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Assessing pressure drivers on the benthic ecosystem in the coastal zone of Western Messinia, Greece

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ABSTRACT

The Messinia region, located in the South – West of the Peloponnese, Greece, is an ecologically valuable area comprising of several important coastal habitats (including coastal lagoons, seagrass meadows, and Mediterranean rhodolith beds) eliciting its inclusion in the Natura 2000 network. Land-based anthropogenic pressures are likely to influence the ecological status of this coastal zone. Here we identify those regional pressures and use physico-chemical elements of the ecosystem, and the status of the macrofauna communities to assess the level of environmental degradation in the coastal and lagoon water bodies. High organic load from the catchment area, geomorphological and hydrological features of the water bodies are the major drivers affecting the ecological quality of the region. The lagoon is severely degraded due to both a high nutrient input from the surrounding river basin (likely due to agricultural run-off), and a relatively low level of connectivity with the marine environment (due to alterations in the regional hydrology). In contrast, the coastal zone is classified as being at a high or good ecological status and seems scarcely impacted by anthropogenic pressures. The macrobenthic communities reflect how vulnerable the lagoon is to multiple stressors (and in particular agricultural practices), and highlight the necessity of defining and implementing holistic, river-basin based management plans for the Gialova lagoon, and the surrounding coastal area of Messinia.

1. Introduction

Coastal habitats, and especially coastal lagoons, constitute one of the most productive ecosystems in the world, providing shelter, nursery grounds and a large variety of habitats for many species, as well as goods and services to humans (De Groot et al., 2012). Using global gridded datasets, Kummu et al. (2016) has estimated that around 40% of the worlds population (40% in 1990, 39% in 2010) lives within 100 km of the coastline, highlighting the importance yet vulnerability of coastal lagoon and estuary systems (Newton et al., 2016). In a major review work Coll et al. (2010) assessed overall spatial and temporal patterns of species diversity and identified major changes and threats of biodiversity in the Mediterranean Sea. Habitat loss and degradation, followed by fishing impacts, pollution, climate change, eutrophication, and the establishment of alien species were shown as the most important threats and affect the greatest number of taxonomic groups. Coastal lagoons, as transitional ecosystems between the land and the sea, are characterized by a high rate of dynamic changes in their natural environment and high diversity and biological productivity, however, the intense exploitation of these systems is often accompanied by a high rate of degradation of their biological resources and ecosystem services (Newton et al., 2014).

The Gialova lagoon complex, situated along the South-Western coast of the Greek Peloponnese, is host to a large variety of fauna and flora, including over 270 species of bird (Norrby, 2017). In recognition of its ecological importance, the entire complex (the lagoon, the semi-enclosed bay in which the lagoon is connected too, and the offshore coastal area) is included in the Natura 2000 network (GR2550008, GR2550004, and GR2550010 respectively). The offshore marine habitat is a suitable environment for many sea turtle and cetacean species, and supports important biogenic habitats (e.g. *Posidonia oceanica* meadows and rhodolith beds, HCMR, unpublished data). The coastal zone also hosts significant formations of Phoenician juniper (*Juniperus phoenicea*) on the sand-dunes of the Voidokilia beach tourist hotspot. However, despite the lagoon being designated almost 20 years ago under the Birds

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Directive as a Special Protected Area (SPA) (Directive 79/409/EEC later amended to 2009/147/EC), there are no implemented management plans for any of the sites (European Commission Vs. Greece, Case C-849/19), and the area suffers from several socio-economic conflicts.

Just like other coastal areas, lagoons are typically threatened by human activities such as draining, filling, hydrological modifications, pollution and over-exploitation. In Greece alone, ca. 70% of coastal wetlands have been lost over the last century (Commission of European Communities, 1995) and many of the remaining ones lack adequate management measures, resulting in a degraded state. Only 5% of the Greek transitional water systems monitored for the EU Water Framework Directive achieve a Good or High ecological status (EEA, 2020). The Gialova lagoon complex has suffered from decades of human interventions that have affected the hydrology, water quality, and ecology of the site (Maneas et al., 2019). Although several studies have investigated the ecology of the Gialova lagoon (e.g. Arvanitidis et al., 1999; Chatzigeorgiou et al., 2011; Koutsoubas et al., 2000a, 2000b), little is known however about the nearby coastal waters and how the different coastal ecosystems (the lagoon, the semi-enclosed Navarino bay, and the wider coastal zone) are affected by anthropogenic pressures of the region, particularly concerning the extent of habitat fragmentation and ecological quality. In addition to past human interventions, touristic arrivals and infrastructures have greatly increased after 2010 (Maneas et al., 2019), and further expansion plans have been announced (Karageorgou, 2019). At the same time, the damage caused by the use of the wetland related habitats by tourists is becoming more apparent by the year (Maneas et al., 2019). Even though biodiversity, landscape and seascape aesthetics related to Gialova lagoon and Navarino Bay play a key role in the advertising promotion of the area, there is a lack of a recent environmental management plan which considers the impacts to basic ecosystem compartments by all human threats present.

Here, the relevant, direct anthropogenic pressures are identified for the region based on the classification systems by Newton et al. (2020) and Elliott et al. (2014). The impact that these pressures have on the ecological state of the region was then assessed using several ecosystem components (physico-chemical parameters, phytoplankton, and zoobenthos). There are several advantages to the monitoring of coastal marine habitats with benthic communities. In coastal zones, macrobenthic organisms are considered the most adequate synthetic descriptors of the environment as they are mostly sedentary and thus more reliable as site indicators for longer periods (especially in comparison to fish and plankton), thus they have long been used as indicators for water quality assessment (Dauer et al., 1993; Simboura and Reizopoulou, 2008). We intend the results to assist in the establishment of holistic management plans for the Gialova lagoon complex.

2. Material and methods

2.1. Direct anthropogenic pressures in the study area

The three waterbodies in the study area (the Gialova lagoon, the adjacent semi-enclosed Navarino Bay, and a coastal section of the open Ionian Sea) are subject to a range of direct and indirect pressures. Multiple sources were used to extrapolate the direct anthropogenic activities for the region. As the lagoon and coastal waters are included as monitoring sites within the Water Framework Directive (WFD), the WFD Database for site pressures was referenced for these sites (EEA, 2020), and the WFD River Basin Management Plans submited to European Environment Agency by the Greek state (Greek Special Secretariat for Water of the Ministry of Environment, Energy and Climate Change, Government Gazette: 1004/B/24-04-2013). An extensive review of anthropogenic induced changes to the Gialova lagoon (Maneas et al., 2019) was heavily consulted, alongside input received by stakeholders during a series of six iterative workshops (Tiller et al., 2021), and the empirical knowledge of the authors (Table 1). The direct pressures were categorized into six typologies based on their anthropogenic activity

Table 1
Tables of main anthropogenic activities identified by stakeholders, their associated direct pressures, and information sources for each activity/pressure.

Anthropogenic activity (based on Newton et al., 2020)	Associated pressures to coastal ecosystem	Source information for Messinia region
Agriculture	Nutrient loading from fertilizers/Pesticides	CORINE Land Cover — Copernicus Land Monitoring Service (land.copernicus.eu) Greek Water Framework Directive River Basin Management Plans (wfdver.ypeka.gr) Literature review
Damming and changes to hydrology	Changes in salinity and water budget	Greek Water Framework Directive River Basin Management Plans (wfdver.ypeka.gr) Literature review
	Loss of connectivity	Satellite images e.g. Google Earth, Hellenic Military Geographical Services. Literature review
	Water column stratification and bottom oxygen deficiency	Literature review
	Increased coastal erosion	Satellite images e.g. Google Earth, Hellenic Military Geographical Services. Literature review
Aquaculture ponds	Change in hydrology	Satellite images e.g. Google Earth Literature review
	Polluting effluents	Satellite images e.g. Google Earth Greek Water Framework Directive River Basin Management Plans (wfdver.ypeka.gr) Literature review
Fishing	Removal of biological populations	Hellenic Statistical Authority (ELSTAT) (statistics.gr) Global Fishing Watch Database (globalfishingwatch.org) Literature Review
	Seabed damage from trawls	Hellenic Statistical Authority (ELSTAT) (statistics.gr) Global Fishing Watch Database (globalfishingwatch.org) Literature Review
Tourism and Eco-tourism	Increase in floating and seabed litter	Marine LitterWatch EEA (eea.europa.eu) Literature review
	Nutrient leaching from Golf course surface run-off	Land use Satellite images e.g. Google Earth, Hellenic Military Geographical Services.
Shipping, ports, marinas	Alien species	ELNAIS - Ellenic Network on Aquatic Invasive Species (elnais.hcmr.gr) iNaturalist Citizen Science Platform (inaturalist.org) EASIN - European Alien Species Information Network (easin.jrc.ec.europa.eu)
	Pollution (marine litter/increased pollutants)	Marine LitterWatch EEA (eea.europa.eu) Beach litter transect surveys (Supplementary material) Greek Water Framework Directive River Basin Management Plans (wfdver.ypeka.gr) Literature review
	Habitat loss	

