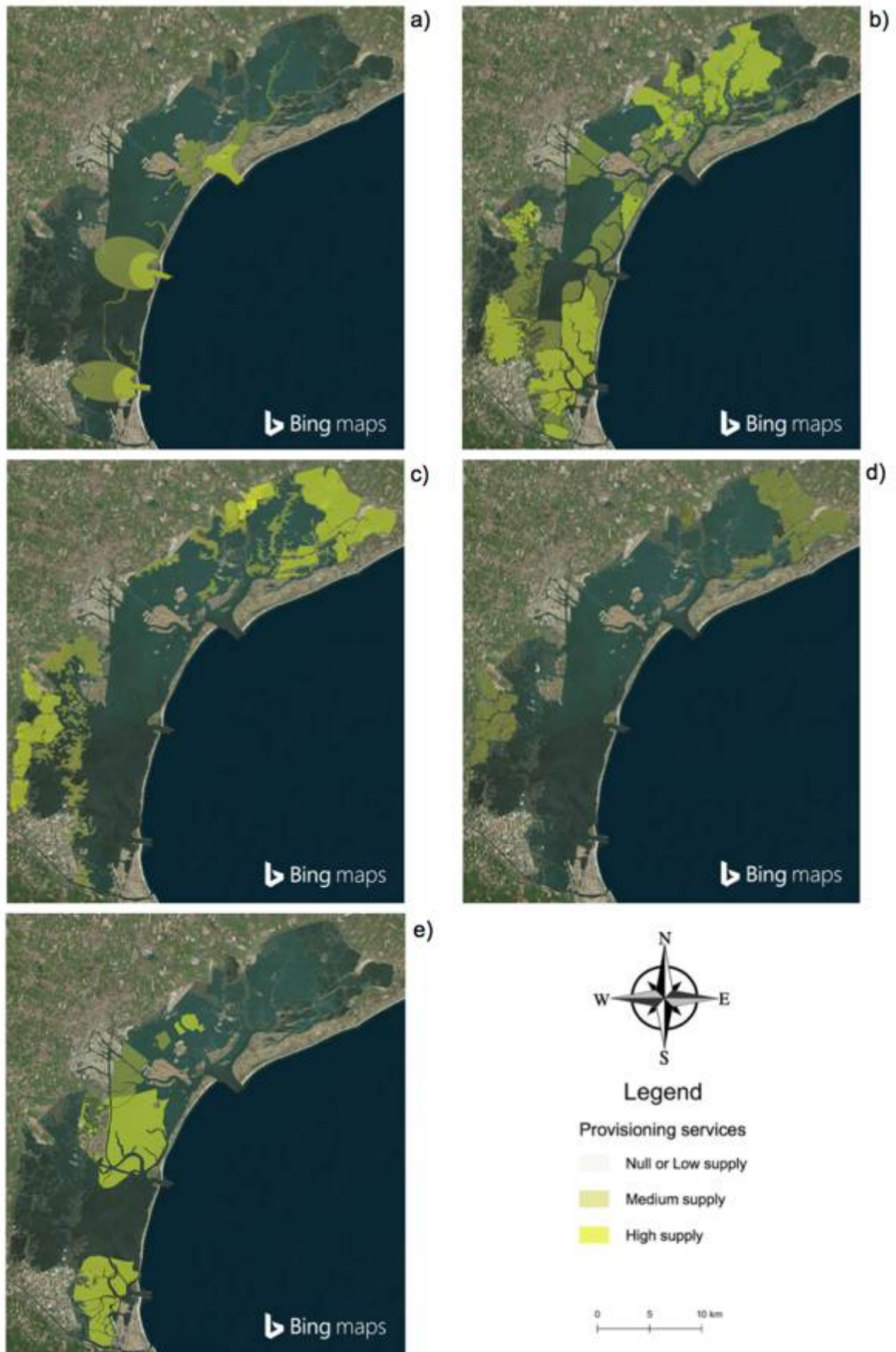


Fig. 21. Qualitative maps of provisioning services: recreational fishing (a); artisanal fishing (b); hunting (birds) (c); aquaculture (d); clam harvesting (e). Data retrieved from Rova et al. (2015). Produced using QGIS on Microsoft Bing Maps.

biofuels is Enalg, which per Pisani (2017) will produce 40 MW by cultivating 8-12 ha near Marghera. As for commerce, an example is given by Shiro enterprise, which per their website produce recycled paper since the 1990s. Anyway, differently from other goods and benefits, because they could rely on often opportunistic algae (e.g. *Ulva*), they don't necessarily need high ecological status.

4.5.2 Regulating services

The most widely produced regulating service here is healthy climate, which conversely to the others, is extremely difficult to assess because of its dependence on many other worldwide climatic factors. This is the element which has the potential to produce the wider environmental positive outcomes to the lagoon, both on confined and not confined water bodies (Rova et al., 2019) but it should have to be described within the context of climate change, in this study only mentioned. However, it is known that the role of carbon sequestration by coastal areas is greater than any other, with salt marshes even greater than by peat lands (Chmura et al. 2003).

Another important I(W) is provided by the prevention of coastal erosion (fig. 22a), which as described in Rova et al. (2015) is a product of three mechanisms: biostabilization, reduction of wind driven resuspension and the susceptibility to wind driven erosion. The biostabilization mechanism is higher because of the colonization of seagrasses (e.g. in front of Pellestrina island), while intermediate to low values have been found in confined areas and north-central areas, due to the presence of benthic diatoms. Salt marshes and emerged land of the northern and south-central part contribute then to reduction of wind driven resuspension, while in confined areas close to Lido-Pellestrina sandbars, the wind blows freely over the water surface. Conversely, wind-driven resuspension and erosion do not occur where the depth of the channel blocks its surface action. Regarding the susceptibility to wind driven erosion, almost half of the area, especially the central part, has overall high potential.

As for clean water and sediments or waste neutralisation indicators, they have not been displayed. Anyway it is possible to assume that most of clean water and sediments benefits are inversely related with the presence of suspended finer material (4.3.1.2 and 4.4.1), while the waste neutralization benefit is offered by a wide range of algae, seagrasses or filtrators (Huesemann et al., 2009; Zeraatkar et al., 2016; Lee et al., 2019; Albarano et al., 2020) (therefore associated to the water quality status displayed in fig. 18) and again inversely related with the suspended material.

