Eutrophication assessment in transitional waters
A performance analysis of the Transitional Water Quality Index (TWQI)

Andrea Bonometto[1], Gianmarco Giordani[2], Emanuele Ponis[1], Chiara Facca[3], Rossella Boscolo Brusà[1], Adriano Sfriso[3] & Pierluigi Viaroli[2]

[1] Italian National Institute for Environmental Protection and Research (ISPRA)

[2] Department of Life Sciences, University of Parma, 43124 Parma, Italy

[3] Department of Environmental Sciences, Informatics & Statistics, University Ca' Foscari, 30123 Venice, Italy

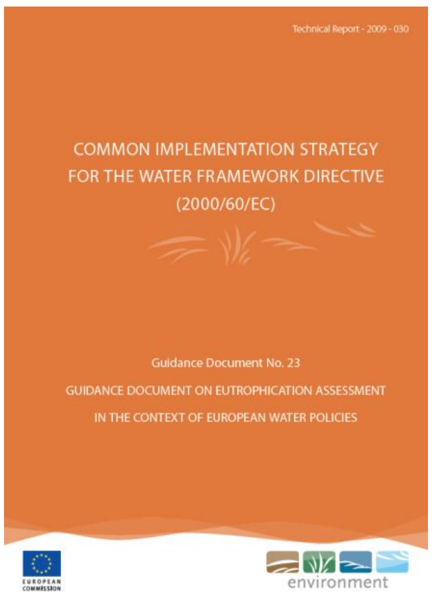
VII EUROLAG - EUROPEAN COASTAL LAGOONS SYMPOSIUM

University of Murcia (Spain), 1st to 4th March 2016

INTRODUCTION

Eutrophication has been considered one of the major threats to the health and integrity of inland, transitional, coastal and marine water ecosystems in the last decades.

A number of EC Directives requires that Member States have to monitor parameters relevant to eutrophication and set ecologically relevant guideline values.

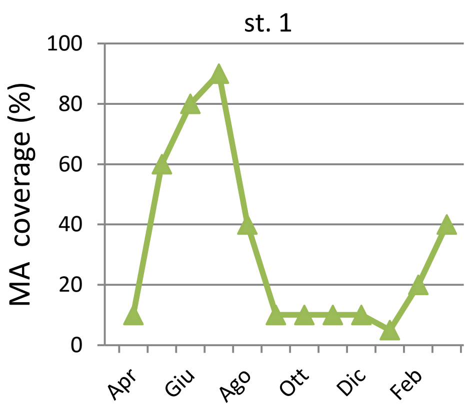


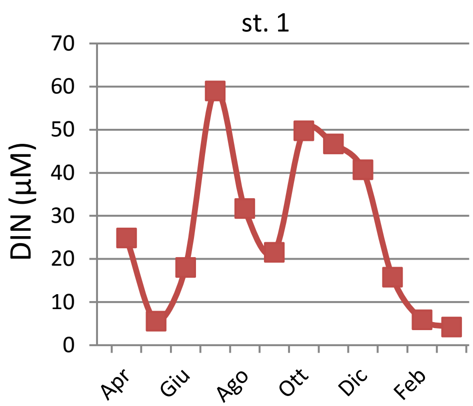
-The Nitrates Directive (91/676/EEC) deals with diffuse pollution of nitrogen from agriculture
- The Water Framework Directive, in addition, has an implicit requirement to assess eutrophication when classifying the Ecological Status of surface water bodies and the risk of failure the GES.

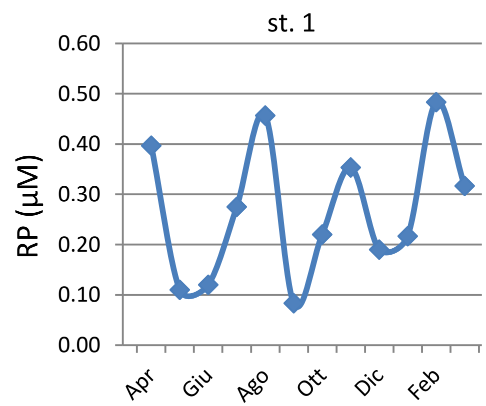
INTRODUCTION

➢ **High variability of physico-chemical and biological conditions.**

The trophic status evaluation with single indicators may significantly fluctuate the year round depending mainly on seasonal factors such as freshwater inputs and seasonal succession within the primary producer community







High monitoring frequency is needed to provide a reliable assessment of trophic status

Expensive and time consuming monitoring effort for local Environmental Agencies in charge of Institutional monitoring activities

OBJECTIVES

Giordani et al. (2009) proposed a multimetric index (TWQI) for eutrophication assessment in transitional waters

ELSEVIER

Ecological Indicators

Volume 9, Issue 5, September 2009, Pages 982–991

Simple tools for assessing water quality and trophic status in transitional water ecosystems