(continued on next page)

Table 1 (*continued*)

Anthropogenic activity (based on Newton et al., 2020)	Associated pressures to coastal ecosystem	Source information for Messinia region
Land reclamation Urbanisation/ Industrialisation		Satellite images e.g. Google Earth, Hellenic Military Geographical Services. Literature review
	Treatment of urban wastes	European Commission Urban Waste Water Database (uwwtd.eu) Greek Water Framework Directive River Basin Management Plans (wfdver.ypeka.gr)
Land reclamation	Untreated wastewater run-off	Greek Water Framework Directive River Basin Management Plans (wfdver.ypeka.gr) Literature review
Urbanisation/ Industrialisation	Industrial effluent	European Commission Urban Waste Water Database (uwwtd.eu) Greek Water Framework Directive River Basin Management Plans (wfdver.ypeka.gr)

(Elliott et al., 2014). These main activities were identified by Newton et al. (2020) and include; agriculture, damming and changes to hydrology, aquaculture ponds, fishing, tourism and eco-tourism, shipping ports and marinas, dredging and sand/salt extraction (not applicable for the present study), land reclamation, and finally urbanisation/industrialisation. The information sources for each pressure group are listed below in Table 1.

After an agglomeration and evaluation of the current pressures facing the study area identified by the literature and data review, the authors used expert judgement (n = 8) to consider the likely influence (Negliable, Low, Medium, and High) of each group of anthropogenic activities for the ecological status of each station. The IDEA protocol (**I**nvestigate, **D**iscuss, **E**stimate, **A**ggregate) was used as a guideline for the expert judgement process (Hemming et al., 2018). Each expert was asked to separately investigate the individual pressures affecting the Western Messinia coastal habitat and assign a quantitative value based on the information collated (Table 1). The experts were then asked to provide their private, individual best-guess point estimates (Round 1). With the assistance of a facilitator the experts then discussed the exhaustive list of anonymous estimates, resolving different interpretations of the questions, and cross-examining the reasoning and evidence provided. In accordance with the protocol, the experts were then invited to provide a second and final private estimate (Round 2). The final estimates were then aggregated to provide the final score presented in the results. In accordance with the protocol differences in the final score were averaged.

2.2. *Ecological impacts of anthropogenic pressures*

To determine the impacts of the pressures described above on the coastal lagoon ecosystems of Messinia, *in-situ* samples were collected from eleven stations. The stations were largely selected in response to the main anthropogenic pressures in the region (agriculture and changes to hydrology, see below) and consist of three lagoonal stations (COGIA 1, 2, and 3), two shallow subtidal (<1 m) stations from the semi-enclosed Navarino bay connected to the lagoon and the coastal region (COAS 3F and 3G), and six deeper (12–50 m) coastal stations (COAS 2A, 2B, 2C, 3A, 3E, and 4a) (Fig. 1; Table 2). The lagoon stations form a general transect from the centre of the lagoon (COGIA 3) to the inlet (COGIA 1). Stations COAS 3G (Navarino Bay), COAS 3F (Navarino Bay) and COAS 3E (Coastal) are a continuation of this transect from the lagoon to open sea. It is expected that any nutrients and pesticides entering the lagoon via agricultural surface run-off will be detected at these stations. The deeper sections of Navarino bay could not be sampled extensively as restrictions are in place due to the presence of archaeological artefacts. Station COAS 3A is located in the tourist hotspot bay of Voidokilia beach and at the mouth of the small Xerolagados canal flow. Stations COAS 2A - 2C form a transect off the mouth of the small river Selas to assess the influence of upstream land-based activities, and station COAS 4A is located near the coastal town of Pylos.

For each station two main groups of parameters were collected during December of 2018; benthic macrofauna, and physico-chemical

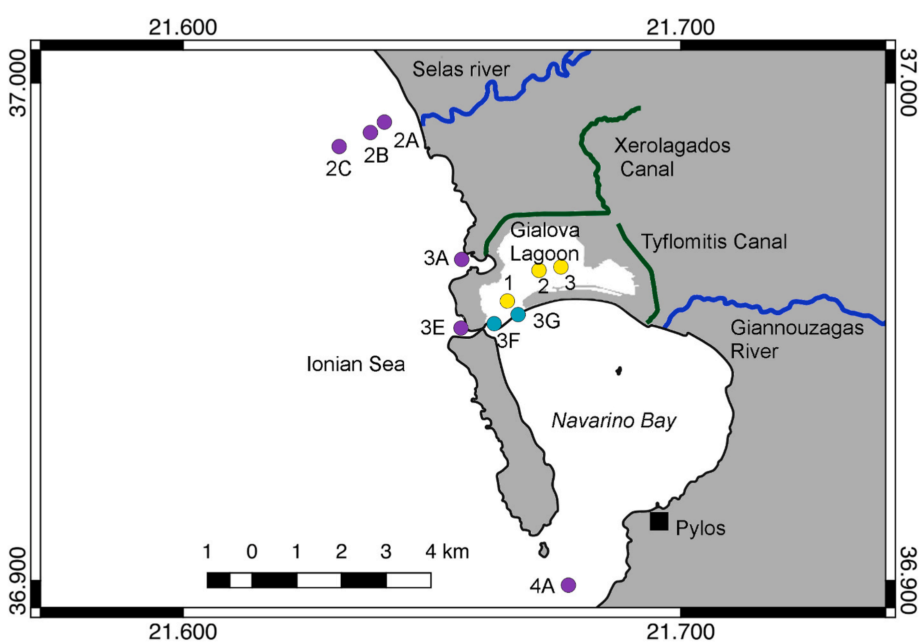

Fig. 1. Study area. Yellow indicates lagoonal stations (1, 2, 3 = COGIA 1, COGIA 2, and COGIA 3). Aqua indicates intermediary stations within Navarino Bay (3F, 3G = COAS 3F and COAS 3G) and purple stations indicate coastal marine stations (COAS 2A, COAS 2B, COAS 2C, COAS 3A, and COAS 3E). Rivers are indicated in blue and artificially modified canals in green. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 2
Station descriptions for the Lagoonal, Intermediary (located within the semi-enclosed gulf), and coastal habitats.