4.5.3 Cultural services

Regarding the Cultural services, as discussed in the Activities section, the Lagoon as a whole, provides a wide range of touristic, recreational, educational and traditional activities. Tourism (fig. 22d) affects approx. 7% of the total surface (Rova et al., 2015), mainly located in the central part

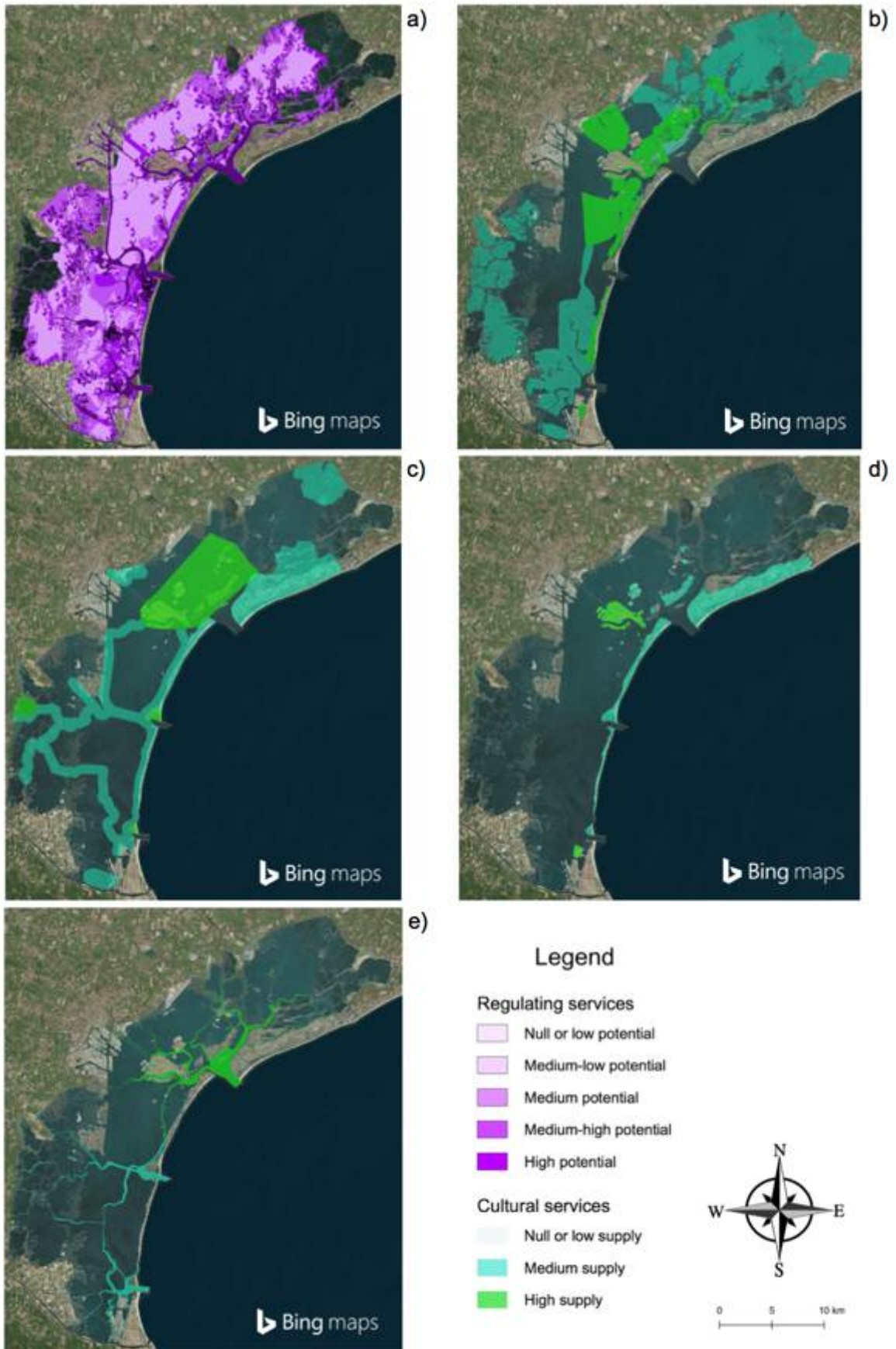


Fig. 22. Qualitative maps of regulating and cultural services: erosion regulation (a); tradition (b); education (c); tourism (d); recreational navigation (e). Data retrieved from Rova et al. (2015). Produced using QGIS on Microsoft Bing Maps.

(City centre and islands), while recreational navigation (fig. 22e) interests most of the channels from the inlets to the inner part. Under the education benefit (fig. 22c) stands both the environmental education (produced from the variety of habitats observed for example in WWF oases of Alberoni or Valle Averno and by the LIPU oases of Ca' Roman, which participate also to the tourism and nature watching element) and the ancient built environment of the city centre and its islands, where tradition (fig. 22b) is distributed as well.

Importantly, besides the already mentioned pollution spreading throughout the Lagoon, with its implications in terms of risk to human health (Di Domenico et al., 1997; Wenning et al., 2000; Raccanelli et al., 2008; Settis, 2014; Migahed et al., 2016), energy expenditure for environmental detoxication (Guerzoni et al., 2007) or environmental exposure on seafood (Frignani et al., 2001; Gregoris et al., 2014; Ademollo et al., 2017), an important outcome is related to ancient buildings survivability and maintenance costs. Indeed, as discovered by La Russa et al. (2018), heavy oil combustion from ship traffic and industrial products such as calcite and oxalates, have the potential to deposit on stone surfaces in form of black crusts, reducing in this way their life span. Together with the overall lagoon healthy state, pollution outcomes contribute to the on-going degradation of what here is called aesthetic benefit, spiritual and cultural well-being. Unfortunately, this indicator as well, it has been noted to be extremely difficult to assess in this context.

4.6 RESPONSES (AS MEASURES)

The selected human Responses adopted in the territory, which should carry with themselves the 10-tenets described by Elliott (2013), have the potential to produce a wide range of feedback loop effects, impacting other elements previously described, as already showed in fig. 1 and 6. The governance structure is composed by different organisation, committees and management authorities as described in fig. 23. National, regional and local authorities share some of the duties, arguably experiencing a lack of coordination in the assessment and management activities (Pastres & Solidoro, 2012).

All the physical and environmental protection works are realized under the responsibility of the State by the Interregional Superintendency for public works of triveneto (ex Magistrato alle acque di Venezia), through the Consorzio Venezia Nuova. The interventions plan, referred by the special legislation for Venice, is defined by the "Mixed Steering, Coordination and Control Committee", ex Law 798/84 ("Comitatone"), where the competent national and local institutions are represented. The projects follow a "General Plan of Interventions" which is composed by 3 distinct lines of action in mutual relationship:

- High water defences (MOSE barriers and local intervention on banks);

- environmental defences (secure ex landfills and poluted areas, protection and reconstruction of lagoon habitats);
- storm surges defences (littoral areas reinforcement).

Only the first two type of Measures will be assessed because of the lagoon area focus of the study. Other measures here described are carried out mainly by research institutes (e.g. Universities, ISPRA and CORILA) as a part of the European LIFE+ projects line. Research institutes such as ISPRA, were also responsible for supervising all the monitoring and compensation works, but since 2014, this role has been covered by Veneto Region through ARPAV (ARPAV, 2019).

In fig. 24 are listed all the discusses Responses, putting attention to their targets in term of framework elements.