G. Giordani[a], J.M. Zaldívar[b], P. Viaroli[a]

Show more

IN THIS STUDY WE INVESTIGATED:

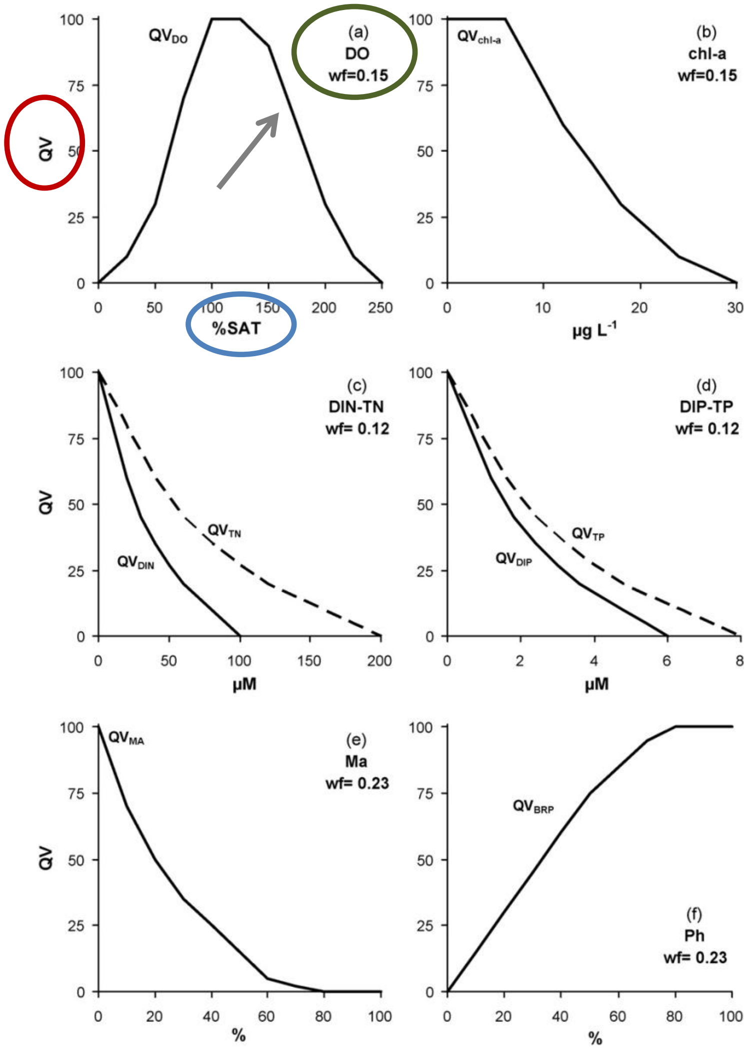
1) THE ROBUSTNESS OF TWQI MULTIMETRIC INDEX TO PROVIDE A RELIABLE TROPHIC STATUS ASSESSMENT **DEALING WITH TEMPORAL FLUCTUATIONS**

2) THE **RELATIONSHIP BETWEEN THE MONITORING FREQUENCY AND THE CONFIDENCE** IN ASSESSMENT OF TROPHIC STATUS AS A CONSEGUENCE OF TEMPORAL VARIABILITY OF INVESTIGATED PARAMETERS.

Giordani, G., Zaldivar, J.M., Viaroli, P., 2009. Simple tools for assessing water quality and trophic status in transitional water ecosystems. *Ecol. Ind. 9(5), 982-991*

MATERIAL AND METHODS

TWQI MULTIMETRIC INDEX



Based on 6 factors

- main **causal** factors: N and P concentrations;
- **key biological elements:** phytoplankton chlorophyll-a (Chl*a)*, benthic phanerogams (Ph) and macroalgal coverage (Ma)
- indicators of eutrophication **effects**: dissolved oxygen saturation (DO)

Measured variable → *Non-linear quality function* → quality value (QV)

Weighing factors were selected based on the ecological relevance of the considered variables