Station	Waterbody Type	Latitude (°N)	Longitude (°E)	Depth (m)	Sediment type
COGIA 1	Lagoon	36.9558	21.6648	0.8	Muddy Sand
COGIA 2	Lagoon	36.9629	21.6704	0.7	Muddy sand
COGIA 3	Lagoon	36.9631	21.6757	0.9	Muddy sand
COAS 3F	Intermediary	36.9516	21.6625	0.7	Sand
COAS 3G	Intermediary	36.9535	21.6673	0.3	Sand
COAS 3A	Coastal	36.9637	21.6605	15	Sand
COAS 3E	Coastal	36.9507	21.6558	27	Sand
COAS 2A	Coastal	36.9906	21.6403	12	Sand
COAS 2B	Coastal	36.9882	21.6348	20	Sand
COAS 2C	Coastal	36.9861	21.6288	50	Muddy Sand
COAS 4A	Coastal	36.8991	21.6774	67	Rhodolith bed

properties of the water column and seabed. For acquiring benthic macrofauna, two replicate samples were collected from each coastal station ("Smith McIntyre" grab with a sampling surface of 0.1 m^2 from R/V "PHILIA") and three replicates from the lagoonal/intermediary stations (hand-operated Ekman box corer with a sampling surface of 0.025 m^2 from a small fishing boat or on foot). Sediments were sieved using a metal sieve with a 0.5 mm mesh and residuals were fixed with 4% formalin and stained with Rose Bengal. Macrofauna was identified in the laboratory to the highest possible taxonomic level. Water temperature, pH, dissolved oxygen (DO), salinity and conductivity were measured in parallel at each station by an *in-situ* portable field instrument for the lagoon and intermediary stations (YSI 650/YSI 6-Series Sonde). The samples for the determination of nutrients and dissolved organic nitrogen and phosphorus were kept deep frozen (−20 °C) until their analysis in the certified according to ELOT EN ISO/IEC 17025:2005 biogeochemical laboratories of HCMR. A Seal III autoanalyzer and a VIS/UV spectrophotometers were used for the nutrient analysis according to standard methods (Mullin and Riley, 1955 for silicate; Stickland, 1972 for nitrate-nitrite, Murphy and Riley, 1962 for phosphate, Koroleff, 1970 for ammonium). Total Dissolved Organic Nitrogen (TDN) and phosphorus (TDP) analyses was performed after a wet-oxidation with persulfate in low alkaline conditions and measured using a SEAL III autoanalyzer (Pujo-Pay and Raimbault, 1994; Raimbault et al., 1999). Values were corrected for the reagent blank. Small subsections of the uppermost 2 cm of the sampled material were collected and frozen in plastic containers at −18 °C before being transported to the laboratory to be analysed for sediment granulometry, organic carbon and nitrogen content. Granulometric analysis included separation of coarse-grained fraction (>63 μm) from the fine-grained fraction (<63 μm) by wet sieving and further classification of silt and clay with an X-ray attenuation analyzer (Sedigraph Micrometrics III Plus). Substrates were classified according to Folk (1954) nomenclature. Organic carbon and nitrogen were determined with CHN elemental analyzer (EA-1108, Fisons Instruments), according to methodology of Verardo et al. (1990). Samples for phytoplankton biomass (chlorophyll *a*) were filtered through Whatman GF/F (Diameter 47 mm; pore size 1.5 μm) filters. A TURNER 00-AU-10 fluorometer was used for Chl-a measurements (Holm-Hansen et al., 1965).

2.3. Statistical analysis for the ecological status of waterbodies

Macrofauna data from the replicate samples were standardised to densities (abundances/m^2) and averaged per station. Colonial organisms and meiofaunal taxa (e.g. copepoda, foraminifera) were excluded from the analyses. The diversity of macrofauna communities was investigated by calculating the following indices: Species richness (S), Abundance (N), Pielou's Evenness (J′) and Shannon-Wiener Diversity (H′) with log base 2.

To assess relatedness of sampling stations based on their benthic communities, data were first log(x+1) transformed to reduce the effect of extreme abundances. The similarity between stations was calculated using the Bray-Curtis similarity index and visualized through a non-metric multidimensional scaling (MDS) plot. The influence of the following abiotic parameters on the biotic communities was tested: depth, granulometry, temperature, salinity, total and organic carbon in the sediment, total nitrogen in the sediment, nitrate (NO_2), nitrite (NO_3), nitrate+nitrite (NO_2+NO_3), ammonium (NH_4), silicate (SiO_4), phosphate (PO_4), total dissolved nitrogen (TDN) and chlorophyll-α in the water column.

The similarity of the stations based on their abiotic characteristics was visualized through Multidimensional Scaling. Data were normalized (log(x+1)) prior to analysis and the similarity between stations was calculated using the Euclidean distance measure. Variables were fitted to the MDS using the *envfit* function of the *vegan* package in R and displayed as vectors on the MDS plot to identify those variables responsible for differentiating the stations. To assess which environmental factors play a role in structuring the benthic communities, a Permutational Analysis of Variances (PERMANOVA) was performed on the log(x+1)-transformed community data, testing the waterbody factor "lagoon/intermediary/coastal" and the factor "sediment type" (characterization of sediment according to Folk (1954), without interactions. A BIO-ENV analysis was performed using the normalized abiotic data to identify those abiotic variables that best match the multivariate community patterns. To complement the BIO-ENV analysis, an analysis of similarity percentages (SIMPER) was run based on Bray Curtis dissimilarities to determine the discriminating species that contribute most to the dissimilarity between habitats; the simper function of the vegan package in R was used (Oksanen et al., 2019).

The ecological status of the sites was calculated for two elements: the biological element (i.e. the benthic community), and the physio-chemical element. All indices are used for transitional and marine water bodies in Greece under the Water Framework Directive (2000/60/EC). The ecological status of the stations was estimated using the Multivariate AMBI (M-AMBI), as it is suited for environments with low species richness, e.g. lagoons and applicable to both transitional and marine regions (Muxika et al., 2007). To enable the comparison between the lagoonal and coastal stations, which have naturally different benthic ecosystem community structures, appropriate reference values were used to calculate the M-AMBI index depending on the habitat type. Reference values for bad/high status of the lagoon sites were: AMBI = 6/0.05, S = 0/50, H' = 0/4, respectively, and for the coastal mixed sediment type sites AMBI = 6/0, S = 0/120, H' = 0/6. Where applicable (the coastal marine sites), the ecological status was also corroborated with the BENTIX index (Simboura and Zenetos, 2002), which is the national index used in WFD coastal monitoring network.

The physicochemical quality of the sites was calculated with the Eutrophication index (EI) (Primpas et al., 2010). The Eutrophication index is a multi-metric index to assess trophic status based on a five-point scale, and is calculated as:

$$E.I = 0.279 * C_{PO4} + 0.261 * C_{NO3} + 0.296 * C_{NO2} 0.275 * C_{NH4} + 0.261 * C_{Chla}$$

Where C_{PO4} is the concentration of phosphate; C_{NO3} is the concentration of nitrate; C_{NO2} is the concentration of nitrite; C_{NH4} is the concentration of ammonium and C_{Chla} is the concentration of phytoplankton Chlorophyll-a (nutrient concentrations are calculated in mmol m^{-3}, and phytoplankton Chl-a in mg m^{-3}) (Primpas et al., 2010). The EI is used within the Greek EU Water Framework Directive and the Marine Strategy Framework Directive as an indicator to calculate Ecological Quality status (WFD) and Ecological status (MSFD). In addition, the EI has been compared to several other indices (the trophic index TRIX (Vollenweider et al., 1998), and the Chlorophyll-a biomass classification scheme (Simboura et al., 2005), and has been found to be a reliable tool for the assessment of eutrophication status in the oligotrophic waters of the Eastern Mediterranean (Pavlidou et al., 2014).

M-AMBI was calculated using the AZTI software (https://ambi.azti.es/), and the Bentix and EI indices were calculated in R (R core team 2018).

3. Results

3.1. Regional pressures originating from anthropogenic activities

Largely due to differences in bathymetry and connectivity, the different waterbodies (the lagoon, the bay, and the open sea) are likely to be impacted by anthropogenic pressures at varying levels (Table 3). However, in agreement with Newton et al. (2020) the dominant pressures to the region are caused by agricultural practices and changes to hydrology, and the lagoonal stations are much more susceptible to anthropogenic pressures than the coastal stations. Below the risk-based assessment of the main anthropogenic activities affecting the environmental conditions of the study area is presented in accordance with the IDEA protocol of evaluating expert judgements (Hemming et al., 2018). During the second evaluation round, the final scores of the experts were almagamaeted and merged, however due to the limited scoring options (Neglible, Low, Medium, High levels of pressures) and the discussion phases of the protocol, this was not applicable for the current study as the expert scores were all aligned for each pressure (SD = 0).

- Agriculture

The main economic activity of the region is agriculture (Hellenic Statistical Authority, 2001; Eurostat, 2015), and the region supports a high intensity of olive oil production, and edible olives, making the region one of the largest olive oil producers in Europe (Pavlidou et al., 2014). Effluents from olive oil wastewater, and nutrients and pesticides via agrochemical run-off from the surrounding areas are likely deposited in the lagoon (Petihakis et al., 1999). In 2016, total agricultural area in the prefecture of Messinia equated to 25% (734.3 km^2) of the total land cover, and olive groves cover approximately 82% (604.1 km^2) of this land (Hellenic Statistical Authority, 2016). Olive groves and agricultural land dominate the region to the north of the Gialova lagoon which are served by the rivers (Selas, and Giannouzagas) and canals (Xerolagados and Tyflomitis) for irrigation.

