Transitional Waters Bulletin
TWB, Transit. Waters Bull. 3 (2009), n.1 29-44
ISSN 1825-229X, DOI 10.1285/i1825229Xv3n1p29
http://siba-ese.unisalento.it

RESEARCH ARTICLE

Fish assemblage response to environmental pressures in the Venice lagoon

Anita Franco[1*], Federico Riccato[1,2], Patrizia Torricelli[1], Piero Franzoi[1]

[1]Dept. of Environmental Sciences, University of Venice, Castello 2737/B - 30122 Venice, Italy.
[2]Laguna Project s.n.c, Castello 6411 - 30122 Venezia, Italy.
* Corresponding author: Phone +390412347732; Fax +390415281494; E-mail afranco@unive.it

Abstract

1 - Venice lagoon (Italy), being a transitional water environment, is subjected to several environmental pressures of anthropogenic origin, with a likely impact on the overall ecological status of the system.

2 - Following the Water Framework Directive (WFD, Directive 2000/60/CE), water bodies are to be characterised by the pressures acting on them, and fish assemblages can be used as biological quality element of their ecological status. The Venice lagoon basin has been divided into 14 water bodies, belonging to 5 types, according to the national classification.

3 - With the aim of comparing the role of anthropogenic pressures and environmental background in affecting the lagoon fish assemblages, human pressures have been identified and their magnitude quantified in each lagoon water body, with particular reference to 3 pressure categories: pollution (including nutrient enrichment), direct pressures on the habitat and the living organisms (with particular regard to fishes), and indirect pressures deriving from ground occupation (adjacent land uses).

4 - Fish assemblage attributes (both taxonomical and functional), in sites located within 4 lagoon water bodies (fish samples were collected in 2001-2002 by using fyke nets), were related to the respective pressures acting on these water bodies, by taking into account also the contribution of natural environmental variability among the studied areas, including habitat diversity.

5 - Results showed similar significant effects of environmental background and anthropogenic pressures on the lagoon fish assemblages. This highlights the importance of controlling for environmental variability to allow the detection of the signal of human impact on biological assemblages when attempting at the evaluation of lagoon ecological status.

Keywords: Venice lagoon; anthropogenic pressures; environmental background; fish assemblage response; Water Framework Directive

Introduction

Despite their important ecological role, estuaries and coastal lagoons are often highly modified and threatened aquatic environments, being subjected to a high degree and a wide array of human pressures and impacts (Vasconcelos *et al.*, 2007). This anthropogenic influence combines with a general high natural environmental variability in these systems, whose effect on the biota may shade off the anthropogenic one (*sensu* Elliott and Quintino, 2007).

The Venice lagoon is an ideal case study to assess this interaction between anthropogenic and environmental influence on biota. Given its wide area (about 55000 ha) and its hydro-morphology, a high spatial natural heterogeneity characterises this system, leading to a mosaic of habitats and multiple environmental gradients (Ravera, 2000;

Franco *et al.*, 2006a, 2006b). This spatial variability reflects on the identification of 4 different water body types within the lagoon basin, defined on the basis of the national criteria for type definition, aimed at fulfilling the Water Framework Directive requirements (WFD, 2000/60/EC; Dm Ambiente 16 June 2008, n.131). Given the common location in the Mediterranean ecoregion, the coastal lagoon type geomorphology, the microtidal range (50 to 100 cm) typical of North Adriatic lagoons, and the wide area (>2.5 km^2), these water body types differ according to salinity (polyhaline and euhaline average annual conditions), and to confinement degree (confined and non-confined). An additional water body type has been given for the highly modified basins, located in correspondence of the main urban and industrial areas (Venice and Porto Marghera) and the fishing ponds (locally named "valli") located at the inner lagoon edges (Figure 1) (MAG.ACQUE-Thetis, 2009).

The Venice lagoon is also highly subjected to anthropogenic pressures. Actually, the lagoon has co-evolved in past centuries with human presence, which modified the natural processes in the system in order to maintain the lagoon morphological structure (e.g. rivers diversion out of the lagoon, sea inlets maintenance, etc.). At present, a variety of pressures is acting on the lagoon, due to the presence of urban areas, industrial sites, agricultural lands in the lagoon drainage basin, leading to several and diverse impacts on the lagoon system and its biota (MAG. ACQUE-Thetis, 2006). Being these pressures not homogeneously distributed in the lagoon, the lagoon water body types have been further divided into 14 water bodies (Figure 1). In order to fulfil the requirements of the WFD, these water bodies need to be characterised according to the pressures acting on them and must be assessed for their ecological status. Biological quality elements, such as fish fauna, can be used for this purpose (WFD, 2000/60/EC; Whitfield and Elliott, 2002; Franco *et al.*, 2009).

The aim of this study was to compare the role of anthropogenic pressures and environmental background in affecting lagoon fish assemblages. Anthropogenic pressures were quantified for the different lagoon water bodies, and were related to the fish assemblage characteristics in the lagoon, by taking into account also the environmental background variability. This would allow to understand the importance of background noise and human signal in affecting lagoon biota, thus providing useful knowledge to cope with the "estuarine quality paradox" (Elliott and Quintino, 2007) while assessing the ecological status of transitional water bodies.

Materials and Methods

Anthropogenic pressures

The main indicators for pressure evaluation in transitional waters were revised from literature, with particular regard to those affecting fish fauna (Deegan *et al.*, 1997; Meng *et al.*, 2002; Aubry and Elliott, 2006; Borja *et al.*, 2006; MAG. ACQUE - Thetis, 2006a; Breine *et al.*, 2007; Vasconcelos *et al.*, 2007; Chainho *et al.*, 2008; Uriarte and Borja, 2009).

Pressures in the lagoon were distinguished into 3 main categories: (I) Pollution (including chemical contamination and nutrients enrichment); (II) Direct pressures on the habitat and the livings (with main regard to fish fauna); (III) Indirect pressures from land uses in the adjacent territory. For each category, several indicators were selected, based on the above mentioned bibliographic research, on their suitability to the lagoon system and on the data availability for their calculation in the different lagoon water bodies. Being the fishing ponds mainly state properties under granted use by private companies, no data were available for these water bodies (VLN and VLCS, Figure 1),