TWQI was then obtained as the sum of weighted QVs

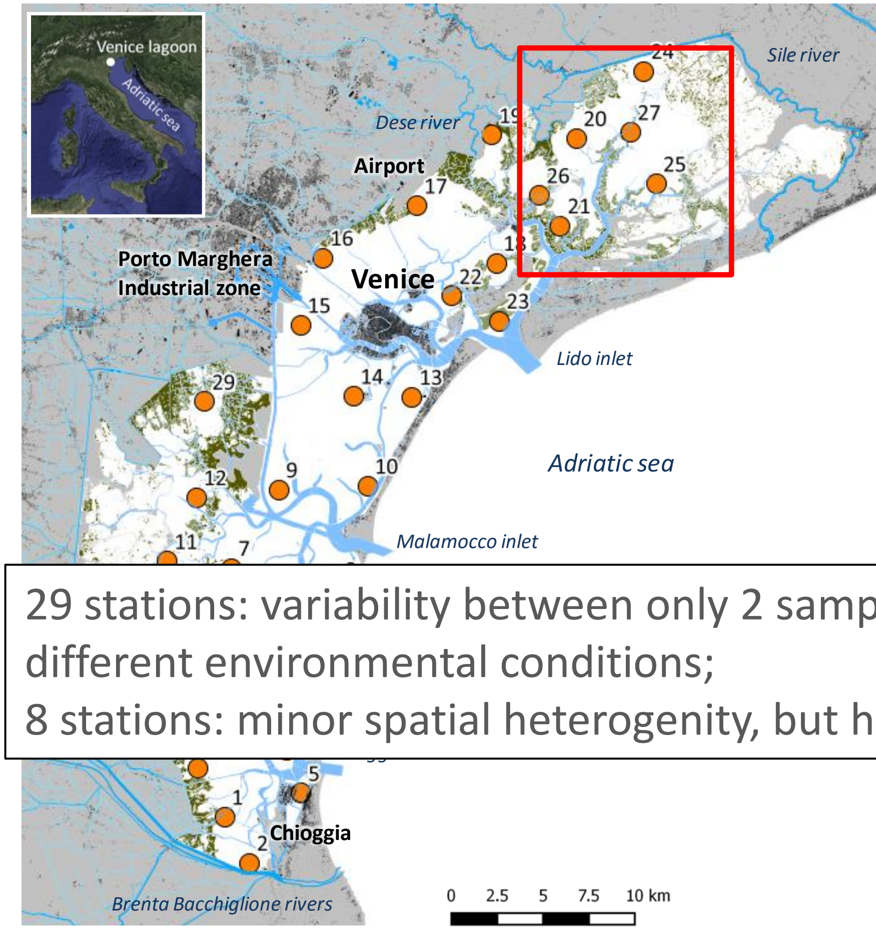
Giordani, G., Zaldivar, J.M., Viaroli, P., 2009. Simple tools for assessing water quality and trophic status in transitional water ecosystems. *Ecol. Ind. 9(5), 982-991*

MATERIAL AND METHODS

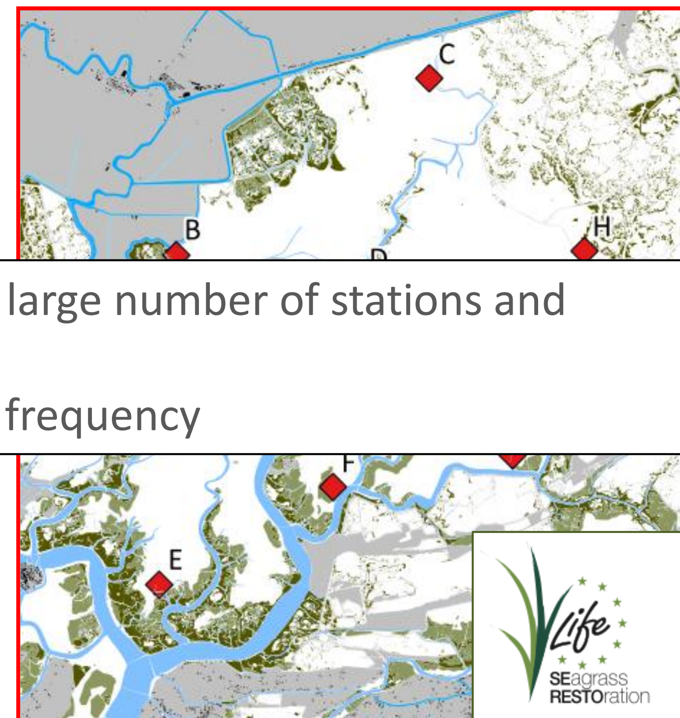
AVAILABLE DATA

Two different dataset have been used

Dataset 1 - 29 sites sampled twice - July and October 2010 (stations 1 – 29)