- Damming and changes to hydrology

The Gialova lagoon has been subjected to drastic anthropological changes over the last decades (Maneas et al., 2019). The nearby rivers were diverted during the 1960s in an attempt to reclaim the wetland for arable farming, and the two rivers that discharged into the lagoon were diverted, the sea-lagoon inlet was closed, a pumping station was installed to pump the water out of the lagoon, and the wetland was drained (Maneas et al., 2019). In an abrupt policy change during the late 1970s, the sea-canal was reopened, the pumping station was made obsolete, and the surrounding wetland was partially restored. During the late 1990s, culverts and sluice gates for freshwater were installed. During this period the sea canal was regularly closed and reopened, mostly because of sediment build-up and a lack of maintenance. Nowadays the lagoon only receives freshwater input from precipitation, surface run-off, groundwater flow, and two narrow sluice gates. The lagoon typology is classified as “restricted” under the Venice Classification system (Battaglia, 1959), and thus has relatively limited communication with the sea. It is separated from the Navarino bay by a 3-km long natural sandbank, and saltwater exchange occurs via a 100-m long canal, measuring 10 m in width, and 1.2 m in depth (Arvanitidis et al., 1999; Maneas et al., 2019). In addition to being redirected, low levels of surface water withdrawal from the Giannouzagas and Selas river are used to supply the Pylos reservoir (capacity of 460,000 m^3), and serves the irrigation needs of 270 km^2 of golf area and 250 km^2 of agricultural land (Special Secretariat for Water of the Ministry of Environment, Energy and Climate Change, 2013).

- Aquaculture ponds

Intensive aquaculture practices are not present in the study area. No aquaculture farms are located along the coastal region and in the Navarino Bay, and only low scale (extensive) traditional practices historically operate within the Gialova lagoon. Although the figure has varied throughout the past decades, currently only a small handful of fisherman exploit the lagoon for fishing by adjusting the outflow of water and thus fishing individuals ensnared at the mouth of the lagoon (Norrby, 2017), and in late 2018 the licensing of the lagoon for aquacultural purposes was in the process of being transferred to a new lessee, meaning no fish farming practices were in operation during the study period.

- Fishing

Fishing effort and landings are low in the study area, and there is no clear evidence of overfishing in the region. Due to its archaeological

Table 3
Pressure evaluation in the study area. The intensity of each pressure was estimated using a scale ranging from 0 to 3 (0 = Negliable, 1 = Low, 2 = Medium, 3 = High) with an expert evaluation based on the descriptions of the literature review sources detailed below and in Table 1.

	Gialova Lagoon			Navarino Bay		Coastal region						Total sum of pressures
	COGIA-1	COGIA-2	COGIA-3	COAS-3F	COAS-3G	COAS 3A	COAS 3E	COAS 2A	COAS 2B	COAS 2C	COAS 4A	
Agriculture	3	3	3	2	2	2	1	2	2	1	1	22
Damming and changes to Hydrology	3	3	3	2	2	1	0	1	0	0	0	15
Aquaculture	1	1	1	0	0	0	0	0	0	0	0	3
Fishing	1	1	1	0	0	1	1	1	1	1	1	9
Tourism and Eco-tourism	1	1	1	1	1	3	1	1	1	1	2	14
Shipping ports and marinas	1	1	1	2	2	1	1	1	1	1	1	13
Land reclamation	2	2	2	0	0	0	0	0	0	0	0	9
Urbanisation/ Industrialisation	0	0	0	1	1	0	0	2	0	0	2	6
Total sum per station	13	13	13	8	8	8	4	8	5	4	7	

status, the Bay of Navarino is a *de-facto* Fisheries Restricted Area (FRA) since 1962 (Fig. 1; Greek Law No: 35/B/1962). The lagoon is not heavily fished (see above), and large-scale fishing effort in the coastal region is low. The international, independent non-profit organisation Global Fishing Watch (globalfishingwatch.org) tracks and processes the automatic identification system (AIS) of large vessels and using an algorithm to detect vessel behavior, it calculates the number of hours spent fishing. In 2016, no AIS registered vessels were recorded fishing in the vicinity of the study area. Fishing hotspots were identified offshore in larger port towns (e.g. Kalamata in the Western Messinia Gulf, and Kyparissia in the Northern part of the Kyparissia Gulf). Despite it being possible for non-AIS registered vessels to be present in the area, the total annual landings for Gulfs of Kyparissia and Messinia was only 223 tonnes in 2019 (Hellenic Statistical Authority, 2019) and consisted mostly of pelagic fish species (hake, mackerel, sea bream, and amberjacks) along with several coastal and brackish species (e.g. red and grey mullets, bogues, and tiger shrimps). The total annual landings are roughly half of those from the neighbouring Laconikos Gulf (57%), 0.3% of the total landings in Greece (81,920 tones) reflecting the differences in fishing effort for the gulfs. Gear used by fisherman registered in the port of Pylos for the Greek national Program for the Collection of Fisheries data includes set gillnets, combined gillnets-trammel nets, set longlines and Beach Seines (https://inale.gr/national-fishing-data-collection-program_el). Importantly, fishing gear which has a drastic direct impact on benthic communities e.g. towed bottom fishing gears (trawls, dredges, and drags) are not registered at the port of Pylos (Kaiser et al., 2003).

- Tourism and Eco-tourism

The whole prefecture of Messina has a capacity of around 10,000 bed places and in 2018 saw a total of 1,142,046 visitors to the region with the majority arriving during the summer months (May–September, 67%) (Hellenic Statistical Authority, 2018). Tourism in the study area is focused on four areas: the harbour town of Pylos, the small coastal village of Gialova, the luxury coastal resort of Costa Navarino, and the Voidokilia beach on the Ionian coast. Very little tourism was present in the area during the sampling period (December, 2% of yearly visitor traffic to the region) (Hellenic Statistical Authority, 2001), and despite Gialova lagoon being classified as a Natura 2000 site, it receives a relatively low flux of tourists year-round. The nearby Voidokilia beach on the other hand is one of the most advertised beaches in the country. The relatively low levels of tourism at the site is not reflected in the amount of recorded marine litter.

The European-wide project Marine Litter Watch which encourages citizens to record observations of beach and marine litter has no records for the region, however, this may be due to temporal and spatial biases associated with citizen science (Callaghan et al., 2019). In 2003, Katsevanakis and Katsarou measured the sea bed litter at two stations within the Navarino bay and found the presence of only plastic, paper/cardboard, and clothing, and metal at relatively low levels (6.82, 0.97, and 0.97, and 0.45 items/km^2 respectively), and despite being located within a bay and thus at higher risk of litter accumulation, these stations were some of the lowest values they recorded in Greek waters (Katsanevakis and Katsarou, 2004). Since then however, the dispersion of litter and plastic waste in the environment has increased exponentially, likely due to the increase of summer arrivals the past decade (Maneas et al., 2019). During the survey period (December 2018, Supplementary files), a very high abundance of beach litter (3,239 items/100 m) was recorded on Voidokilia beach, compared to both the baseline value for the Ionian and the Central Mediterranean Sea (241 items/100 m, Hanke et al., 2019), and the acceptable threshold value of 20 items/100 m, recently adopted by the Marine Strategy Coordination Group (MSCG) for European coastlines to achieve "Good Environmental Status" under the Marine Strategy Framework Directive (Van Loon et al., 2020). The beach litter abundance on Divari and Romanos beaches was 746 and 596 items/100 m, respectively. Plastics were the most abundant material on all beaches (more than 93%), with cigarette butts being the second most frequent item found on Voidokilia and Divari beaches, indicating beach-users as the main source of litter.