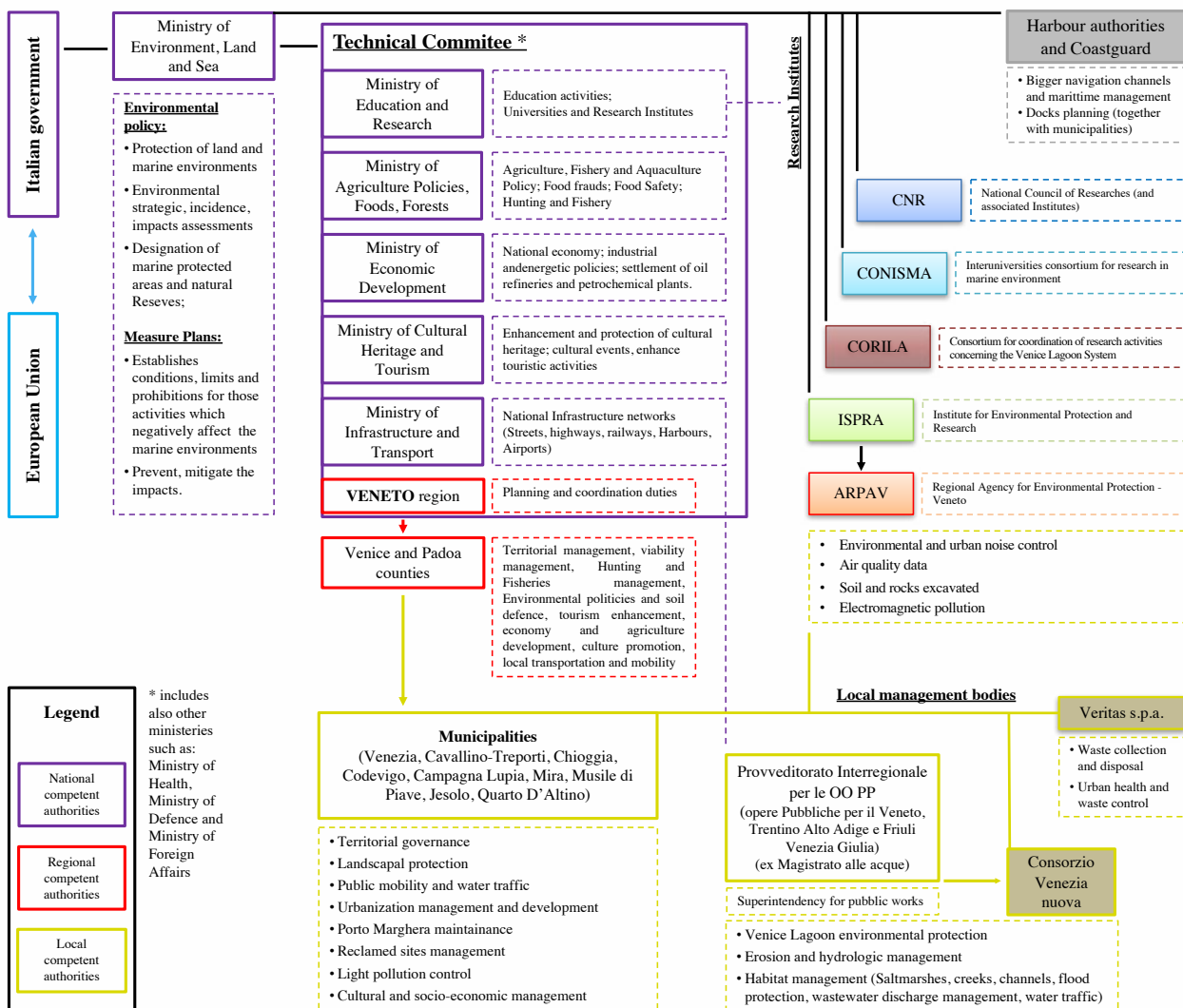


Fig. 23. Schematic view of the main environmental management bodies and their main duties.

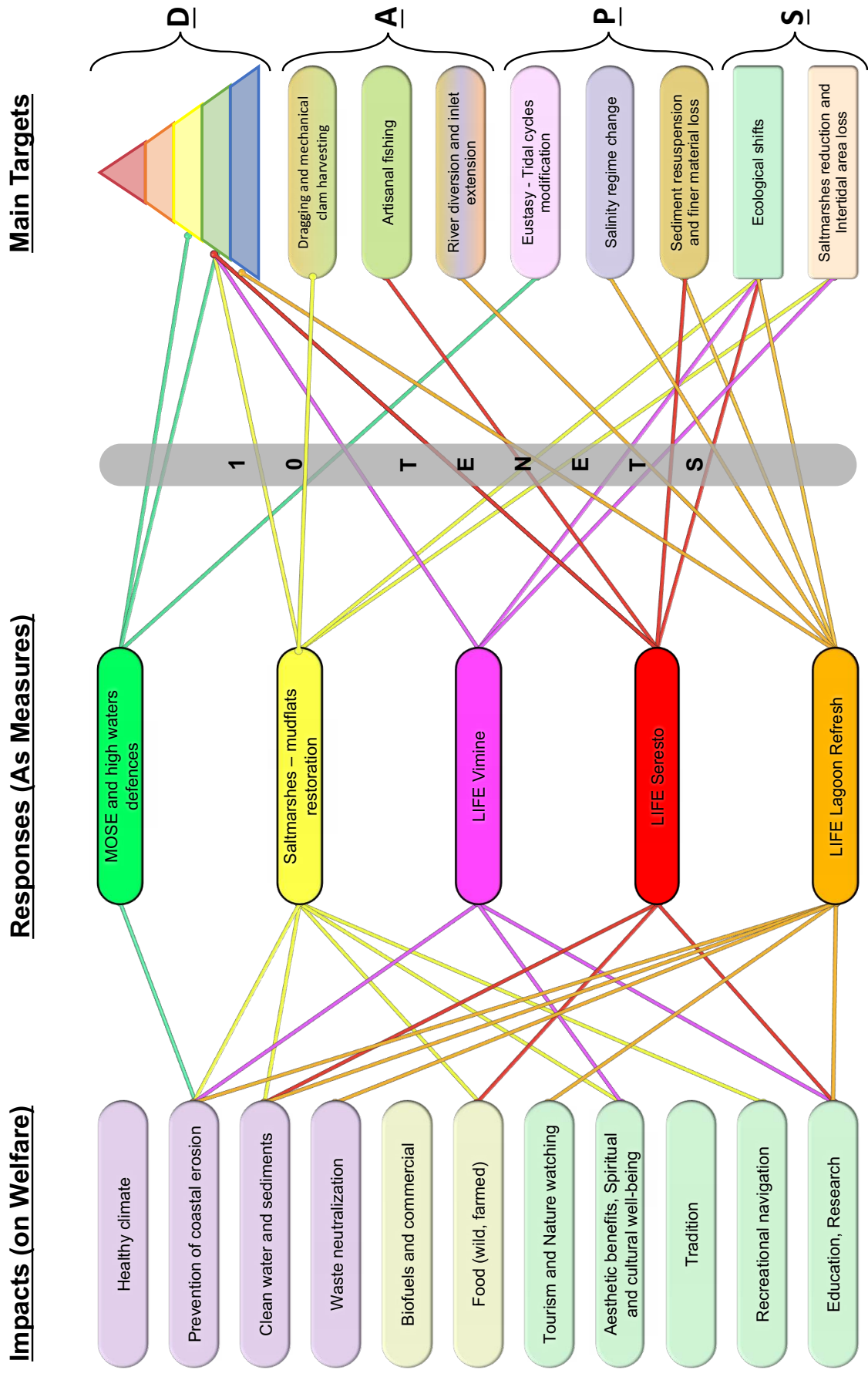


Fig. 24. Discussed Measures related to their Impacts, tenet accomplishment and target on other elements of the framework.