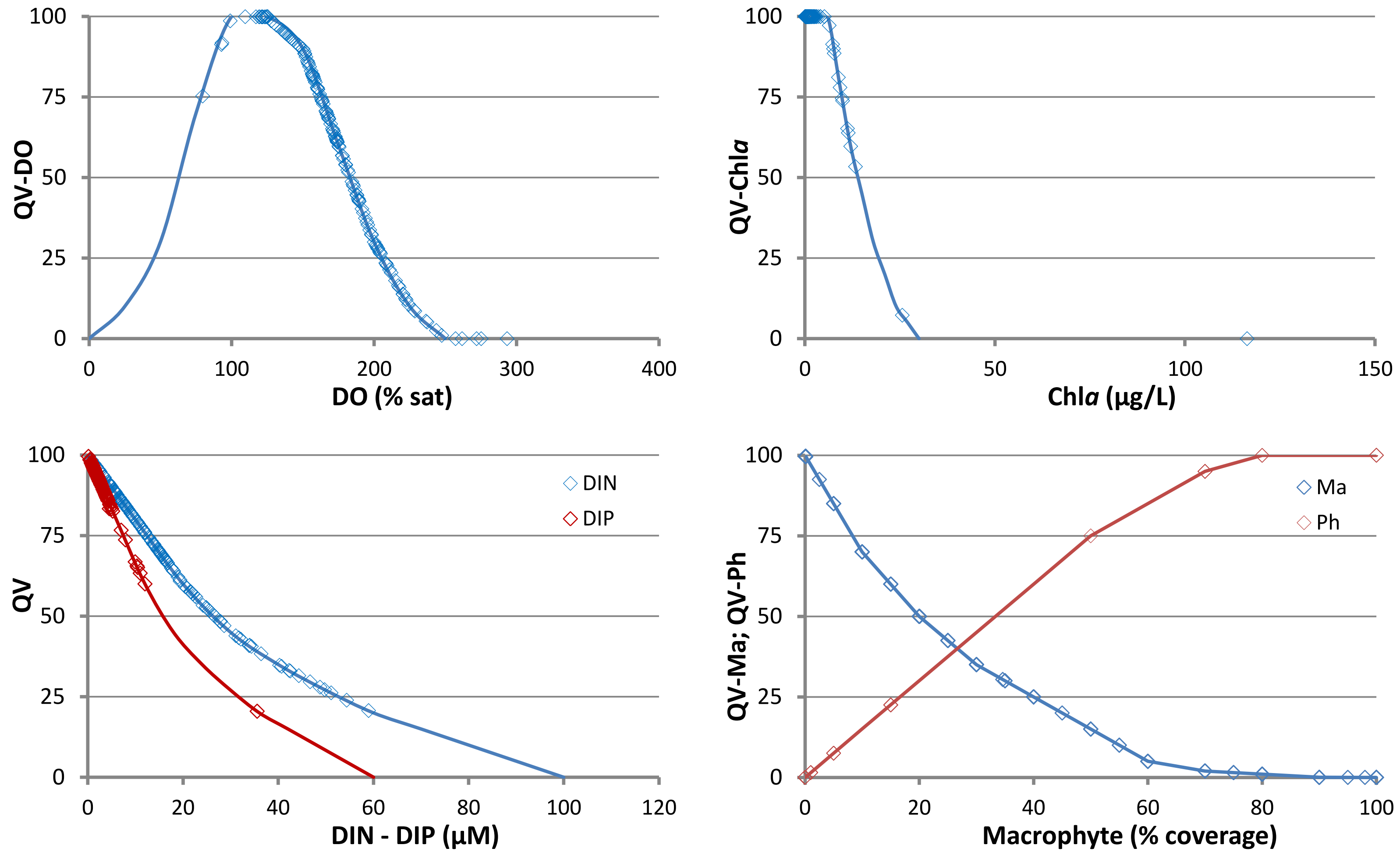
Dataset 2 - 8 sites, located in SCI IT3250031, monitored monthly (April 2014 -March 2015) in the framework of LIFE SERESTO project (stations A - H)



29 stations: variability between only 2 sampling, but in a large number of stations and different environmental conditions;
8 stations: minor spatial heterogenity, but high sampling frequency