- Shipping, ports, marinas

The study area is host to a small port and marina (Pylos) and a landing jetty for small vessels (Gialova). As noted in the UK Admiralty Sailing directions, Pylos Port is suitable for handling small vessels only, primarily local ferries, pleasure craft and yachts, and fishing vessels (UK Hydrographic Office, 2020). The low levels of port traffic in the study area are reflected in the observed numbers of alien species in the region, as invasive alien species are commonly found in increased numbers in the vicinity of ports and harbours after being transported in ballast waters or as biofouling on hulls of recreational and commercial vessels (Firestone and Corbett, 2005). Of the 850 invasive species in Greek waters recorded by the Hellenic Network for Invasive species (ELNAIS) database, a total of 16 species (observed in over 340 locations) have been recorded in the wider vicinity of the study area (the South Eastern Ionian coastline), and eight within the study area (Gialova lagoon, Navarino Bay, and the Pylos coastal region) (https://elnais.hcmr.gr/elnais-database). Of these sightings, 30% are traced to two Lessepsian migrant Rabbitfish (*Siganus rivulets* and *Siganus luridus*) which have become well established in the area, and are considered to be linked to frequent overgrazing of the Navarino Bay rocky habitats (P. Lardi pers. comm.). Other invasive species observed within the Gialova lagoon, and the Navarino bay include *Fistularia commersonii* (n = 2) (Poursanidis and Zenetos, 2013), the decapod *Percnon gibbesi* (n = 1) (Poursanidis and Zenetos, 2013), the gastropod *Polycerella emertoni* (n = 1) (Koutsoubas et al., 2000b), and the rhodophyta *Asparagopsis taxiformis* (n = 1) (Tsiamis et al., 2010). Compared to other regions of the Ionian and Greek waters (e.g. the Laganas Bay on the Island of Zakynthos), the invasive species observations density in the region is low and does not appear to exert heavy pressure on the marine ecosystem.

- Land reclamation

Substantial areas of wetland marsh habitat have been lost over the last decades (See above, changes to hydrology). Since 1960, 48% of the marshland has been reclaimed for agriculture in the Gialova region (Maneas et al., 2019). Habitat loss for wild species, increased CO_2 and N_2O production from agriculture, and an increase in flooding events are all common consequences of wetland reclamation (Li et al., 2018), and are likely to have impacted the present study area.

- Urbanisation/Industrialisation

Out of the 381 industries that have been recorded in the river basin where the Gialova loagoon is located (Pamisos – Nedontas – Neda River Basin), 188 have been assessed as significant for the Water Framework Directive (e.g. they form the cause for the water basin to be in danger of not achieving its environmental objectives). Most of them relate to olive oil production (72% of the plants) and production of jams and mashed fruits (Greek Special Secretariat for Water of the Ministry of Environment, Energy and Climate Change, Government Gazette: 1004/B/24-04-2013). There are two Wastewater Treatment Plants (WWTP) in the region. The smaller of the two is connected to the village of Nestor, near the mouth of the Selas river (Fig. 1), serving a population equivalent of 12,000. The larger WWTP of Pylos has an entering load capacity equivalent to a population of 17,330 and serves the needs of both the town and the adjacent tourist resort. During the sampling period of 2018, the sites complied with most requirement thresholds for the EU Waste Water Treatment Directive (biodegradable organic substances (BOD5), chemical oxygen demand (COD), total suspended solids (TSS)), however, Pylos failed to reach the threshold for appropriate biodegradable organic substance levels (Greek Wastewater Treatment Plants

Monitoring Database). It is unclear the impact the wastewater discharge from these plants has on the nearby marine environment. A recent study on the metal pollution of coastal and transitional waters of Greece, based on results from the WFD national monitoring, has classified as the water bodies of the lagoon for nickel and cobalt as being "above background levels" and likewise for copper levels in the Navarino Bay, indicating a "moderate" chemical status for the area (Tzempelikou et al., 2021).

3.2. Environmental conditions in the study area

Generally, the lagoon, intermediary and coastal stations indicate a clear environmental gradient as the habitat transitions from a terrestrial brackish environment to a deeper saline coastal habitat. The less saline muddy substrate lagoon stations have a higher organic carbon load in the sediments, higher nutrient and chlorophyll-α load in the water column, and higher dissolved oxygen concentration due to their shallower depths and increased wave action throughout the water column (Table 4).

3.3. Benthic invertebrate communities

In total 202,667 individuals/m^2 belonging to 20 taxa were recorded at the lagoonal stations (an average of over 67,000/m^2 individuals per station), with Annelida being the most abundant phylum for the lagoon stations, due to the abundance of oligochaeta species at these sites. The lagoon sites were dominated by Chirinomidae and Oligochaetes, taxa typically found in regions with increased freshwater input, species typical of euryhaline brackish water species found only close to the lagoon mouth (*Abra segmentum*, COGIA-1) (Nicolaidou et al., 2005). The polychaete *Capitella capitata*, an opportunistic species commonly found in organically enriched areas, was recorded in high numbers at all three lagoon stations (Table S1, Supplementary files). The high abundances in the lagoon results in, as expected, a low evenness (Pielou's index), as the benthic communities were of a low species richness and low diversity (Shannon-Wiener). The SIMPER analysis shows that few taxa strongly distinguish the benthic communities of the lagoonal stations from the intermediary and coastal stations (Table 5). Oligochaeta species and the polychaete *Capitella capitata* contributed to over 70% of the dissimilarity in community structure in both cases (Table 5). No clear dissimilarities were apparent for the coastal vs intermediary stations. The tanaid *Apseudopsis* cf. *apocryphus* contributed most to the waterbody dissimilarity (5.11%), and only 15 species contributed to more than 1% of the dissimilarities between the two waterbodies.

The intermediary stations (COAS 3F and 3G) were the least species-rich and showed the lowest abundance; 1689 individuals/m^2 belonging to 12 taxa were recorded. This is likely associated with the shallow station depths and the influence of wave action at the sites. Arthropods (crustaceans) were the most abundant phylum for the intermediary stations (COAS 3F and 3G), and most of the taxa recorded at the sites (83%) are exclusively marine organisms, with the exception of the polychaete *Capitella capitata*.

The coastal stations were characterised by very evenly distributed communities, and higher levels of species richness and diversity (maximum lagoon species richness = 12, maximum coastal species richness 137; Table 6). In total, 7761 individuals/m^2 belonging to 273 taxa were recorded at the coastal stations (an average of 1294/m^2 individuals per station). The highest number of species and individuals was recorded at station COAS-4A (137 species, 2410 individuals; Table 6), this is due to the presence of a complex biogenic habitat with complex structure at the site (Rhodolith beds), providing micro-habitats that support a plethora of macroinvertebrate species. Annelids, arthropods, echinoderms and molluscs were all present at the coastal stations, with the dominating phylum alternating depending on the site. Burrowing species typical of fine silty sands were common (e.g. *Bathyporeia guilliamsoniana*, *Moerella donacina*, and *Myrtea spinifera*). A species of bloodworm (*Glycera oxycephala*) was recorded in the two stations closest to the lagoon (COAS-3A and COAS-3E); this is the first known record for Greek waters.

Multidimensional scaling revealed a clear separation of the lagoonal stations from the coastal stations, with the shallow-water intermediary stations being placed in an equidistant position and secondly a separation of the stations COAS-2C and COAS-4A from the other coastal stations and to each other (Fig. 2A). This is confirmed by the PERMANOVA analysis, which found sediment composition to significantly affect the community structure, after the water body factor (lagoon/intermediary/coastal) ($F = 5.7024$, $p = 0.002$/$F = 1.9174$, $p = 0.033$, respectively). This strong differentiation of the stations based on their benthic community composition reflects the strong differentiation of the stations based on their environmental characteristics, and indeed, the MDS pattern obtained from the set of environmental variables shows a similar grouping (Fig. 3B).

Fitting the environmental variables onto the MDS plot reveals that sediment characteristics and depth are the two major vectors differentiating the deeper COAS 2C station (50 m) from the remaining coastal

Table 4
Selected environmental variables per station.