4.6.1 General Plan of Interventions

4.6.1.1 High waters defences

Since 2003, when the construction works started, MOSE (<https://www.mosevenezia.eu/>) has always been one of the heaviest criticised infrastructure projects in Italy (Giovannini, 2007; Robbins, 2019; Harlan & Pitrelli, 2019). The structure, managed by Consorzio Venezia Nuova, should be finished in 2021-2022, with a total estimated cost of more than 6 billion €. It consists of a network of 78 flap-gates created to separate the Lagoon from the Adriatic Sea, therefore protecting it (and especially the city centre) from high tides. But besides the many critics, especially on corruption and concussion episodes (Giavazzi & Barbieri, 2014; Andolfatto et al., 2014), few agree on the actual usefulness of such a monumental structure (e.g. Ponti, 2014) and especially on its positive outcomes on the surrounding environment (Venturi et al., 2019; Robbins, 2019). Anyway, because it is still in the testing phase, it is currently difficult to assess its efficacy outcomes. Known are the environmental monitoring of the construction process (Campostrini et al., 2015)

Other local defences described in the MOSE website include the raise of critical banks and bottom areas, the realisation of systems to prevent the filtration of water from the subsoil and the regurgitation from manholes, or barriers to intercept the high water coming from outside the channels. In Chioggia, following the website, it has been also planned the so called “baby MOSE”, which is composed by smaller barriers blocking the water entering inside the city’s channels.

4.6.1.2 Compensation plan

As part of the infringement procedure 2003/4762, for the alleged violation of art. 4, par. 4 of Directive 79/409 / EEC (Birds Directive), has been prepared the “Plan for compensation, conservation and environmental requalification measures of SCI (Site of Community Importance) IT3250003, IT3250023, IT3250031, IT3250030 and of the SPA (Special Protected Area) IT3250046”, which define environmental compensation Measures connected with the construction of the mobile gates (MOSE) at the port mouths of the Venice Lagoon (Consorzio Venezia Nuova, 2016). Those Measures have been implemented with the indications and suggestions of the Ministry of the Environment and the Protection of the Territory and the Sea, sent to the European Commission in 2007 (prot. n. 9104), approved in 2009, updated in 2011 (Consorzio Venezia Nuova et al., 2011), and then reapproved by European commission in 2012. All the Measures described in this section are therefore part of that last update, retrieved from the MOSE website and represented in fig. 25.

The total estimated costs for the plan is 266 M€, and should cover 2 main categories of interventions:

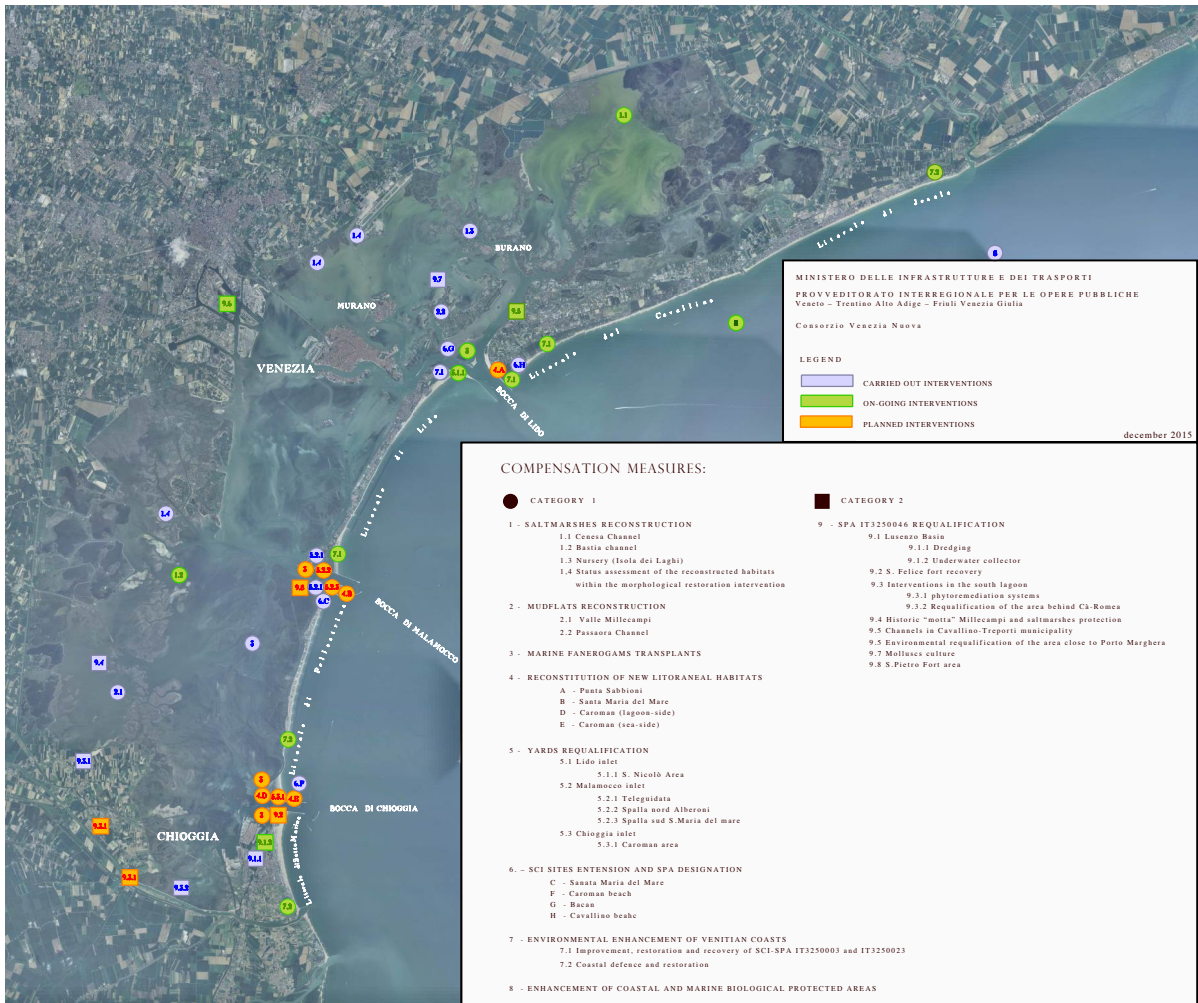


Fig. 25. Representation of the planned compensation Measures updated in 2015. Image retrieved translated from MOSE website (mappa degli interventi).