MATERIAL AND METHODS

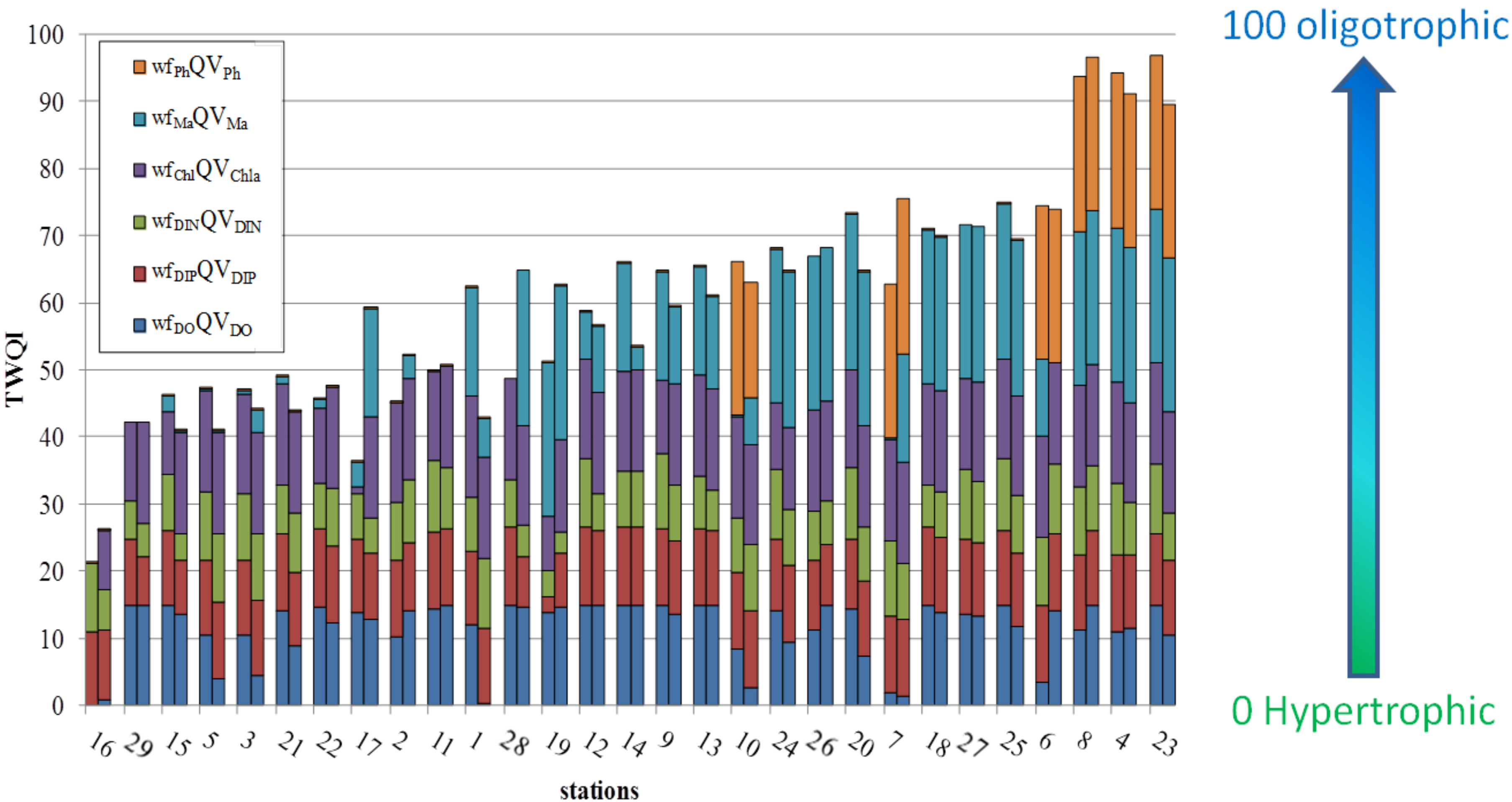
AVAILABLE DATA



Collected raw data and related QVs cover a wide spectrum of environmental and trophic conditions. Therefore the dataset is suitable for testing TWQI.

MATERIAL AND METHODS

AVAILABLE DATA



Collected raw data and related QVs cover a wide spectrum of environmental and trophic conditions. Therefore the dataset is suitable for testing TWQI.

MATERIAL AND METHODS

SEASONAL VARIABILITY – dataset 1

The seasonal variability (July vs October) of TWQI and of the metrics (QVs) composing the index have been calculated and compared.

QVs of each parameter has been used in place of the measured variables to highlight the reduction of variability depending on the integration of different factors and not that due to variable transformation by non linear functions

metric ***i***

station ***j***

station	$QV_{DIN,j}$ July	$QV_{DIN,j}$ October	$\Delta QV_{DIN,j}$	$QV_{Ma,j}$ July	$QV_{Ma,j}$ October	$\Delta QV_{Ma,j}$	ΔQV_j	$TWQI_j$ July	$TWQI_j$ October	$\Delta TWQI_j$	R_j
1	67.0	86.9	19.9	70.0	25.0	45.0	24.0	62.2	42.8	19.4	0.8
2	70.5	77.9	7.4	0.0	15.0	15.0	9.6	45.2	52.2	7.0	0.7
3	81.7	81.9	0.3	1.5	15.0	13.5	8.9	46.8	44.0	2.8	0.3
…	…	…	…	…	…	…	…	…	…	…	…

QV***i,j*** July QV***i,j*** October

MATERIAL AND METHODS

SEASONAL VARIABILITY – dataset 1

The seasonal variability (July vs October) of TWQI and of the metrics (QVs) composing the index have been calculated and compared.