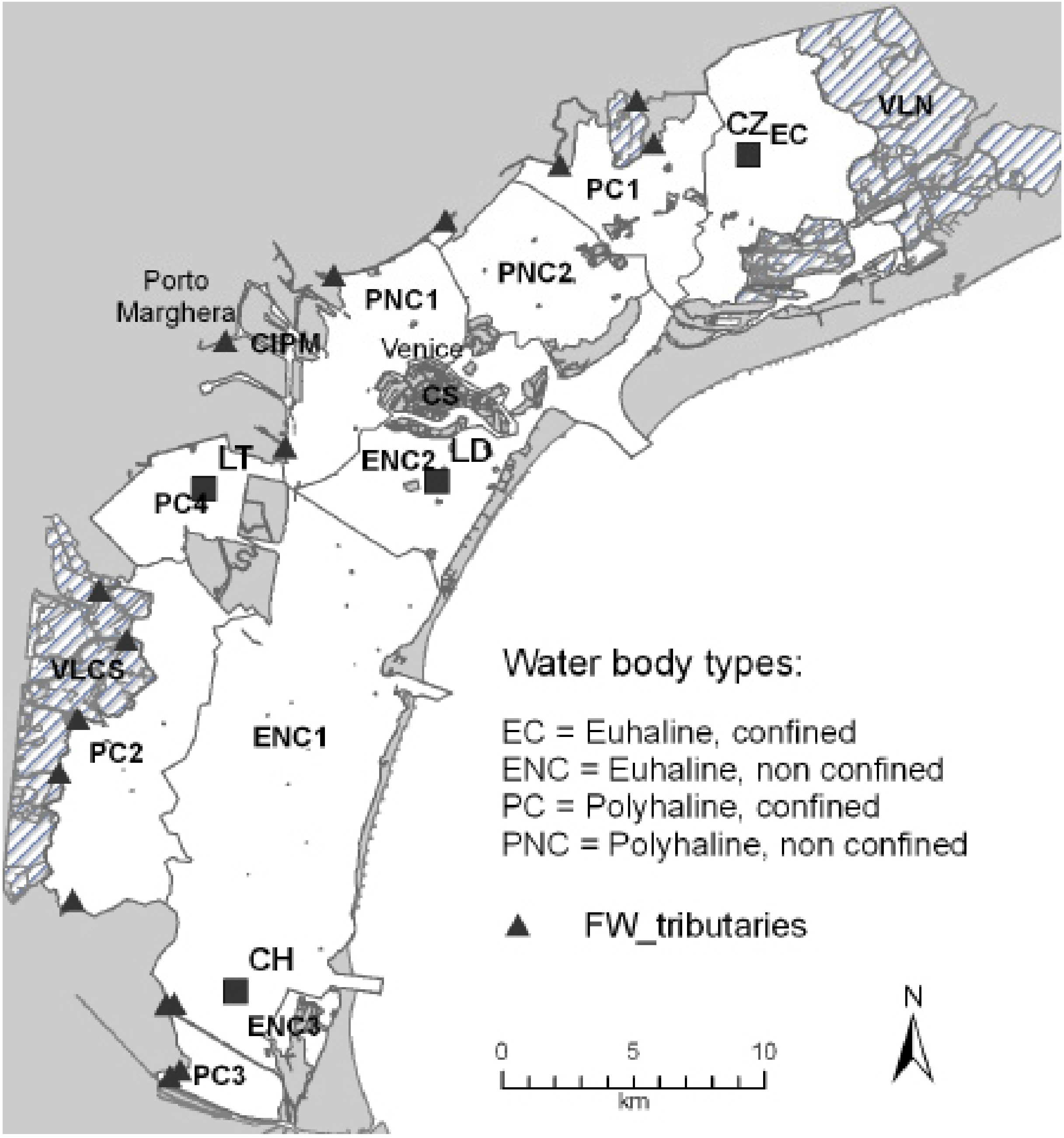

Figure 1. Water bodies in the Venice lagoon and location of the fish sampling sites (CH, CZ, LD, LT). Natural water bodies are named according to their typology (euhaline or polyhaline, E or P, and confined or non-confined, C or NC) and their progressive number. Highly modified water bodies are: CS, city of Venice; CIPM, industrial area of Porto Marghera; VLN, fishing ponds of the northern lagoon; VLCS, fishing ponds of the central-southern lagoon.

hence they were excluded from the analysis.

Seven pollution indicators were identified (Table 1). The average annual load of nutrients (total Nitrogen and Phosphorus) directly introduced into each water body by the main lagoon freshwater tributaries (years 2001-2005; ARPAV, 2009) and by localised inputs from the main industrial

Table 1 - List of the pressure indicators applied to the Venice lagoon water bodies and their measurement units.

Pressure	Indicator	Description	meas. unit
Pollution	NutrLoad	Total Nutrients Load	t y^{-1}
	TrophState	Yearly average "trophic" level index	(avePC1)
	DO	Minimum dissolved oxygen concentration (Ind-)	%sat
	PollLoad	Total Metals Load	t y^{-1}
	Shipyards	No. of shipyards using antifouling organotin paint	(no.)
	SedPoll	Surface sediment screening risk (Apitz *et al.* 2007)	(mHQ)
	WatPoll	Water screening risk	(mHQ)
Direct impact	Aquacult	% of area occupied by fish/shellfish farms	Area%
	Fishery	Density of fyke nets	no.nets ha^{-1}
	Traffic	Total ship traffic flux	no.ships day^{-1}
	Dredging	Average amount of dredged sediments	m^3 y^{-1}
	DeltaBatim	Bottom instability (|bathimetric change| > 0.1m)	area%
	MarshLoss	% of (natural) marsh area lost over the last decade	area%
	SeagrLoss	% of seagrass area lost over the last decade	area%
	MarshGain	% of (natural) marsh area gained over the last decade	area%
	SeagrGain	% of seagrass area gained over the last decade	area%
Land uses	Urban	Urban area (Corine Land Cover)	area%
	Industr	Industry (Corine Land Cover)	area%
	Agric	Agriculture (Corine Land Cover)	area%
	Ports	Port activities (Corine Land Cover)	area%
	Transports	Transport infrastructures (roads, railways, airports) (Corine Land Cover)	area%
	Valli	Fishing ponds (Corine Land Cover)	area%

and urban areas (year 2002; MAG. ACQUE - Thetis, 2006b) were calculated. Similarly, the pollutants load was estimated, by using data on metal loads (total Pb, Zn, Cr, Cu, Cd, Hg, Ni, As) coming from the main tributaries (year 1999; Collavini *et al.*, 2005; MAG.ACQUE - OGS - UNIVE, 2006a) and from the industrial area of Porto Marghera (year 2002; MAG.ACQUE - Thetis, 2005). The trophic status was derived from MAG. ACQUE - OGS - UNIVE (2006a, 2006b), where a "yearly average trophic level" was measured as the linear combination of three variables: nutrients concentration in the water (dissolved Nitrogen and reactive Phosphorus), Chlorophyll-*a* concentration, and suspended solids. This combination was the result of a principal component analysis, performed on the annual mean values of these variables, measured in 18 lagoon sites in the years 2001-2005. The average annual trophic status (i.e. the coordinate on the first PCaxis) was calculated for each site and mapped on the whole lagoon basin (IDW interpolation method), and the average value was estimated for each water body. Due to its possible influence on fish distribution in the lagoon, the dissolved oxygen concentration was measured as the average minimum annual concentration (% saturation) in each water body, calculated by mapping data obtained from water quality monitoring surveys carried out in the period 2000 - 2005 (MAG. ACQUE - Thetis, 2004; MAG.ACQUE - OGS - UNIVE, 2006a). The number of shipyards using antifouling paints containing organotin compounds was also measured as indicator of pollution pressures in the lagoon water bodies (data from a census survey on 2001; ARPAV, 2004). The sediment contamination by metals and organic micropollutants was measured by the "sediment screening risk" indicator, provided by Apitz *et al.* (2007) as the mean hazard quotient (mHQ, i.e. the ratio between the contaminant concentration and a standard value) calculated over different contaminants. Authors used data on contaminants concentrations (As, Cd, Cr, Ni, Pb, Cu, Zn, Hg, pesticides, PAH, PCB, HC, HCB) in the lagoon surface sediments (years 1996-2003; see Apitz *et al.*, 2007 for details on data sources), and assumed a consensus-based probable toxic effects concentration as standard value (Apitz, 2003). The resulting mHQ was mapped on the lagoon basin (Apitz *et al.*, 2007) and the average value for each water body was calculated. Similarly, a water pollution indicator was derived as the mHQ calculated from data on dissolved metals concentration in the water (As, Cd, Cr, Ni, Pb, Cu, Zn, Hg) in 21 lagoon sites (years 2003-2004; MAG.ACQUE - Thetis, 2006c), and using the imperative values provided in the Ronchi Costa Decree (DM 23/04/1998, setting the quality objectives for the Venice lagoon) as standards.