- Category 1: all measures directly attributable to the compensation purposes following the Directive 92/43 / EEC.
- Category 2: all the proposed interventions not directly attributable to the compensation purposes but having a marked positive impact on improving the lagoon system of habitats and species.

The focus here will be mainly on category 1 Measures. Category 2 works are on the other hand too specific to the environmental pollution (e.g. environmental requalification, phytodepuration) or too limited (i.e. pilot project on molluscs culture). The most recent available data (Bidinotto & Cerasuolo, 2018) on their progression is displayed (in a condensed form) in tab. 5.

Tab. 5. Current available data (in a condensed form) of the extension of the completed and planned compensation Measures. Data retrieved from Bidinotto & Cerasuolo, (2018).

Measure	Expected area (ha)	Realised (ha)	Planned (ha)
Saltmarshes reconstruction	275,5	141,8	133,3
Mudflats reconstruction	93	71,5	21,5
Construction works requalification	8.79	1.95	6.86

Back to the 1990s all over the Lagoon have been established 100 km of artificial marshes on already existing partially submerged mudflats (Scarton et al., 2000) (fig. 3). Coupled with artificial creeks, those structures aimed to enhance morphological and hydrodynamic aspects only, without considering its ecological function. Conversely, D'Alpaos et al. (2007) explain how they neither considered morphological complexity and thus neither recreate natural structures. Nonetheless many researchers (Havens et al., 2002; Raposa, 2002; Boys & Williams, 2012) have outlined how artificial saltmarshes provide protected habitats for biodiversity in areas away from anthropogenic pressures, especially nesting sites for birds (Scarton et al., 2015), even though there could be fewer assemblages, as shown by Havens et al. (1995), when the artificial sites are not yet established (Minello & Zimmerman, 1992; Minello & Webb, 1997; Larkin et al., 2009).

In 2007, as per the plan previously discussed (Consorzio Venezia Nuova et al., 2011), has been prepared the restoration of saltmarshes in 2 areas: one close to Cenesa, Boer, Siletto channels (Nord lagoon) (160 ha), while the other close Bastia channel (south lagoon) (115 ha) (fig. 25). Furthermore, they also intent to use a vivarium where protected and easy growing halophile plants (e.g. *Spartina maritima*, *Puccinellia palustris*, *Limonium serotinum*, *Sarcocornia fruticose*) could be easily transplanted in order to better consolidate the sediments avoiding future erosion risks. Coupled with this measure, the same plan intends to restore mudflats by raising the ground in areas where the bathymetry have strongly changed due to erosion processes, but because the structures will be constructed by using “partially or totally” the dragged sediments, those actions could see an increase in pollution spreading (4.3.1.2 and 4.3.1.3) in areas previously less polluted. The actions have been planned to be pursued in 2 areas: Valle Millecampi (75 ha) and the one close to Passaora channel (18 ha). In addition to that, avoiding erosion, they planned to morphological recover 12 minor island.

The project relies also on the establishment of high quality aquatic plants which possess high potential to promote sediment biostabilisation, helping to reduce the on-going process of bathymetry change. Indeed, species like *Cymodocea nodosa*, *Zostera marina*, *Zostera noltei* and *Ruppia cirrhosa* are fundamental to the pristine state restoration, consolidating the seabed and preventing erosion (Ondiviela et al., 2014), supporting benthic and fish communities (Hemmings, 2000; Jackson et al., 2006; Horinouchi et al., 2009) with a major role in carbon sequestration (Duarte et al., 2005).

Besides the phanerogams transplanting, which can be seen more a pilot project due to the limited extension of 0,9 ha (later expanded to ad other 1.2 ha), it is important to mention the compensation works adopted to counterbalance the current impact of the MOSE construction sites, which should be requalified after the end of the construction (Consorzio Venezia Nuova et al., 2011). Those Measures should together bring back 19.78 ha of characteristic litoraneal protected habitats currently partially occupied by the construction sites (2.31 ha).

4.6.2 Life+ projects

4.6.2.1 Life Vimine

An important project aiming to improve the saltmarshes (in northern basin) has been the LIFE Vimine. This operation (as well as others later described) has been funded by LIFE+, a financial instrument which contributes to the implementation of European biodiversity directives and to the implementation of Natura 200 network (one of the EU's main policy instrument for conservation of valuable habitats and species), focusing on long term sustainable conservation. With Vimine, University of Padova meet these standards running the project from 2013 till 2017, reducing sediment loss from saltmarshes in confined areas (95 ha). As described in Barausse et al. (2015), through low-impact and low-cost bioengineering works it has provided synergically nature protection, environmental education and socio-economic fulfilments, using the labour of locals and stakeholder participation (Reed, 2008). Practically, it has created works and enhanced the ecotourism in the area. An overview of this and other LiFE+ project is given in fig. 26.