QVs of each parameter has been used in place of the measured variables to highlight the reduction of variability depending on the integration of different factors and not that due to variable transformation by non linear functions

$$\Delta QV_{i,j} = abs\ \frac{QV_{i,j\_july} - QV_{i,j\_october}}{maxQV_i}\ x\ 100$$

maxQV$_{i,j}$ = 100 for all parameters *i*

% variation of QVs

metric *i*

station *j*	$QV_{DIN,j}$ July	$QV_{DIN,j}$ October	**$\Delta QV_{DIN,j}$**	$QV_{Ma,j}$ July	$QV_{Ma,j}$ October	**$\Delta QV_{Ma,j}$**	ΔQV_j	$TWQI_j$ July	$TWQI_j$ October	**$\Delta TWQI_j$**	**R_j**
1	67.0	86.9	19.9	70.0	25.0	45.0	24.0	62.2	42.8	19.4	0.8
2	70.5	77.9	7.4	0.0	15.0	15.0	9.6	45.2	52.2	7.0	0.7
3	81.7	81.9	0.3	1.5	15.0	13.5	8.9	46.8	44.0	2.8	0.3
…	…	…	…	…	…	…	…	…	…	…	…

QV***i,j*** July — QV***i,j*** October

MATERIAL AND METHODS

SEASONAL VARIABILITY – dataset 1

The seasonal variability (July vs October) of TWQI and of the metrics (QVs) composing the index have been calculated and compared.

QVs of each parameter has been used in place of the measured variables to highlight the reduction of variability depending on the integration of different factors and not that due to variable transformation by non linear functions

$$\Delta QV_{i,j} = abs\,\frac{QV_{i,j\_july} - QV_{i,j\_october}}{maxQV_i}\,x\,100$$

$$\Delta QV_j = mean_i\,\Delta QV_{i,j}$$

metric *i*

station *j*	$QV_{DIN,j}$ July	$QV_{DIN,j}$ October	$\Delta QV_{DIN,j}$	$QV_{Ma,j}$ July	$QV_{Ma,j}$ October	$\Delta QV_{Ma,j}$	**ΔQV_j**	$TWQI_j$ July	$TWQI_j$ October	$\Delta TWQI_j$	Rj
1	67.0	86.9	19.9	70.0	25.0	45.0	24.0	62.2	42.8	19.4	0.8
2	70.5	77.9	7.4	0.0	15.0	15.0	9.6	45.2	52.2	7.0	0.7
3	81.7	81.9	0.3	1.5	15.0	13.5	8.9	46.8	44.0	2.8	0.3
…	…	…	…	…	…	…	…	…	…	…	…

QV*i,j* July   QV*i,j* October

MATERIAL AND METHODS

SEASONAL VARIABILITY – dataset 1

The seasonal variability (July vs October) of TWQI and of the metrics (QVs) composing the index have been calculated and compared.

QVs of each parameter has been used in place of the measured variables to highlight the reduction of variability depending on the integration of different factors and not that due to variable transformation by non linear functions

$$\Delta QV_{i,j} = abs\ \frac{QV_{i,j\_july} - QV_{i,j\_october}}{maxQV_i}\ x\ 100$$

% variation of TWQI

$$\Delta TWQI_j = abs\ (TWQI_{j\_july} - TWQI_{i,j\_october})$$

$$\Delta QV_j = mean_i\ \Delta QV_{i,j}$$

metric *i*

station *j*	$QV_{DIN,j}$		$\Delta QV_{DIN,j}$	$QV_{Ma,j}$		$\Delta QV_{Ma,j}$	ΔQV_j	$TWQI_j$		$\Delta TWQI_j$	Rj
station	July	October		July	October			July	October		
1	67.0	86.9	19.9	70.0	25.0	45.0	24.0	62.2	42.8	19.4	0.8
2	70.5	77.9	7.4	0.0	15.0	15.0	9.6	45.2	52.2	7.0	0.7
3	81.7	81.9	0.3	1.5	15.0	13.5	8.9	46.8	44.0	2.8	0.3
…	…	…	…	…	…	…	…	…	…	…	…

QV***i,j*** July QV***i,j*** October

MATERIAL AND METHODS

SEASONAL VARIABILITY – dataset 1

The seasonal variability (July vs October) of TWQI and of the metrics (QVs) composing the index have been calculated and compared.

QVs of each parameter has been used in place of the measured variables to highlight the reduction of variability depending on the integration of different factors and not that due to variable transformation by non linear functions

$$\Delta QV_{i,j} = abs\,\frac{QV_{i,j\_july} - QV_{i,j\_october}}{maxQV_i}\ x\ 100$$

$$\Delta TWQI_j = abs\,(TWQI_{j\_july} - TWQI_{i,j\_october})$$

$$\Delta QV_j = mean_i\, \Delta QV_{i,j}$$

metric *i*

station *j*

station	$QV_{DIN,j}$ July	$QV_{DIN,j}$ October	$\Delta QV_{DIN,j}$	$QV_{Ma,j}$ July	$QV_{Ma,j}$ October	$\Delta QV_{Ma,j}$	ΔQV_j	$TWQI_j$ July	$TWQI_j$ October	$\Delta TWQI_j$	R_j
1	67.0	86.9	19.9	70.0	25.0	45.0	24.0	62.2	42.8	19.4	0.8
2	70.5	77.9	7.4	0.0	15.0	15.0	9.6	45.2	52.2	7.0	0.7
3	81.7	81.9	0.3	1.5	15.0	13.5	8.9	46.8	44.0	2.8	0.3
…	…	…	…	…	…	…	…	…	…	…	…