Nine indicators were identified in the category of direct pressures on the habitat and the livings (Table 1). The coverage (% area) of shellfish farms (*Tapes philippinarum* and *Mytilus galloprovincialis*) in each water body was calculated on information (year 2008) derived from Provincia di Venezia (2009). The average density of fyke nets (no. traps/ha) deployed in the water bodies was calculated on data related to the periods of maximum fishing effort in the lagoon (March and October) in 2007 (Provincia di Venezia, 2009). The boat traffic in each water body was calculated as the mean traffic flux (no. boats/day) in summer, derived from the simulation of a traffic model calibrated on data collected during a monitoring program of fluxes in the main lagoon canals in 2000 (MAG.ACQUE - Thetis, 2006d). The average amount of dredged sediments in the water bodies was calculated as the mean annual volume of sediments (m^3/y) dredged in the lagoon over the period 1986-2000 (MAG. ACQUE - Thetis-Selc, 2003). The degree of bottom instability was measured in each water body as the relative (%) bottom area subject to a bathymetric variation of >10 cm (either in erosion or deposition) over the period 1970-2000, following the information provided in Molinaroli *et al.* (2009). The habitat loss was measured as the relative (%) area in each water body covered by marsh and seagrass habitats, lost between 1992 and 2001 (MAG. ACQUE, 1993, 2003) and between 1990 and 2004 (MAG.ACQUE, 1991; MAG.ACQUE - Selc, 2005), respectively. When present, the habitat gain was also measured.

Six indicators were considered to account for the pressures derived from the land uses of the areas adjacent to the lagoon water bodies (Table 1). Data on the ground occupation were obtained from the Corine Land Cover map of the region (CISIS, 2009). The main categories considered were: urban areas (level 1.1 of the Corine classification system), industrial areas (level 1.2.1), agricultural areas (level 2), port areas (level 1.2.3), transport infrastructures (including roads, railways, and airports; levels 1.2.2 and 1.2.4) and fishing ponds (level 4.2.4). A 1 km-wide territory belt was identified around each water body, and the relative area dedicated to the different uses was measured as % over the total area of the band (calculated excluding continental and maritime waters).

The indicators values were standardised in the range 0-1 by using the formula *[(obs-min)/(max-min)]*, where obs is the observed value in the water body, min and max are the minimum and maximum values recorded for the indicator across the lagoon water bodies. In case of indicators which were negatively correlated with pressure degree (oxygen concentration and habitat gain), the complementary value of the standardised indicator was considered.

Fish assemblage

Fish assemblages were sampled in four sites, located into four water lagoon bodies (Figure 1). Forty-seven samples were collected overall, from March 2001 to October 2002, during spring and autumn months, by means of fyke nets (8 mm mesh size), with the aid of local fishermen. Fish catches were standardized as CPUE, using the single trap end and a period of 2 days as unit effort. Fish assemblages were characterized by taxonomical and functional aspects, by measuring the assemblage structure (based on species CPUE), the overall species diversity (total no. of species and dominance), the total fish abundance (total CPUE), habitat use aspects (no. of resident species, no. of marine migrant species, and % abundance of these groups), and trophic aspects (no. of benthivorous species, no. of detritivores, no. of species feeding on demersal-pelagic prey, and % abundance of these groups). Most of these indicators have been used as metrics of the Habitat Fish Index (HFI) for the evaluation of the lagoon ecological status (Franco *et al.*, 2009).

Environmental background

The environmental background in each water body was assessed by using water temperature and salinity measured at sampling sites and by quantifying the habitat diversity in the water body. Habitats were distinguished into deep areas (canals) and shallow habitats. The latters further divided into seagrass areas, marsh areas (of either natural or artificial origin), mudflats and sandflats (mainly of artificial origin). Habitats were mapped in the lagoon water bodies, and the following habitat diversity indicators were calculated: total area of the water body, area of each habitat in the water body (as both absolute and % area), Shannon diversity (calculated over the relative coverage areas of the different habitats in a water body).

Data analysis

Fish assemblage characteristics were compared by using a three-way factorial PERMANOVA design (Site x Season x Year), applied to similarity matrices (Bray-Curtis for multivariate fish assemblage structure, Euclidean distance for univariate indicators), based on log-transformed data (Anderson *et al.*, 2008). Particular attention was paid to spatial differences.

The relationship between fish data and either pressures or environmental background was explored by using BIOENV routine (Clarke and Warwick, 2001), applied to average data in each water body. Euclidean distance matrices were calculated on normalised environmental and pressure data.

Statistical analyses were performed by means of PRIMER-E package (Clarke and Warwick, 2001).

Results

Anthropogenic pressures

The resulting standardized values of pressure indicators in the lagoon water bodies are reported in Table 2. Pollution indicators showed highest values in the highly modified water body including the industrial area of Porto Marghera (CIPM, mean 0.89), followed by the polyhaline non-confined water body located between the industrial area and the

Table 2 - Standardized values of the pressure indicators in the lagoon water bodies (nd = no data; - = seagrass or marsh habitat not present).