Station	Temp (°C)	Salinity	% of Sand in sediment	% Organic carbon in sediment	Dissolved oxygen (mg/l)	NO3 + NO2 (μmol/l)	PO4 (μmol/l)	NH4 (μmol/l)	TDN (μmol/l)	Chl α (μg/l)
COGIA-1	12.15	34.77	61.70	2.73	8.63	4.41	0.36	11.55	52.20	3.08
COGIA-2	12.52	34.35	53.58	3.95	8.89	4.30	0.06	14.61	61.00	3.70
COGIA-3	12.44	34.21	69.84	2.49	9.12	5.59	0.04	13.93	52.50	3.23
COAS-3F	18.83	38.75	97.33	0.08	8.31	4.05	0.15	10.76	63.60	0.13
COAS-3G	13.14	34.03	97.58	0.10	9.80	1.95	0.06	5.90	62.30	0.31
COAS-3A	18.90	38.98	97.70	0.08	4.53	0.08	0.15	0.21	3.70	0.04
COAS-3E	19.06	38.93	96.89	0.18	4.54	0.24	0.06	0.05	3.80	0.06
COAS-2A	18.98	38.96	95.73	0.07	4.46	0.08	0.02	0.48	23.70	0.03
COAS-2B	18.95	38.95	96.15	0.06	4.42	0.08	0.02	0.18	4.00	0.08
COAS-2C	19.26	38.98	55.96	0.45	4.43	0.08	0.02	0.05	4.10	0.09
COAS-4A	19.26	39.00	26.30	0.74	5.91	0.08	0.03	0.05	3.60	0.09

Table 5
Comparative results of SIMPER analysis between the lagoon and intermediary/coastal offshore stations. Species contributing to 90% of cumulative Bray Curtis dissimilarity metric total are shown. Figures are rounded to 2 significant figures.

	Lagoon vs Intermediary		Lagoon vs Offshore	
	% Average Contribution	Cumulative %	% Average Contribution	Cumulative %
Oligochaeta	47.88	48.36	49.80	50.10
Capitella capitata	25.18	73.78	26.33	76.58
Neodexiospira pseudocorrugata	9.23	83.11	9.59	86.24
Chironomidae	2.00	85.13	2.08	88.33
Idotea balthica	1.07	86.2	1.11	89.44
Onchnesoma steenstrupii steenstrupii	0.80	87.01		
Apseudopsis apocryphus	0.71	87.73		
Mysidae	0.54	88.28	0.72	90.17
Scoloplos armiger	0.46	88.74		
Aricidea (Acmira) assimilis	0.35	89.09		
Kirkegaardia heterochaeta	0.33	89.43		
Micronephthys longicornis	0.28	89.71		
Loripes lacteus	0.26	89.98		
Heteromastus filiformis	0.23	90.22		

Table 6
Ecological indices: total number of species (S), Diversity (H'), Evenness J and abundance N (ind/m^2) for each station.

	Station	Species richness (S)	Min-Max S per region	Mean abundance/ m^2 (N)	Min-Max N per region	Shannon- Wiener (H′ log_2)	Min-Max H′ per region	Pielou's (J′)	Min-Max J′ per region
Lagoon	COGIA 1	12	10–12	26837	17981–26837	1.47	1.47–1.9	0.52	0.52–0.68
	COGIA 2	10		17981		1.69		0.60	
	COGIA 3	10		23659		1.9		0.68	
Intermediate	COAS 3F	9	5–9	533	356–533	2.98	2.00–2.98	0.85	0.85–0.69
	COAS 3G	5		356		2.00		0.69	
Coastal	COAS 3A	56	56–137	1401	913–24010	5.29	4.91–6.61	0.96	0.95–0.98
	COAS 3E	44		913		5.11		0.96	
	COAS 2A	46		1003		4.91		0.95	
	COAS 2B	61		965		5.73		0.98	
	COAS 2C	79		1418		6.05		0.98	
	COAS 4A	137		24010		6.61		0.98	

stations. Besides salinity, temperature, and sediment characteristics, nutrient load and physicochemical conditions separate the coastal stations from the lagoon system, with lagoonal stations showing higher values in chlorophyll-α, dissolved oxygen, NH_4, NO_2, NO_2+NO_3, organic carbon, SiO_4, TDN, total carbon, total nitrogen and NO_3, and lower values of temperature and salinity than the deeper coastal stations. The shallow-water stations are characterised by high values of dissolved oxygen (due to wave action) and TDN, while the NH_4, NO_2 NO_3, NO_2+NO_3 and SiO_4 measurements show intermediate values between coastal and lagoonal stations.

Concerning salinity and temperature, the shallow-water intermediary stations do not show a spatial gradient; the station closest to the lagoonal mouth shows similar temperatures and salinity values to the lagoonal stations, the station further towards the sea is characterized by a marine temperature and salinity regime. The BIO-ENV analysis also confirmed that the combination of salinity, dissolved oxygen, silicate, total dissolved nitrogen and the percentage of sand were the main variables (Rho = 0.938) influencing the structure of the benthic communities (e.g. the number of species and their relative abundances).

3.4. Ecological quality

The coastal stations in the study area present a Good or High ecological quality for both the biological elements (M-AMBI) (average coastal station M-AMBI score ± STDEV: 0.77 ± 0.11) and the trophic elements (EI) (average coastal stations EI score ± STDEV: 0.11 ± 0.04), showing that the coastal area has not deteriorated as a result of anthropogenic activities (Fig. 4). The M-AMBI ecological status of the coastal stations was corroborated by the BENTIX index (status ranged from GOOD to HIGH). Contrarily, the lagoonal stations are classified as POOR or BAD by the M-AMBI index, indicating that the ecosystem is strongly affected from anthropogenic stressors, especially from nutrient enrichment (average lagoon stations M-AMBI score ± STDEV: 0.22 ± 0.03; average lagoonal stations EI score ± STDEV: 5.85 ± 0.52) (Fig. 4). The shallow intermediary stations near the lagoon are classified into Poor and Moderate ecological statuses (average intermediary station M-AMBI score ± STDEV: 0.38 ± 0.05), and as a Bad physico-chemical status (average Intermediary station EI score ± STDEV: 3.17 ± 1.32) (Fig. 4).

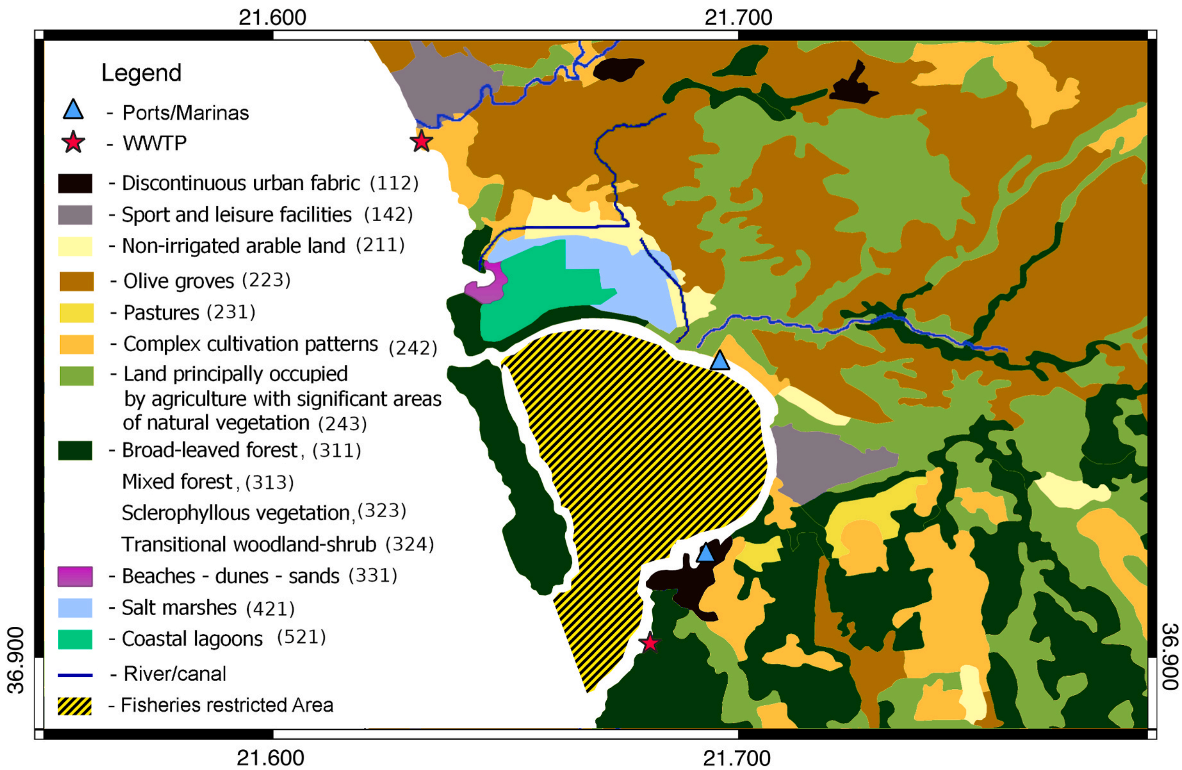

Fig. 2. Land Cover uses of the study area (2018) primarily based on CORINE Land Cover (CLC) inventory (Copernicus Land Monitoring Service). Numbers in legend represent the corresponding CLC classes.