QV***i,j*** July   QV***i,j*** October

Values R_j**<1** indicate a variability of TWQI lower than the mean variability of parameters at the site (j).

$$R_j = \frac{\Delta TWQI_j}{\Delta QV_j}$$

MATERIAL AND METHODS

MONTHLY VARIABILITY – dataset 2

The temporal variability of each metric of QV and **TWQI at 8 sites sampled monthly** was determined as the annual standard deviation (st.dev.): **ST.DEV-QV$_{i,j}$** of each parameter (i) at any station (j) and ST.DEV-TWQIj at each station (j).

e.g. station A

month	QV_DO	QV_chla	QV_DIN	QV_DIP	QV_Ma	QV_Ph	TWQI
Apr	93.1	100.0	52.7	86.8	70.0	0.0	61.8
Mag	5.5	100.0	88.9	96.3	5.0	0.0	39.2
Giu	95.0	100.0	63.9	96.0	1.0	0.0	48.7
Lug	91.1	100.0	20.7	90.8	0.0	0.0	42.1
Ago	51.6	100.0	43.3	84.8	25.0	0.0	43.9
Set	1.0	100.0	57.7	97.2	70.0	0.0	49.8
Ott	44.7	100.0	27.2	92.7	70.0	0.0	52.2
Nov	39.1	100.0	29.6	88.2	70.0	0.0	51.1
Dic	68.8	100.0	34.4	93.7	70.0	0.0	56.8
Gen	62.1	100.0	68.5	92.8	85.0	0.0	63.2
Feb	28.7	100.0	88.2	83.9	50.0	0.0	51.5
Mar	0.0	100.0	91.6	89.4	25.0	0.0	42.5
st.dev.	**35.1**	**0.0**	**25.2**	**4.5**	**31.8**	**0.0**	**7.7**

$$R_j = \frac{\Delta TWQI_j}{\Delta QV_j}$$

$\Delta QV_j = mean_i\ ST.DEV\ QV_{i,j}$

$\Delta TWQI_j = ST.DEV\ TQWI_{i,j}$

$\Delta QV_{j,j} = ST.DEV_{i,j}$

annual variability of six factors (ST.DEVi,j)							$\Delta TWQI_j$	ΔQV_j	R_j
stazione	QV-DO	QV-Chla	QV-DIN	QV-DIP	QV-MA	QV-SG			
A	35.1	0.0	25.2	4.5	31.8	0.00	7.7	16.1	0.48
B	21.35	0.00	21.04	9.43	6.76	0.00	3.81	9.76	0.39
…	…	…	…	…	…	…	…	…	…

RESULTS

SEASONAL VARIABILITY – dataset 1

$$R_j = \frac{\Delta TWQI_j}{\Delta QV_j}$$

N=29

temporal variability of each TWQI factor ($\Delta VQ_{i,j}$)									
d	QV-DO	QV-DIP	QV-DIN	QV-Chla	QV-Ma	QV-Ph	ΔQV_j	ΔTWQI	Rj
1	77.7	1.7	19.9	0.0	45.0	0.0	24.0	19.4	0.8
2	25.6	9.8	7.4	0.0	15.0	0.0	9.6	7.0	0.7
3	39.6	0.0	0.3	0.0	13.5	0.0	8.9	2.8	0.3
…									
29	1.3	23.3	7.5	22.0	0.0	0.0	9.0	0.2	0.0
mean	**20.1**	**7.5**	**15.0**	**11.7**	**17.0**	**0.9**	**12.0**	**6.2**	**0.50**

Rj < 1 in most stations; mean R = 0.50 → **Reduction of 50% of temporal fluctuations**