Pressure	Indicator	EC	ENC1	ENC2	ENC3	PC1	PC2	PC3	PC4	PNC1	PNC2	CIPM	CS
Pollution	NutrLoad	0.00	0.40	0.00	0.00	0.73	0.12	0.32	0.00	0.63	0.08	1.00	0.34
	TrophState	0.18	0.00	0.10	0.26	0.63	0.41	0.93	1.00	0.78	0.60	0.91	0.28
	DO	0.34	0.10	0.37	0.20	0.28	0.00	0.68	0.56	0.92	0.41	1.00	0.76
	PollLoad	0.00	0.26	0.00	0.00	0.79	0.07	0.20	0.00	0.34	0.03	1.00	0.00
	Shipyards	0.24	0.24	0.29	0.29	0.18	0.06	0.00	0.00	0.53	0.29	0.35	1.00
	SedPoll	0.09	0.02	0.09	0.09	0.08	0.09	0.00	0.47	0.32	0.05	1.00	0.10
	WatPoll	0.19	0.32	0.37	0.21	0.00	0.21	0.19	0.41	0.54	0.15	1.00	0.48
	Average	*0.15*	*0.19*	*0.18*	*0.15*	*0.38*	*0.14*	*0.33*	*0.35*	*0.58*	*0.23*	*0.89*	*0.42*
Direct impact	Aquacult	0.00	0.68	1.00	0.04	0.00	0.00	0.63	0.00	0.00	0.83	0.00	0.00
	Fishery	0.23	0.11	0.12	1.00	0.23	0.21	0.61	0.52	0.18	0.22	0.00	0.01
	Traffic	0.00	0.14	0.44	0.07	0.31	0.02	0.00	0.17	0.36	0.53	0.16	1.00
	Dredging	0.01	0.27	0.41	0.00	0.02	0.38	1.00	0.90	0.27	0.28	nd	nd
	DeltaBatim	0.36	0.80	0.73	0.65	0.49	0.65	0.77	0.88	0.37	0.00	1.00	0.94
	MarshLoss	1.00	0.03	0.04	0.00	0.45	0.08	0.44	0.46	0.06	0.30	nd	-
	SeagrLoss	0.54	0.43	0.27	0.89	0.43	1.00	0.47	-	-	0.23	-	0.00
	MarshGain	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	nd	1.00
	SeagrGain	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00
	Average	*0.46*	*0.50*	*0.56*	*0.41*	*0.44*	*0.48*	*0.66*	*0.62*	*0.40*	*0.49*	*0.43*	*0.42*
Land uses	Urban	0.02	0.14	0.46	0.68	0.01	0.00	0.05	0.00	0.28	0.10	0.20	1.00
	Agric	0.54	0.41	0.50	0.32	0.73	0.25	1.00	0.46	0.21	0.47	0.11	0.00
	Industr	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.31	0.03	1.00	0.00
	Ports	0.02	0.00	0.09	0.00	0.00	0.00	0.00	0.01	0.63	0.00	1.00	0.35
	Transports	0.00	0.10	0.00	0.37	0.33	0.00	0.08	0.00	0.16	1.00	0.09	0.28
	Valli	0.84	0.00	0.00	0.00	0.22	1.00	0.00	0.05	0.06	0.00	0.05	0.00
	Average	*0.24*	*0.11*	*0.18*	*0.23*	*0.22*	*0.21*	*0.19*	*0.09*	*0.28*	*0.27*	*0.41*	*0.27*
Total	Average	0.30	0.29	0.33	0.28	0.36	0.30	0.43	0.37	0.43	0.35	0.60	0.38

city of Venice (PNC1, mean 0.58). In turn, euhaline water bodies, either confined or not, and the polyhaline confined basin PC2 showed the lower pollution levels (mean<0.20), thanks also to the absence of direct inputs from the drainage basin in these areas (Figure 1). Pressures connected to direct impacts on the habitats and the living organisms showed a generally higher level in the lagoon than pollution, with the highest pressure degree in the polyhaline confined basins PC3 and PC4 (mean >0.60), mainly due to the intense dredging activity connected to the bathymetric instability in these areas (Table 2). Lower levels of direct impacts, in turn, were observed in the polyhaline and euhaline non-confined water bodies PNC1 and ENC3 (mean <0.42), mainly due to the low relative coverage of shellfish farms and almost absent marsh loss in both areas (with a moderate habitat gain in ENC3). The lowest pressure levels, on average, were observed in the lagoon regarding land uses, with the highest average value (0.41) recorded in the CIPM basin, due to the concentration of industrial and port activities in this area. The lowest pressures were recorded in the water bodies PC4 and ENC1 (mean <0.12), surrounded by lands with a dominant agricultural use, and with a markedly reduced pressure from other uses. When considering the overall pressure, calculated as the average of the measured indicators, the highest degree resulted in the industrial basin CIPM (0.60), with relatively high values (>0.34) observed also in polyhaline water bodies, either confined or not (except for PC2). Lower pressure levels were detected in euhaline basins (around 0.30).

Fish assemblage distribution

Forty-seven fish taxa were collected overall in the four sites (Table 3). Fish assemblage structure differed significantly among sites (df=3, SS=6991.8, pseudo-F=2.05, $p<0.01$), years (df=1, SS=3127.1, pseudo-F=2.75, $p<0.05$) and seasons (df=1, SS=6076.9, pseudo-F=5.35, $p<0.001$), with no significant interactions among factors. Spatial comparison, in particular, highlighted a differentiation between CZ (located in the water body EC) and the other sites, mainly due to the higher abundance of marine migrant species such as flatfishes (*Platichthys flesus* and *Solea solea*) and *Engraulis encrasicolus*, as confirmed also by the spatial comparison carried out on the % abundance of the marine migrant group (df=3, SS=14.8, pseudo-F=4.09, $p<0.05$). Other significant spatial differences were detected with regard to the total number of species (df=3, SS=0.51, pseudo-F=11.60, $p<0.05$) and the number of resident species (df=3, SS=0.81, pseudo-F=33.96, $p<0.01$), in Autumn 2002 only (seasons and years were analysed separately given a significant interaction among factors), when higher values in CH (located in the water body ENC1) and lower in LD (located in the water body ENC2) were detected. As regards the number of resident species, a significant spatial difference was detected also in the spring 2001 (df=2, due to the lack of data for CH in this season, SS=0.07, pseudo-F=5.94, $p<0.05$), when higher values were found in CZ (water body EC) and lower in LT (located in the water body PC4).

Environmental background

The average temperature in the studied sites varied between 15.9 °C in CH (min 7°C, max 28°C) and 18°C in CZ (min 8°C, max 27.5°C). Average salinity ranged from 29 in LT (min 18, max 35) to 31 in LD (min 24, max 36). The water bodies related to each site showed a wide variability in their area, with the largest value in ENC1 (1358 ha, CH) and values ≤ 500 ha in the others, with a minimum in PC4 (204 ha, LT). Most of these basins (>50% area) were covered by mudflats, but a certain diversity in the other habitats' coverage was detected (Figure 2). EC showed the lowest habitat diversity (Shannon index = 0.68), being covered by mudflats (80%), marsh habitats (9%) and canals (9%). The other euhaline water bodies showed a significant coverage of seagrass, particularly ENC1, where the distribution of all the habitats led to a general higher diversity (Shannon index = 1.20). Marsh habitats were very abundant in the shallow basin PC4, which showed an overall habitat diversity value of 1.03. An intermediate level of habitat diversity, in turn, was recorded in ENC2 (0.75), where 25% of the area was covered by deeper habitats (canals).