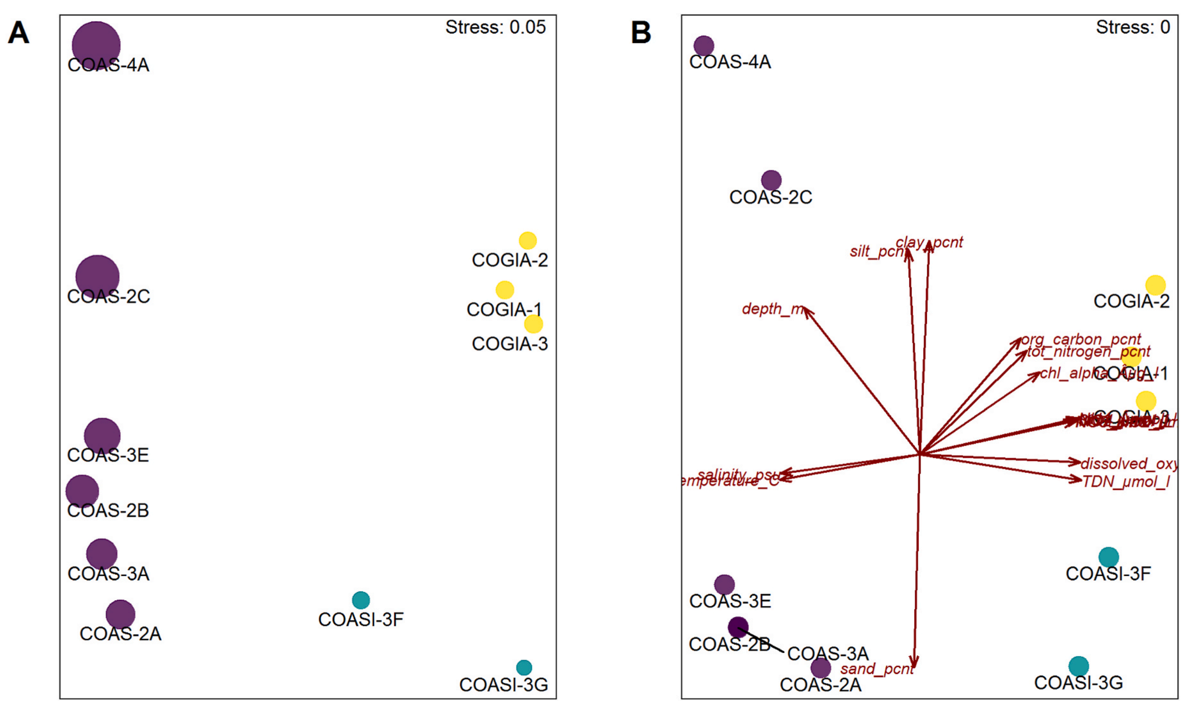

Fig. 3. **A**) MDS based on species densities, point sizes indicate depth. **B**) MDS based on abiotic variables with fitted vectors of environmental variables as an overlay. Point colours indicate waterbody characterization: yellow = lagoon, aqua = intermediary shallow-water, purple = coastal. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

3.5. Discussion

The assessment of the regional pressures clearly showed that the Gialova lagoon is the most affected site in the area. Intense agriculture, human induced changes to hydrology, and land reclamation are the primary pressures for this transitional waterbody. Other important human activities, such as tourism, shipping, and urbanization appear to only moderately influence the ecological status of the Gialova lagoon,

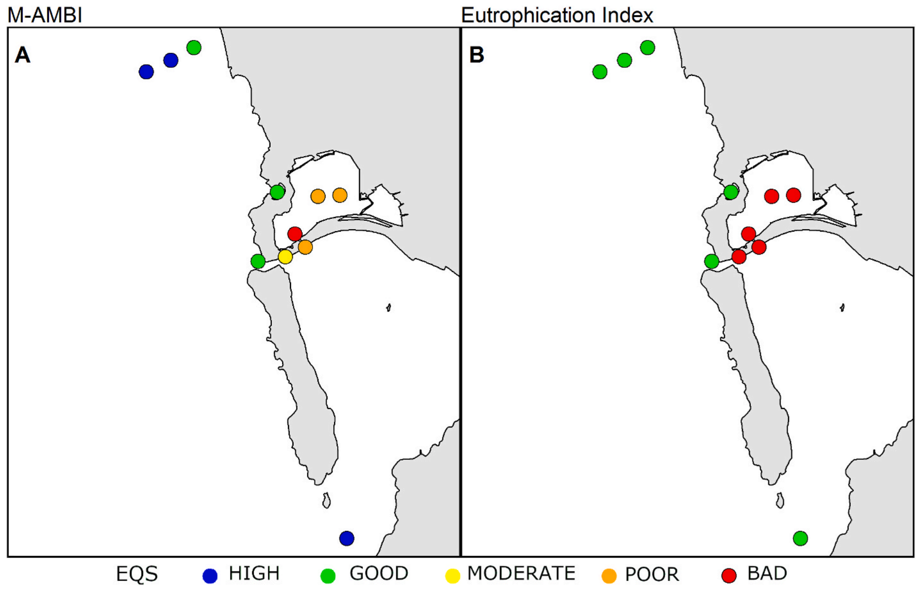

Fig. 4. Ecological status of each station shown on the map of the area using the A) M-AMBI index and B) the Eutrophication Index.

the Navarino Bay and the other coastal sites, but their environmental impact especially in tourist hotspots could increase with further touristic development in the area. Despite expert judgements being commonly used for gauging pressure intensities in coastal ecosystems, where empirical data is typically unavailable (e.g. Barbone et al., 2012), it is important to note the fallacies associated with its use. It is clear that it's reliability as a method, will always be sensitive to the profile and experience of selected experts, and how questions are formulated and assessed. However, the incorporation of the IDEA protocol used in this case (Hemming et al., 2018) is an attempt to reduce the level of individual bias through crowd wisdom and discussion-based techniques.

The results of the environmental study show that the status of the benthic communities, clearly reflects the environmental conditions, with remarkable differences between the water body types (transitional vs coastal), highlighting the vulnerability of the lagoon to anthropogenic impact, especially eutrophication. During the study period, the lagoon was heavily degraded compared to the surrounding coastal zone. This is reflected both in the trophic status (Eutrophication Index) and the ecological status (M-AMBI index). Reasons for this degradation have to do with the geomorphological features and hydrological regime of the lagoon, regarding both the freshwater input from the river basin, and the degree of communication with the sea, a common issue for Mediterranean lagoons (Reizopoulou et al., 2014). Excessive nutrient levels in the freshwater inputs can cause accelerated growth of algae in the water column resulting in bio-chemical equilibrium shifts, and ultimately a decay of oxygen levels, something coastal lagoons are particularly vulnerable to (ZaldívarJosé-Manuel et al., 2008; Ménesguen and Lacroix, 2018). Dystrophic crises have been recorded during warmer months by several past studies (Arvanitidis et al., 1999; Koutsoubas et al., 2000a, 2000b; Chatzigeorgiou et al., 2011). During the study period (winter), the lagoon had relatively high oxygen levels due to wind-induced mixing of the water column, and the dominance of Chironomidae and Oligochaetes at the lagoon sites, indicates that the lagoon was subject to high freshwater inputs (e.g rainfall, groundwater flow) around the time of the sampling.