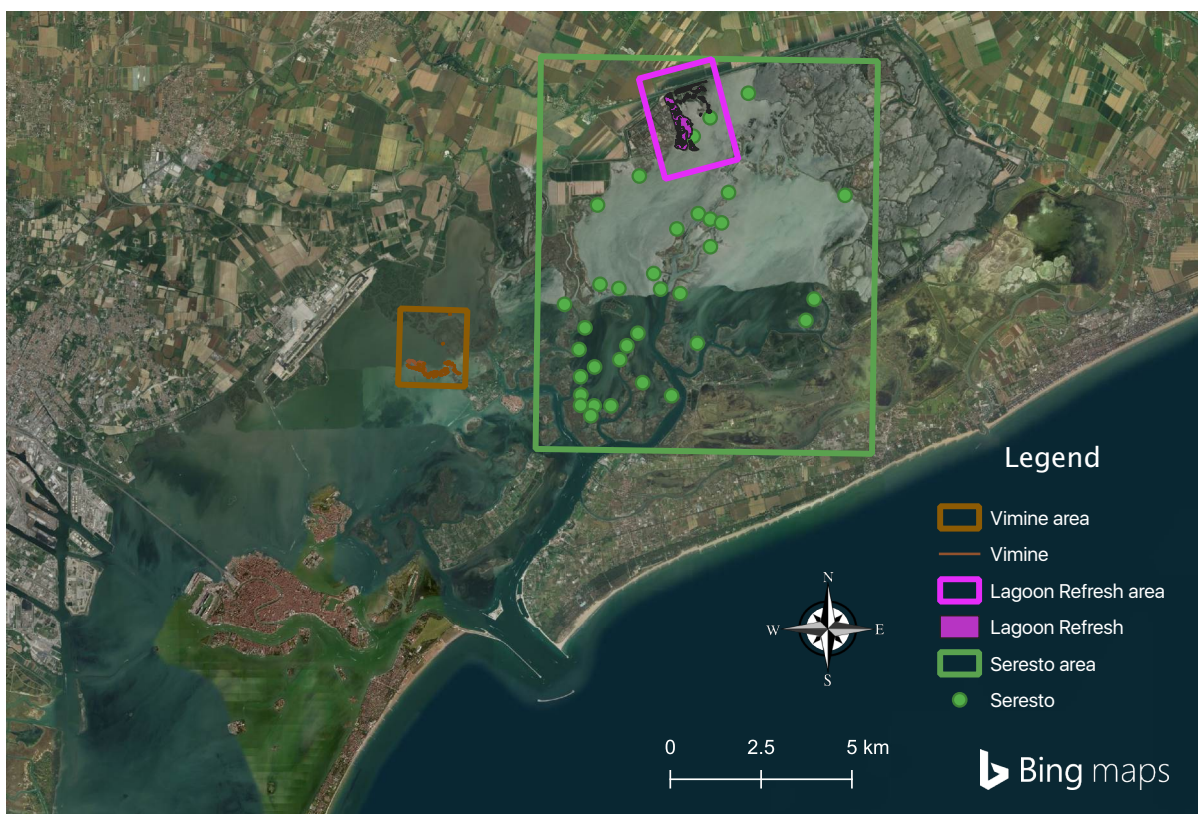


Fig. 26. North lagoon representing the LIFE+ projects discussed in the text. Data retrieved from Geoportale regione veneto and Alice Stocco (phd candidate at University of Venice). Produced using QGIS on Microsoft Bing Maps.

4.6.2.2 Life Seresto

SeResto (SEagrass RESTOration) project (<http://www.lifenseresto.eu/>) aimed in 2014-2015 to restore and later monitor the angiosperm meadows in the Northern basin of Venice Lagoon (fig. 26),

where they strongly decreased due to anthropogenic Activities, and their natural recolonization find many morphological difficulties (Sfriso et al., 2019b). In this context, the project funded by EU, in line with the achievement of a good ecological status as per WFD (2000/60/EC), has accomplished 2 main strengths: transplanting angiosperm (sod-bearing plants, rhizomes and seeds), in 35 sites (with 8 being periodically monitored with biological and chemo-physical analysis) and involve hunters and fishermen participation (Sfriso, 2018). In this way, they enhanced the water quality of the whole area as displayed in fig. 27.

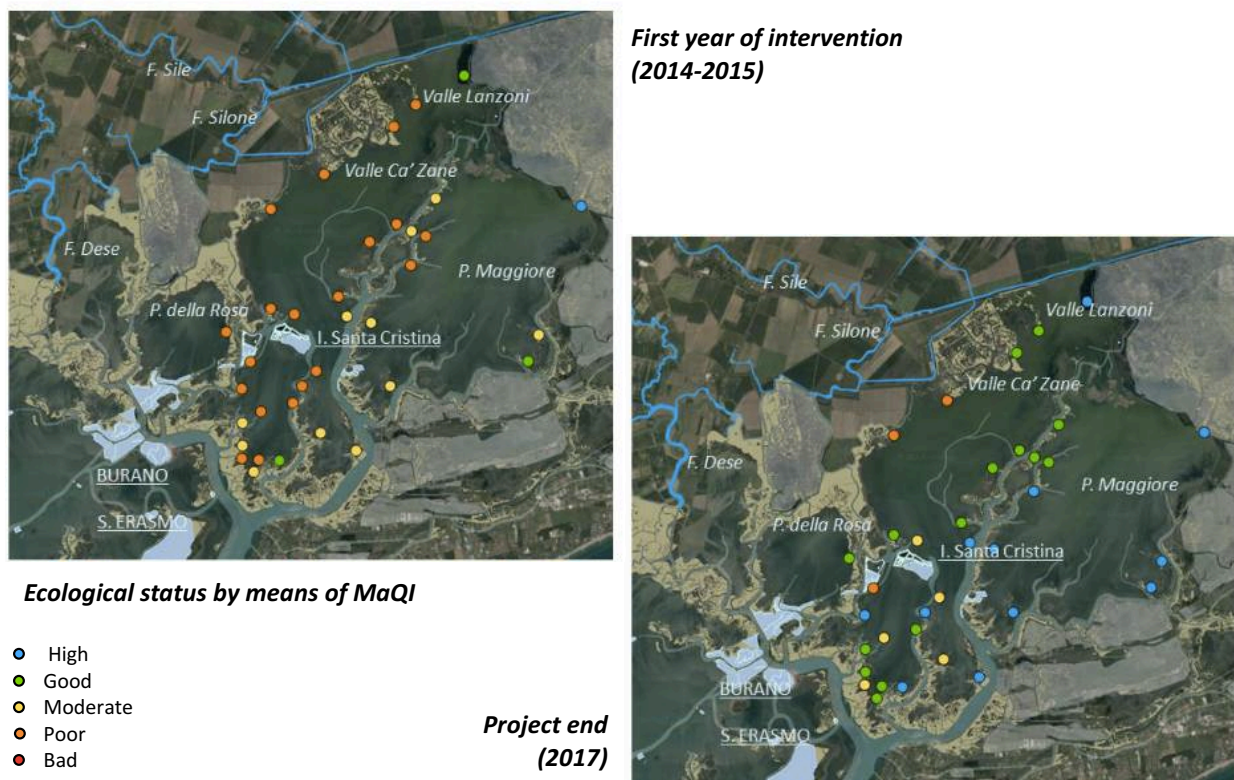


Fig. 27. Comparison between the ecological status (MaQI), before (2014) and after (2017) SeResto project in the intervention sites. Modified (translated) from Sfriso, (2018).

4.6.2.3 Life Lagoon Refresh

Lagoon Lagoon Refresh (<http://www.lifelagoonrefresh.eu>) aims to recreate the salinity gradient (oligo-mesohaline) typical of the original territory prior the diversion of its effluents (2.) (fig. 11). It started in 2017 and expected to finish in 2021 (the expected state is represented in fig. 28).

To do so, Cà Foscari University together with ISPRA and other partnerships, will reintroduce freshwater coming from Sile River (up to 1.000 l/s) together with the re-establishment of rushes habitats (*Phragmites australis* populations) which should reduce banks erosion (e.g. Yu et al., 2020). By transplanting Rushes, promoting eutrophication reduction and phytodepuration (Kleche et al., 2013; Al-Thani et al., 2020; Shahid et al., 2020), they also aim to offer more suitable conditions for many endangered (e.g. *Pomatoschistus canestrinii*) and other high ecological value nekton species

(including nesting sites for many important commercial fish species such as *Chelon ramada* and *Platichthys flesus*) which require more oligo-mesohaline conditions (Scapin et al., 2019). As discussed in the website, they facilitate the process by transplanting *Ruppia cirrhosa*, *Z. noltei* and *Z. marina* (similarly to Seresto), and aim to improve not only the aquatic ecosystem, but also the creation of hibernating and nesting habitats for the conservation of avifauna (e.g. *Locustella luscionioides*, *Phalacrocorax pygmeus*). Furthermore, to enhance ecological status, it has been planned to temporarily reduce hunters and fishermen Pressures through the involvement of the local administration and stakeholders.