Fish assemblage and environmental and pressure variability

The relationship between the fish assemblage

Table 3 - Fish species caught with the fyke nets, their mean abundance (CPUE, no. individuals trap^{-1} 2days^{-1}) in each site and allocation to functional groups (R=residents, M=marine migrants, Bv=benthivores, Dv=detritivores, D-Pp=demersal-pelagic prey feeders, according to their definition in Franco *et al.*, 2008; feeding mode functional groups are evaluated on non-straggler species only, including residents, marine migrants and diadromous). The names of sampling sites are abbreviated as in Figure 1.

family	species	LT	LD	CZ	CH	Habitat use	Feeding mode
Anguillidae	*Anguilla anguilla*	0.097	0.029	0.058	0.056		D-Pp
Atherinidae	*Atherina boyeri*	66.269	42.015	31.251	43.184	R	D-Pp
Belonidae	*Belone belone*	0.091	0.125	0.029	0.020	M	D-Pp
Blenniidae	*Parablennius gattorugine*	0	0.005	0	0		
	Salaria pavo	0.132	1.016	0.013	0.163	R	
Callionimidae	*Callionymus risso*	0	0.005	0	0		
Carangidae	*Trachurus trachurus*	0	0.010	0.090	0		
Clupeidae	*Alosa fallax*	0.003	0.003	0	0.004		D-Pp
	Sardina pilchardus	0	0.002	0	0.002	M	
	Sprattus sprattus	0.288	14.488	1.602	0.017	M	
Congridae	*Conger conger*	0	0	0.004	0.004		
Cyprinodontidae	*Aphanius fasciatus*	2.564	0.002	0.255	0.043	R	
Engraulidae	*Engraulis encrasicolus*	0.214	0.721	5.028	0.257	M	
Gadidae	*Merlangius merlangus*	0.002	0	0	0		
Gobiidae	*Gobius cobitis*	0.013	0.221	0.025	0		
	Gobius niger	0.471	3.233	2.628	2.195	R	D-Pp
	Knipowitschia panizzae	1.000	0.292	0.078	0.013	R	Bv
	Pomatoschistus canestrinii	0.012	0	0.008	0	R	Bv
	Pomatoschistus marmoratus	0.059	0.148	0.229	0.102	R	Bv
	Pomatoschistus minutus	0.010	0.077	0.190	0.024	M	Bv
	Zosterisessor ophiocephalus	2.008	5.932	2.055	4.849	R	Bv
Labridae	Labridae indet.	0	0.058	0	0		
Moronidae	*Dicentrarchus labrax*	0.090	0.038	0.730	0.021	M	D-Pp
Mugilidae	*Chelon labrosus*	0.001	0.087	0	0	M	Dv
	Liza aurata	0.769	0.900	0.480	0.430	M	Dv
	Liza ramada	0.603	0.425	0.590	0.435	M	Dv
	Liza saliens	1.165	1.815	0.876	0.612	M	Dv
Mullidae	*Mullus surmuletus*	0	0.006	0.051	0.007	M	Bv
Pleuronectidae	*Platichthys flesus*	0.487	0.075	3.220	0.096	M	Bv
Poeciliidae	*Gambusia holbrooki*	0	0	0	0.002	R	
Salmonidae	*Salmo trutta*	0.002	0.001	0	0		
Sciaenidae	*Umbrina cirrosa*	0	0	0.002	0	M	Bv
Scombridae	*Scomber scombrus*	0	0	0.002	0		
Soleidae	*Solea solea*	0.909	0.439	5.790	0.251	M	Bv
Sparidae	*Boops boops*	0	0.055	0.003	0.005		
	Diplodus annularis	0.023	0.180	0.069	0.027	M	
	Diplodus sargus	0	0.016	0	0		
	Diplodus vulgaris	0	0.010	0.006	0		
	Lithognathus mormyrus	0	0.007	0	0.002	M	Bv
	Sparus aurata	0.577	0.031	0.471	0.003	M	Bv
Syngnathidae	*Hippocampus guttulatus*	0.009	0.070	0.120	0.020	R	Bv
	Hippocampus hippocampus	0.007	0.009	0	0.007	R	Bv
	Syngnathus abaster	0.027	0.105	0.033	0.125	R	Bv
	Syngnathus acus	0.001	0.030	0	0.011	M	Bv
	Syngnathus tenuirostris	0.003	0.036	0.002	0.018	M	Bv
	Syngnathus typhle	0.005	0.192	0.019	0.149	R	D-Pp
Triglidae	*Trigla lucerna*	0	0.001	0.006	0		

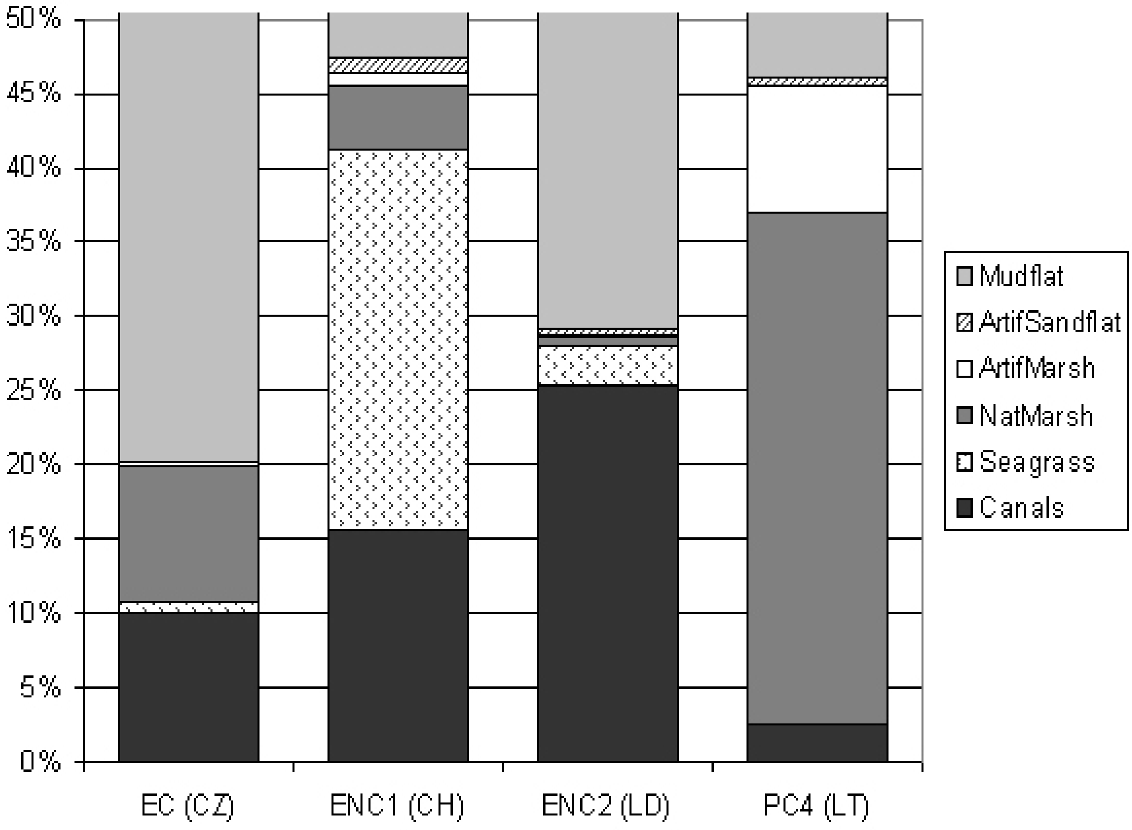

Figure 2. Habitat coverage in the lagoon water bodies studied for fish fauna. Water bodies are named according to their typology (euhaline or polyhaline, E or P, and confined or non-confined, C or NC) and their progressive number, and the names of the fish sampling sites (CH, CZ, LD, LT) in the water bodies are indicated in brackets.