The number of species (S), and the level of diversity (H) were of some of the lowest values ever recorded for the Gialova lagoon (Koutsoubas et al., 2000b), and much lower than other Western Greek lagoons (Reizopoulou and Nicolaidou, 2004). The degraded status of the lagoon becomes also evident when comparing Gialova to other lagoons in the monitoring network of Greek Lagoons for the Water Framework Directive (http://wfdver.ypeka.gr). Typical euryhaline brackish water species (e.g *Abra segmentum)* were notably limited in number for the lagoon stations and found only close to the lagoon mouth, reflecting the overal ecological status of the lagoon. Overall, the lagoon stations had a low number of species with very uneven distribution, dominated by oligochaetes; a common occurrence for transitional waters with high levels of organic matter (Nicolaidou et al., 2005; Armendáriz et al., 2011). In addition, the strong presence of the opportunistic polychaete *Capitella capitata* at all three lagoon stations strongly suggests organic enrichment occurred previous to the time of sampling. Leaching of excess nutrients from agricultural practices, and domestic wastewaters are the likely cause of the higher levels of nutrients during the winter months (Petihakis et al., 1999), however it is important to note that changes in nutrient dynamics due to substantially increased tourism and coastal occupation rates during the summer months are also expected (Pérez-Ruzafa et al., 2019). The environmental results are in-sync with the identification of anthropogenic pressures in the study area.

The coastal marine stations on the other hand were more diverse and supported higher rates of sensitive species (higher AMBI and BENTIX index values). Despite a natural difference in species diversity and richness being expected between the two habitats due to physial stresses in place within lagoonal ecosystems, the poor status of the Gialova lagoon accentuated the differences in the two habitats. The status of the stations downstream of the Selas River (COAS 2A, COAS 2B, COAS 2C) were seemingly unaffected by any downstream discharge of nutrients, or the nearby wastewater treatment plant (AMBI, Eutrophication and diversity indices). Also, no deterioration of status was apparent at station COAS 3A, by any potential nutrient discharges from the Xerolagados canal or pollution originating from the nearby tourist hotspot (plausibly due to the sampling season). The slow-growing biogenic rhodolith habitat recorded at station COAS 4A just south of the port town of Pylos, harboring the highest macrofauna diversity of the area, is extremely sensitive to demersal fishing methods and bouts of increased nutrient pollution (Grall and Hall-Spencer, 2003). The station is a strong indication that fishing pressure in the area is indeed low, and that the failure of the Pylos WWTP to achieve the threshold for appropriate biodegradable organic substance levels in 2018 did not materialise in any obvious habitat degradation during the study period.

The status of the intermediary stations appears to be influenced by the winter exodus of brackish water from the Gialova lagoon (Eutrophication index classification: Bad), indicating a flushing of excess nutrients from the lagoon to the intermediary stations. It is expected that during the winter months the brackish water output from the lagoon

(lagoon → coastal) is at its highest due to increased rainfall (Manzoni et al., 2020), however, there appears to be relatively low levels of connectivity between the lagoon, the intermediary zone, and the coastal area. A typical lagoon confinement gradient could not be detected in benthic communities (Reizopoulou and Nicolaidou, 2004; Canu et al., 2012), however during the study period, a eutrophication gradient appears to occur along the nutrient-rich lagoonal waters, the intermediary area operating as a sharp environmental filter, and the coastal zone.

The degradation of the lagoon ecosystem status (especially in comparison to the coastal environment) induces multiple impacts to the ecosystem services the lagoon provides. The study area hosts a large variety of fauna and flora, including over 270 species of birds (Norrby, 2017), and the designation of the Gialova lagoon as a Special Protection Area (SPA) under the birds directive (GR2550008), means that the Greek state is obliged to take appropriate management measures to avoid pollution or deterioration of habitats or any disturbances affecting the birds (2009/147/EC). Although not explicitly measured here, macro-invertebrate communities are an important trophic link for top predators in transitional water ecosystems (i.e. birds) (Touhami et al., 2018), and contribute towards the overall health of the ecosystem (Guareschi et al., 2015). Other direct impacts caused by the degradation of ecological status in the lagoon are likely to involve the loss of suitability for aquaculture and fish production. Secondary impacts e.g. the loss of flood protection, water purification, and oxygen production services are also a risk (Newton et al., 2018).

To maintain a healthy lagoonal ecosystem and to develop the provision of ecosystem services, management plans are proposed to open additional inlets to increase hydrological circulation, and restrict the extent, and duration, of dystrophic crises. Despite regular closures in the past, the sea-lagoon inlet allows water exchange almost continuously since 2010 (Maneas et al., 2019), yet the ecological status monitored under the WFD monitoring program has remained "Poor" since monitoring of the site began in 2013 (EEA, 2020). The physical barriers limit the connection to the sea and restrict the water renewal. As noted by previous studies, past dystrophic episodes in the Gialova lagoon were likely caused in part due to the limited seawater influx permitted by the shallow 100-m long entrance canal (Arvanitidis et al., 1999; Chatzigeorgiou et al., 2011; Koutsoubas et al., 2000a, 2000b). In addition, the lagoon acts as a sink for agrochemical wastewaters, a challenge recognized by the local farming communities that have participated in a series of stakeholder meetings organized as part of the EU Horizon COASTAL project. Therefore, simply increasing lagoon-sea connectivity, without addressing the role that high levels of excess nutrients have on the ecological status of the adjacent marine that area, is likely to be counter-productive.

A stepwise approach of response policies is required if a holistic ecosystem approach is recommended. Firstly the quantity of excess nutrients that leaches into the Gialova lagoon needs to be addressed, either by directly reducing the amount of fertilizer applied within the river basin or by indirectly restoring local wetlands to operate as filters for the removals of nutrients from the water column (Mateo and Romero, 1997). Reducing the amount of fertilizers applied is also in line with the Farm to Fork Strategy of the European Green Deal. Once the excess nitrite-nitrate levels of the lagoon are reduced, the second response should be to ensure increased seawater flushing into the lagoon by the enlargement and maintenance of the sea-lagoon exchange inlet. Flushing lagoons with seawater limits sediment accumulation, protects against oxygen depletion, and ensures a continuous supply of marine colonisers into the lagoon thus ensuring a more robust system. The co-creation of a system dynamics model, following participatory modeling strategies (Voinov et al., 2018) as part of the stakeholders workshops organized within the framework of the COASTAL project (Akinsete et al., 2021) fosters analytic-deliberation and promotes social learning about the system among participants (Stave, 2010). Including stakeholders in the process increases understanding about system behaviours and helps connect local concerns with lagoon management which is essential for achieving the transition towards collaborative integrated agricultural practices that will enable the restoration of lagoon connectivity (both with upstream rivers/canals and the marine coastal zone) without further adverse impacts on the lagoon ecology (Manzoni et al., 2020).

4. Conclusion

The macrobenthic community reflects the environmental condition of the coastal area in SW Messinia and indicates that the Gialova lagoon is severely degraded, most likely due to high nutrient input from the agricultural practices that are prevelent in the river basin. In comparison, the coastal area enjoys a status of high ecological quality, and appears less impacted by human activities, with the exception of tourism that seems to be an important source of beach litter. To some extent, the lagoon operates as a buffer between the land and sea. It retains the agrochemical waste from the surrounding catchment area, with the nearby coastal area affected by the flushing of nutrients from the lagoon. Although further studies are required to examine the influence of anthropogenic pressures during other seasons, this information is an important basis for addressing management measures taking in account the socio-economic conflicts in the area.

CRediT authorship contribution statement

Laura Bray: Conceptualization, Formal analysis, Methodology, Writing – original draft. **Sarah Faulwetter:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing, Validation. **Helen Kaberi:** Methodology, Writing – original draft, Writing – review & editing. **Aristomenis P. Karageorgis:** Funding acquisition, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Erasmia Kastanidi:** Investigation, Methodology, Writing – original draft, Writing – review & editing. **Nikolaos Katsiaras:** Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Alexandra Pavlidou:** Methodology, Writing – original draft, Writing – review & editing. **Nikolaos Providakis:** Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Kaliopi Sigala:** Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Emanuela Voutsinas:** Conceptualization, Investigation, Writing – review & editing, Methodology, Writing – original draft. **Christina Zeri:** Methodology, Writing – original draft, Writing – review & editing. **Sofia Reizopoulou:** Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Visualization, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecss.2022.107935.

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