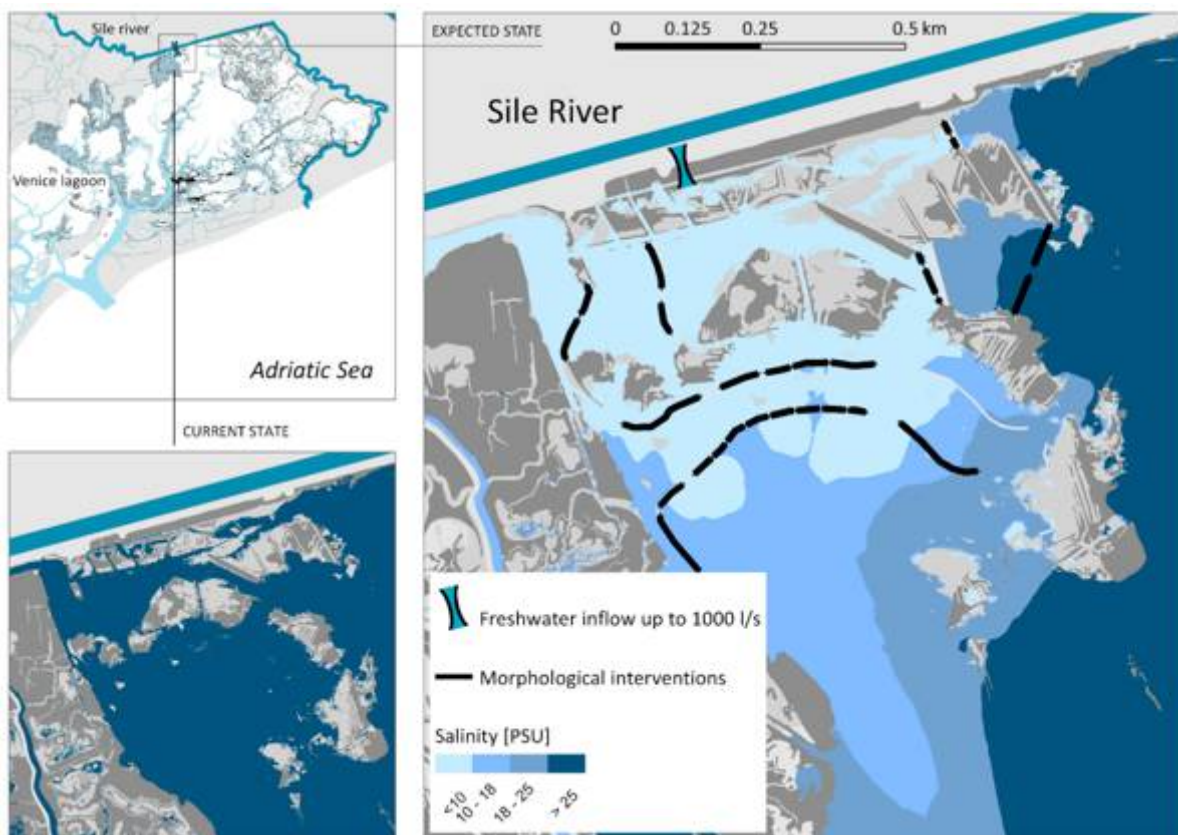


Fig. 28. Project area of LIFE Lagoon ReFresh. Current state of salinity condition (bottom-left) and expected state after the creation of a freshwater input from the Sile river on low tide conditions (right). The freshwater inflow and morphological interventions are also represented. Retrieved from Scapin et al., (2019).

5. CONCLUSION

5.1 AN OVERVIEW

As already expressed by Provveditorato interregionale per le OO. PP. (2016), the most critical Activities, in terms of connection with Pressures (4.3), are fishing, commerce and industry. Particularly the fishing (including aquaculture) is the most widely Activity carried out in the area, leaving industries more confined to specific zones (Porto Marghera and Murano), with artisanal

fisheries much more sustainable than others (especially regarding mechanical clam harvesting) (Provincia di Venezia, 2009; Zucchetta et al., 2016). Commerce, linked closely with the industrial sector, produces as well many damages to the surrounding, disturbing the environment and dispersing many contaminants (here only mentioned). On the other hand, they are all related to different extent to primary needs, making them essential for the society. Surely there could be more interest in their road to the full sustainability, but many efforts have been always done in term of Measures, with *ad hoc* LIFE+ projects (4.6.2) and especially the general plan of interventions by Consorzio Venezia Nuova (4.6.1.2).

Other highly impacting Activities includes tourism, which has been categorised as product of the self-actualisation Drivers, but also esteem-need due to the high importance for the economy. Regarding this, and particularly the large ships traffic, many ideas and projects are still being discussed by the government including limits to the tons permitted to entrance in the city centre (e.g. Buckley, 2017), due to the recent protests on “Grandi Navi” (www.nograndinavi.it), but there is still no consensus on the decision. The suggested solution is to reroute vessels along the Malamocco-Marghera industrial channel and dredge a channel from Malamocco to the dock in the port of Marghera, with tourists being transferred to the city by bus (Cadena Ser, 2017; Teatini et al., 2017). This channel, planned by the Venice Port Authority, should be called Marghera-Venice Channel (MVC) and long approximately 3-km, 10-m deep. However, this eventuality could further enhance the already intense negative outcomes of commercial traffic through the Malamocco-Marghera channel (4.2.2)

Moving on to the Pressures (4.3), a paramount importance for the Lagoon survivability is covered by climate change (4.3.2.1). Related to this, eustasy is at the centre of a public debate, which couple with subsidence exponentially worsen its effects. Many structures which provide defence from high water have been here mentioned in 4.6.1.1, including the well-known monumental MOSE, now in the testing phase. Besides that, many other ideas are on the table, such as the anthropogenic raising of Venice (e.g. by seawater injection into deep geologic formations as expressed by Comerlati et al., 2004 or Castelletto et al., 2008) to avoid the submergement, but are still far from being adopted. Furthermore, in term of climate change mitigation, as expressed in the Venice municipality website, the Municipality of Venice developed its own Sustainable Energy Action Plan (SEAP) in 2012. Through the involvement of citizens and stakeholders, pursues important objectives by the reduction of greenhouse gas emissions, enhancement of energy savings and usage of renewable sources. As for other Responses, the draft of the Climate Action Plan is expected to be ready by 2020, assessing the risks and vulnerability the territory in relation to climate change (historic city, lagoon and mainland), accompanied by a series of mitigation and adaptation actions in line with the Paris Agreement.