features and the best subset of either environmental variables or pressure indicators explaining the similarity among samples were explored by using a BIOENV analysis. The best subsets of environmental and pressure indicators included from 1 to 3 variables (Table 4). The environmental subsets often included temperature, water body area, and the relative coverage of several habitats in the water body (e.g. canals, sandflats, marsh habitats). The pressure subsets often included pressures from land uses (e.g. industrial areas) or pollution indicators (e.g. water pollution, nutrients loads, shipyards). The Spearman correlation coefficients resulted in both cases quite high (>0.80), with similar values between the two datasets.

Discussion

The analysis carried out in the present paper allowed an integrated quantification of the pressures acting on the Venice lagoon fish assemblages, an essential step in the evaluation process of the ecological status of transitional water bodies (WFD, 2000/60/EC). In particular, pressures were intended as both direct pressures on fish (e.g. fishery effort) and indirect ones, deriving from impacts on other compartments (e.g. pollution, impacts on habitats). In fact, though fishery is a highly threatening anthropogenic factor concerning fish populations, other anthropogenic factors may contribute to alter lagoon fish assemblages, such as for example pollution,

Table 4 - Results of the BIOENV analysis applied to fish assemblage, environmental and pressure datasets. The number of variables included in the best subset explaining fish data and the correlation coefficient are reported separately for environmental and pressure datasets.

	Best subset (no. variables)		Spearman correlation coefficient	
	Env. Background	Pressures	Env. Background	Pressures
Assemblage structure	2	2	0.943	0.943
Tot CPUE	2	3	0.771	0.829
Tot. No. Species	1	2	1	0.971
Dominance	2	2	1	1
No. Resident Sp.	2	1	0943	0.943
No. Marine Migrant Sp.	2	1	1	0.943
%Ab. Resident Sp.	2	1	1	0.943
%Ab. Marine Migrant Sp.	2	2	1	1
No. Benthivorous Sp.	1	2	1	1
No. Detritivorous Sp.	1	1	0.883	0.905
No. Sp. Dem.-Pelagic prey	1	1	0.986	0.986
%Ab. Benthivorous Sp.	3	2	0.943	0.943
%Ab. Detritivorous Sp.	3	2	0.943	0.943
%Ab. Sp. Dem.-Pelagic prey	2	2	1	1

morphological changes in the environment, and habitat loss (Vasconcelos *et al.*, 2007).

According to the results of this study, the most important pressure in the lagoon, in terms of overall magnitude, is the significant bathymetric change occurred in the last decades, resulting in a general "smoothing" of the lagoon morphology (erosion of shallows and deposition in channels), as a result of destabilizing factors such as changes in local hydrodynamics, decrease of sediment supply, clam harvesting and loss of seagrass habitat, combining with the overall effect of mean sea level rise (Molinaroli *et al.*, 2009). Such an impact, in some cases, led to additional pressures, as in the case of the water bodies PC3 and PC4, where significant dredging has been carried out to contrast the strong depositional trend and allow boat circulation. Seagrass habitat loss is also an important pressure in the lagoon overall, due particularly to the extreme reduction of *Nanozostera noltii* beds, which completely disappeared in certain areas (e.g. PC2) (Rismondo and Mion, 2008). Besides the multiple consequences of a reduction in habitat complexity, variety and heterogeneity on fish populations (Vasconcelos et al., 2007), the loss of *N. noltii* beds might have contributed to a decline in biodiversity of the lagoon, given also the observed high species diversity of fish assemblages associated to this habitat (MAG.ACQUE-DSA UNIVE, 2007), hence leading to possible effects on the structure and functioning of the whole system. The trophic status and oxygenation conditions of the lagoon waters were important pressures as well. Eutrophication and subsequent hypoxia and anoxia events may have negative effects on the habitat quality for fish, leading to possible reduction of suitable habitats for juveniles and to a decrease in prey availability in case of intermittent events of anoxia occurring (Powers *et al.*, 2005). A significant pressure on the lagoon water bodies was also due to the main agricultural use of the adjacent territory, with an indirect contribution to the above mentioned pressures.

In the Venice lagoon such different pressures occur with an uneven spatial distribution, as highlighted by the differences among water bodies. The most affected water body overall was the highly modified industrial area of Porto Marghera (CIPM), showing maximal pollution pressures and impacts, as expected. Similar conditions were observed in the adjacent water body (PNC1), located between this area and the city of Venice, while significant morphological modifications were observed in the confined water body at the southernmost lagoon area (PC3), as mentioned above. Surprisingly, the highly modified water body located on the urban area of Venice (CS) did not show particularly high pressure level overall. However, the pressures in this area could have been underestimated, given the lack of information on direct impacts in the city canals for several pressure indicators (e.g. sediment pollution, dredging). A similar situation could be valid for the water body located on the city of Chioggia (ENC3), resulting as the area less impacted by human pressures in the lagoon. A low pressure degree was also detected for the large water body ENC1, possibly ascribed to a “dilution effect” of several pressures, given the wide area of this basin. This observation suggests the importance of the natural vulnerability of the water body to pressures, as a measure of its buffering capacity to human activities (Ferreira, 2000). Vulnerability, in fact, may be related to factors such as for example the water body area, its mean depth, water volume and residence time, and should be taken into consideration as a counterbalancing factor in the pressure evaluation (Vasconcelos *et al.*, 2007). Though a direct measure of this factor was not carried out in this work, it was indirectly considered by defining most of the indicators as relative measures with respect to the water body area (e.g. % area, density of nets).

Though fish assemblages in the lagoon showed both spatial and temporal variability, only the former was considered in order to investigate the relationship with pressures, leading to the analysis of the average data per station/water body. As a result, the spatial variability of fish assemblages and their main characteristics, either structural or functional, was highly related to both pressure and habitat variability among water bodies. The correlation coefficients were similar in the two analyses, suggesting the important effect of both the variability sources, natural and anthropogenic, on the investigated biological quality element, hence underpinning the “estuarine quality paradox” concept formulated by Elliott and Quintino (2007) for estuaries. As a consequence, the assessment of the response of the lagoon water bodies, in terms of their ecological status, to anthropogenic impacts cannot leave out of consideration the natural environmental variability which highly affects the lagoon biota. The distinction of water bodies in different typologies, according to the differences in salinity and confinement degree, only partly account for this environmental variability. As resulting from the analysis of fish assemblages and of habitat distribution in the four studied water bodies, in fact, differences were observed also among water bodies of a same type (ENC1 and ENC2). This intra-type variability, mainly ascribed to the habitat heterogeneity in the water bodies, suggests a possible unsuitability of the sole national typology classification (Dm Ambiente 16 June 2008, n.131) in identifying relatively homogeneous conditions for which a specific biological reference could be reliably derived, as required by the WFD. This would highlight the importance of integrative approaches for the lagoon fish assemblages assessment, as, for example, the habitat fish index recently proposed by Franco *et al*. (2009).

Conclusions

The European Water Framework Directive (WFD, 2000/60/EC) provides guidelines for the protection of transitional waters, requiring the assessment of their ecological status and the quantification of the significant anthropogenic pressures in them. This latter task was carried out in this paper for the Venice lagoon water bodies, by identifying the type and magnitude of the main human pressures and impacts. Particular regard was given to those pressures affecting the lagoon fish fauna, hence having a likely effect on the ecological status measured through this biological quality element. Identifying such pressures is an essential requirement to allow the evaluation and prediction of their effect on fish assemblages, and to plan appropriate mitigation measures in order to reach good status, as called for by the WFD.

In this process, the distinction of the anthropogenic impact signal from the environmental background noise is of paramount importance to cope with the "estuarine quality paradox" (Elliott and Quintino, 2007), in coastal lagoons as well as in estuaries, as highlighted in the present paper. This would allow a correct evaluation of the ecological status of such systems through the investigation of their biological quality elements, with important implications for the proper application of the WFD in Mediterranean coastal lagoons.

Though the present study represents a preliminary exploration of the relationship of fish assemblages with the environmental background and the human pressures in the lagoon, the identification and quantification of the pressure typologies in such a system through appropriate indicators represents an important baseline for the development of multimetric index approaches to address environmental issues. Such approaches, in fact, may provide effective management tools by simplifying extensive information and making them available for decision-makers, yet in scientific valid forms (Aubry and Elliott, 2006; Vasconcelos *et al*., 2007).

Acknowledgments

Authors thank the Venice Water Authority (Magistrato alle Acque di Venezia) and its sole agent Consorzio Venezia Nuova for having provided reports and data on local pressures.

References

Anderson MJ, Gorley RN, Clarke KR, 2008. PERMANOVA+ for PRIMER: *Guide to software and statistical methods*. PRIMER-E, Plymouth, UK.

Apitz SE, 2003. Analysis of the internationally used sediment quality guidelines (SQGs) for use in Venice Lagoon sediment assessment and management. Report to Thetis S.p.A. Venice, Italy, SEA Environmental Decisions, Herts, UK.

Apitz S, Barbanti A, Bernstein GA, Bocci M, Delaney E, Montobbio L, 2007. The assessment of sediment screening risk in Venice Lagoon and other coastal areas using international sediment quality guidelines. *Journal of Soils and Sediments* **7**: 326-341.

Arpav, 2004. Dipartimento provinciale di Venezia -Servizio Laboratori – Unità operativa Chimica di base. Studio triennale dell’accumulo di composti organostannci nell’ecosistema lagunare di Venezia. Final Report, Venice, Italy.

Arpav, 2009. *http://www.venetoambiente.net/acqua/htm/bacino_scolante_dati4.asp*

Aubry A, Elliott M, 2006. The use of environmental integrative indicators to assess seabed disturbance in estuaries and coasts: Application to the Humber Estuary, UK. *Marine Pollution Bulletin* **53**: 175-185.

Borja A, Galparsoro I, Solaun O, Muxika I, Tello EM, Uriarte A, Valencia V, 2006. The European Water Framework Directive and the DPSIR, a methodological approach to assess the risk of failing to achieve good ecological status. *Estuarine, Coastal and Shelf Science* **66**: 84-96.

Breine J, Maes J, Quattaert P, Van den Bergh E, Simoens I, Van Thuyne G, Belpaire C, 2007. A fish-based assessment tool for the ecological quality of the brackish Schelde estuary in Flanders (Belgium). *Hydrobiologia* **575**: 141-159.

Chainho P, Chaves ML, Costa JL, Costa MJ, Dauer DM, 2008. Use of multimetric indices to classify estuaries with different hydromorphological characteristics and different levels of human pressure. *Marine Pollution Bulletin* **56**: 1128-1137.

CISIS 2009. http://*www.centrointerregionale-gis.it/script/corinedownload.asp*

Clarke KR, Warwick RM, 2001. *Change in marine communities: an approach to statistical analysis an interpretation*, *2nd edition*. PRIMER-E, Plymouth, UK.

Collavini F, Bettiol C, Zaggia L, Zonta R, 2005. Pollutant loads from the drainage basin to the Venice Lagoon (Italy). *Environment International* **31**: 939-947.

Deegan LA, Finn JT, Ayvazian SG, Ryder-Kieffer CA, Buonaccorsi J, 1997. Development and validation of an Estuarine Biotic Integrity Index. *Estuaries* **20**: 601-617.

Elliott M, Quintino V, 2007. The estuarine quality paradox, environmental homeostasis and the difficulty of detecting anthropogenic stress in naturally stressed areas. *Marine Pollution Bulletin* **54**: 640–645.

Ferreira JC, 2000. Development of an estuarine quality index based on key physical and biogeochemical features. *Ocean and Coastal Management* **43**: 99-122.

Franco A, Franzoi P, Malavasi S, Riccato F, Torricelli P, Mainardi D, 2006a. Use of shallow water habitats by fish assemblages in a Mediterranean coastal lagoon. *Estuarine Coastal and Shelf Science* **66**: 67-83.

Franco A, Malavasi S, Zucchetta M, Franzoi P, Torricelli P, 2006b. Environmental influences on the fish assemblage of the Venice Lagoon, Italy. *Chemistry and Ecology* **22**: 105-118.

Franco A, Torricelli P, Franzoi P, 2009. A habitat-specific fish-based approach to assess the ecological status of Mediterranean coastal lagoons. *Marine Pollution Bulletin* **58**: 1704-1717.

Magistrato alle Acque di Venezia, 1991. Studio A.3.16/I - Composizione delle comunità biologiche - I fase - Rilievi sui popolamenti delle barene ed aree circostanti e sulla vegetazione dei bassifondi. Technical Report, produced by

Concessionario, Consorzio Venezia Nuova, Venice, Italy.

Magistrato alle Acque di Venezia, 1993. Carta Tecnica Regionale - Contorno barene naturali 1992. Technical Report, produced by Concessionario, Consorzio Venezia Nuova-Servizio Informativo, Venice, Italy.