Even though the focus here has never been about contaminants, which have been conveyed into the ecological modification, a few words about its expected Measures are here necessary. The possible actions are almost unlimited, some of which are already planned in the MOSE compensation plan (4.6.1.2). From the most futuristic such as the proposed adoption of ICE-hybrids water-busses by Morandin et al. (2015), to the much more viable and quite unavoidable remediation actions in Porto Marghera. The total estimated clean-up cost was over 750 million € per Tonin (2012), but this could have many other economic positive effects, such as the effect on property price. The Provveditorato interregionale per le OO. PP. and the industries involved (with a strong collaboration of the energy enterprise Eni) has planned to install 70 km of impermeable engineering barriers around the dock (Paris et al., 2011) (55 of which have been completed), together with “pump & treat” systems to avoid the movement of the contaminants into the lagoon and to prevent erosion of the shores, thus ensuring navigation (Beretta & Terrenghi, 2016).

Regarding other important Pressures, this study has shown many times how most Activities led to sediment resuspension and finer material loss (4.3.1.2), with the side effect of spreading away contaminants. Fortunately, it has also been discussed some Measures which aimed to address this issues (e.g. Life SeResto and Life Refresh in the north lagoon), even though at small scale. The strategy rely on the recreation of angiosperm meadows (including rushes), which trap the finer sediments otherwise dispersed, and target the desired ecological state by triggering its natural restoration process. Particularly, Refresh intend to reintroduce freshwater from the previously diverted river Sile, in this way aiming to bring back the original salinity regime and to reintroduce new sediments, hitting also old activities such as the element “River diversion and Inlet extension”.

Moving to State changes (4.4), it is notable the heavy effort to couple with the current ecological shifts (4.4.2). Poor water quality index (fig. 18) can be found both on the north and south part, but only the Measures of the compensation plan (4.6.1.2) is responding on the southern lagoon, with the Vimine and SeResto which have acted in the north part (and probably its current better status should thank their intervention). Another critical State change object of many interventions, especially by the compensation plan (4.6.1.2) but also by Life Vimine for example, is the saltmarshes and intertidal area loss (4.4.1). Effects of the sediment loss, those areas have always been to the centre of attention due their high importance for the whole lagoon ecosystem (2.), and now they are perhaps seeing brighter future due to the many Responses (Bidinotto & Cerasuolo, 2018).

As for the ecosystem services, it has been adopted here the ES chain with indicators provided by Turner et al., 2015, which have led to the goods and benefits here called Impacts (on human Welfare) (4.5). Their set up and localisation has been provided by Rova et al. (2015; 2019), Rova & Pranovi (2017) works. Provisioning services such as related to the food industry and hunting Activities

strongly related to the ecological State changes, have seen the wider outcomes. Those areas related to fisheries can be seen as the most impacted by the previously described changes, reducing for example year by year their landings (Fortibuoni et al., 2017). Then, regulating services could be seen as the second most important benefit for society, with the displayed “prevention of coastal erosion” which is more or less everywhere important. Finally, cultural services provide very significant benefits in such a historical landscape, especially regarding tradition, education and tourism. To different extent those I(W) are related to the responses. For a more detailed connection between elements in Annex 1 is provided a full diagram.

5.2 FINAL REMARKS

Using this framework, it has been successfully described, even if not extensively, this complex environment. The DAPSI(W)R(M) has been proven to be useful for future management plans to relate the different aspects of the complex socio-economic-environmental system named Venice Lagoon, highlighting the many links existing between Drivers, Activities, Pressures, State changes, Impacts (on human Welfare) and Responses (as Measures). It has been also explained how, without smart and extensive interventions, the criticism could worsen progressively compromising the entire ecosystem. Anti-erosive Measures, sediment resuspension control, mitigation of the eustasy/subsidence effects are fundamental not only to maintain the ecosystem functions but also to avoid the inevitable sedimentary deficit, which is not solely at sub-unit scale but concern the entire basin. Those effects have the potential to alter hydro-morphodynamic conditions by flattening and deepening of the seabed, loosing saltmarshes and mudflats or compromise the functionality of channels (4.4.1). Not to mention the biotic environment (4.4.2), with its high degree of Pressures, which on the other hand sustain most of the ecosystem services and goods and benefits (4.5). Nevertheless, many measures including the compensation plan carried out by Consorzio Venezia Nuova (4.6.1.2) or the LIFE+ projects (4.6.2) are going in the right direction.

By means of this analysis it has been gathered much information possible to set and relate the different elements (D – A – P – S – I(W) – (R(M))), not only by diagrams but also representing the elements spatially. Possibly it could be useful to create novel indicators, adapted in this context, and try to make a full assessment of the Responses, based on the relative importance of the other connected elements. Future analysis using the framework could try to better describe climate change and pollution effects, particularly in the S and R(M) section. As for the Impacts (on human Welfare), it is fundamental the availability of other ecosystem services and disservices, but this could require an analysis of its own. Anyway, for its future application, is fundamental a wider and much more

detailed set of cartographical tools, including some remote sensing images which could be used to spatially relate all the elements.

Overall the study has provided a description of the main issues and its Responses over the time, therefore it is suggested its development as a primary tool for complex marine territory management, for academic purpose itself but especially to be adopted in a governmental assessment such as in the next issue of Provveditorato interregionale per le OO. PP (2016). With a stronger workforce, it could be possible to better address the main criticism of the territory, develop *ad-hoc* plans, see any limit of underestimated/overestimated management activities. As for the environmental sciences, this work adds to the marine management of Venice Lagoon a novel complete and holistic environmental template framework. The only limit for its future development is time.

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Atlante della laguna: http://atlante.silvenezia.it/it/index_ns.html

Comitato no grandi navi website: <http://www.nograndinavi.it/tag/marghera/>

Favini paper website: <https://www.favini.com/gs/carte-grafiche/shiro/caratteristiche/>

Geoportale regione Veneto: <https://idt2.regione.veneto.it/>

LIFE Lagoon Refresh website: <http://www.lifelagoonrefresh.eu>

LIFE SeResto website: <http://www.lifeseresto.eu/>

Murano glass distric website: Patto del distretto del vetro di Murano retrieved from http://www.distrettovetromurano.it/Home_files/DISTRETTO-DEL-VETRO-DI-MURANO.pdf

Porto Marghera website: <http://www.portomarghera100.it/node/150>

Venice Municipality website: <https://www.comune.venezia.it/it/content/energia>

7. ANNEX 1

Diagram representing (and summarising) the entire DAPSI(W)R(M) problem-structuring framework applied to the Venice Lagoon. Each color, different for every connected couple (D and A – A and P – P and S – S and I(W) – I(W) and R(M) - R(M) and every other impacted element), follow the color of the elements surrounded by a black border.