Magistrato alle Acque di Venezia, 2003. Carta Tecnica Regionale - Contorno barene naturali 2001. Technical Report, produced by Concessionario, Consorzio Venezia Nuova-Servizio Informativo, Venice, Italy.

Magistrato alle Acque di Venezia - DSA UNIVE, 2007. Studio B.12.3/III - La funzionalità dell'ambiente lagunare attraverso rilievi delle risorse alieutiche, dell'avifauna e dell'ittiofauna. - Individuazione di indicatori di funzionalità ambientale. Technical Report, produced by Concessionario, Consorzio Venezia Nuova, Venice, Italy.

Magistrato alle Acque di Venezia - OGS - UNIVE, 2006a. Attività di monitoraggio ambientale della laguna di Venezia MELa 3 – OP/285. Rapporto tecnico finale sulle attività di monitoraggio della qualità delle acque. Volume 1. Technical Report, produced by Concessionario, Consorzio Venezia Nuova, Venice, Italy.

Magistrato alle Acque di Venezia - OGS - UNIVE, 2006b. Attività di monitoraggio ambientale della laguna di Venezia MELa 3 – OP/285. Rapporto tecnico finale sulle attività di monitoraggio della qualità delle acque. Volume 2. Allegati. Technical Report, produced by Concessionario, Consorzio Venezia Nuova, Venice, Italy.

Magistrato alle Acque di Venezia - Selc 2005. Attività di monitoraggio ambientale della laguna di Venezia MELa 2 - Rilievo delle fanerogame marine in Laguna di Venezia con taratura di un sistema di telerilevamento e completamento delle conoscenze sulle macroalghe - Resocontazione finale della distribuzione della vegetazione acquatica sommersa (fanerogame marine e macroalghe) in Laguna di Venezia (2002-2003-2004.) Technical Report, produced by Concessionario, Consorzio Venezia Nuova, Venice, Italy.

Magistrato alle Acque di Venezia- Thetis 2004. Progetto MELa2. Attività E. Estensione delle attività di monitoraggio della qualità delle acque. Rapporto finale attività II anno. Technical Report, produced by Concessionario, Consorzio Venezia Nuova, Venice, Italy.

Magistrato alle Acque di Venezia - Thetis, 2005. Attività di monitoraggio ambientale della laguna di Venezia MELa 2. Aggiornamento al 2003 delle stime dei carichi esterni ed interni e composizione del quadro relativo ai bilanci di massa degli inquinanti in laguna. Technical Report, produced by Concessionario, Consorzio Venezia Nuova, Venice, Italy.

Magistrato alle acque di Venezia - Thetis, 2006a. Attività di monitoraggio ambientale della laguna di Venezia. Stato dell'ecosistema lagunare veneziano aggiornato al 2005, con proiezioni al 2025 - DPSIR 2005. Technical Report, produced by Concessionario, Consorzio Venezia Nuova, Venice, Italy.

Magistrato alle Acque di Venezia - Thetis, 2006b. Attività di monitoraggio ambientale della laguna di Venezia. Stato dell'ecosistema lagunare veneziano aggiornato al 2005, con proiezioni al 2025 - DPSIR 2005. Stato trofico. Technical Report, produced by Concessionario, Consorzio Venezia Nuova, Venice, Italy.

Magistrato alle acque di Venezia - Thetis, 2006c. Attività di monitoraggio ambientale della laguna di Venezia. Stato dell'ecosistema lagunare veneziano aggiornato al 2005, con proiezioni al 2025 - DPSIR 2005. Contaminazione da microinquinanti e rischio per la salute umana e per l'ecosistema lagunare. Technical Report, produced by Concessionario, Consorzio Venezia Nuova, Venice, Italy.

Magistrato alle Acuqe di Venezia - Thetis, 2006d. Attività di monitoraggio ambientale della laguna di Venezia. Stato dell'ecosistema lagunare veneziano aggiornato al 2005, con proiezioni al 2025 - DPSIR 2005. Dinamica dei sedimenti e rischio per la salute umana e per l'ecosistema lagunare. Technical Report, produced by Concessionario, Consorzio Venezia Nuova, Venice, Italy.

Magistrato alle Acque di Venezia -Thetis 2009.

Piano di gestione dei bacini idrografici delle Alpi orientali. Subunità idrografic bacino scolante, laguna di Venezia e mare antistante. Progetto di Piano di Gestione. Technical Report, produced by Concessionario, Consorzio Venezia Nuova, Venice, Italy.

Magistrato alle Acque di Venezia - Thetis-Selc, 2003. Studio C.2.10/I - Attività di aggiornamentodel piano degli interventi per il recupero morfologico in applicazione della delibera del Consiglio dei Ministri del 15.03.01. Catalogo strutturato. Technical Report, produced by Concessionario, Consorzio Venezia Nuova, Venice, Italy.

Meng L, Orphanides CD, Powell CJ, 2002. Use of a Fish Index to Assess Habitat Quality in Narragansett Bay, Rhode Island. *Transactions of the American Fishery Society* **131**: 731-742.

Molinaroli E, Guerzoni S, Sarretta A, Masiol M, Pistolato M, 2009. Thirty-year changes (1970 to 2000) in bathymetry and sediment texture recorded in the Lagoon of Venice sub-basins, Italy. *Marine Geology* **258**: 115-125

Powers SP, Peterson CH, Christian RR, Sullivan E, Powers MJ, Bishop MJ, Buzzelli CP, 2005. Effects of eutrophication on bottom habitat and prey resources of demersal fishes. *Marine Ecology Progress Series* **302**: 233-243.

Provincia di Venezia 2009. *Piano per la gestione delle risorse alieutiche delle lagune della provincia di Venezia*. A cura di: Torricelli P., Boatto, V., Franzoi, P., Pellizzato, M., Silvestri, S., Agri.Te.Co. Arti Grafiche Zoppelli, Treviso, Italy.

Ravera O, 2000. The lagoon of Venice. The results of both natural factors and human influence. *Journal of Limnology* **59**: 19–30.

Rismondo A, Mion D, 2008. Variability in Venice lagoon marine seagrasses populations: natural dynamics or induced modifications? *Biologia Marina Mediterranea* **15**: 130–133.

Uriarte A, Borja A, 2009. Assessing fish quality status in transitional waters, within the European Water Framework Directive: setting boundary classes and responding to anthropogenic pressures. *Estuarine, Coastal and Shelf Science* **82**: 214-224.

Vasconcelos RP, Reis-Santos P, Fonseca V, Maia A, Ruano M, Franca S, Vinagre C, Costa MJ, Cabral H, 2007. Assessing anthropogenic pressures on estuarine fish nurseries along the Portuguese coast: A multi-metric index and conceptual approach. *Science of the Total Environment* **374**: 199-215.

Whitfield AK, Elliott M, 2002. Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. *Journal of Fish Biology* **61**: 229–250.