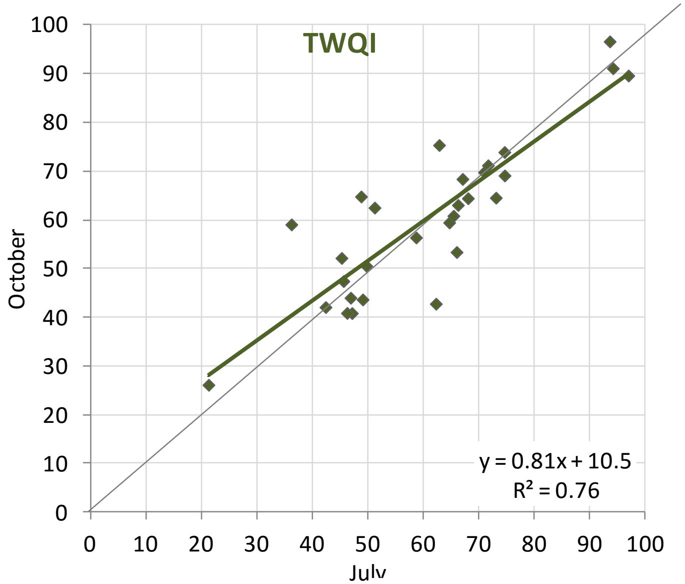
mean QVs variability resulted 12%

Mean temporal variability of TWQI (mean ΔTWQI) resulted 6.2%

DO, DIN and Ma resulted the most variable metrics: mean value 20.1%, 15%, 17%

RESULTS

SEASONAL VARIABILITY – dataset 1



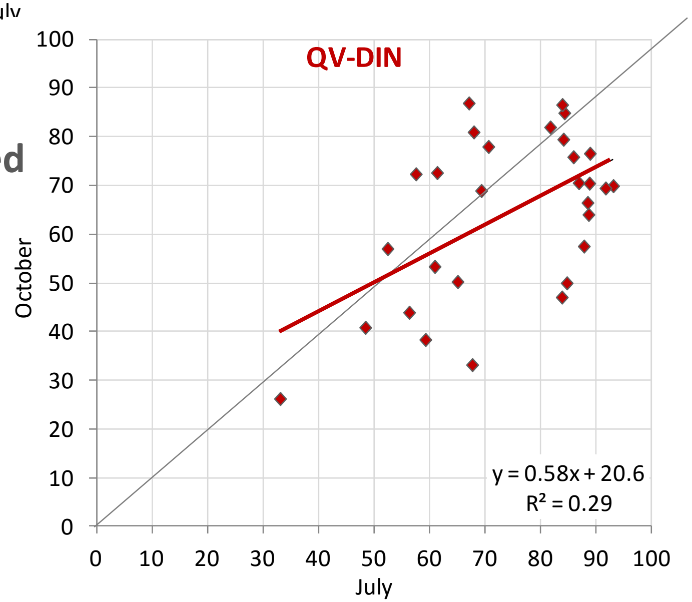
Results can be better displayed by a scatter plot of July vs October values

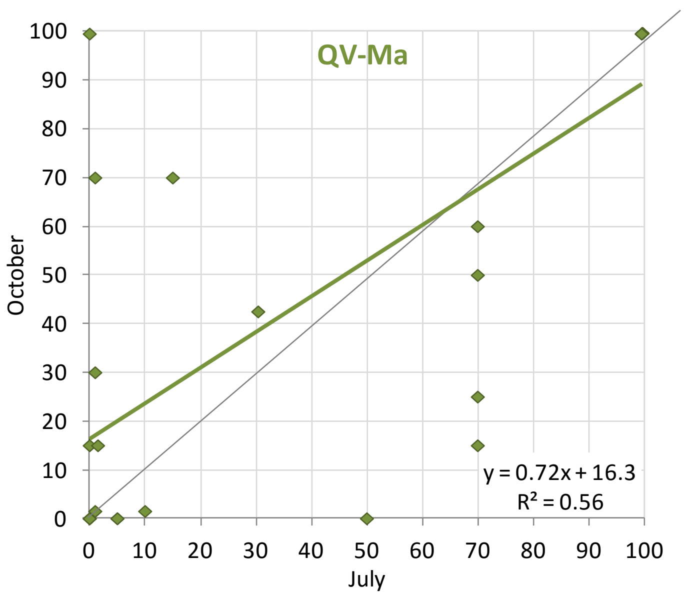
Slope of the linear regression line close to 1 indicates similar scores over the two campaigns

High correlation indicates a similar spatial distribution of the estimated trophic status between the two campaigns

Slope of TWQI regression line resulted the closest to 1

TWQI presented the highest correlation





EUROLAC Murcia 2016

RESULTS

MONTHLY VARIABILITY – dataset 2

N=8

annual variability of six factors (ST.DEVi,j)							mean ST.DEV. of six metrics	ST.DEV. TWQI	R_j
stazione	QV-DO	QV-Chla	QV-DIN	QV-DIP	QV-MA	QV-SG			
A	35,07	0,00	25,25	4,50	31,78	0,00	16,10	7,65	0,48
B	21,35	0,00	21,04	9,43	6,76	0,00	9,76	3,81	0,39
C	21,74	0,00	16,52	4,55	23,49	0,00	11,05	8,94	0,81
…	…	…	…	…	…	…	…	…	…
H	21,40	0,00	8,31	3,29	14,50	0,00	7,92	4,68	0,59
mean	**25,08**	**0,00**	**14,93**	**4,45**	**19,33**	**0,00**		**6,17**	**mean value (R)**
									0,59

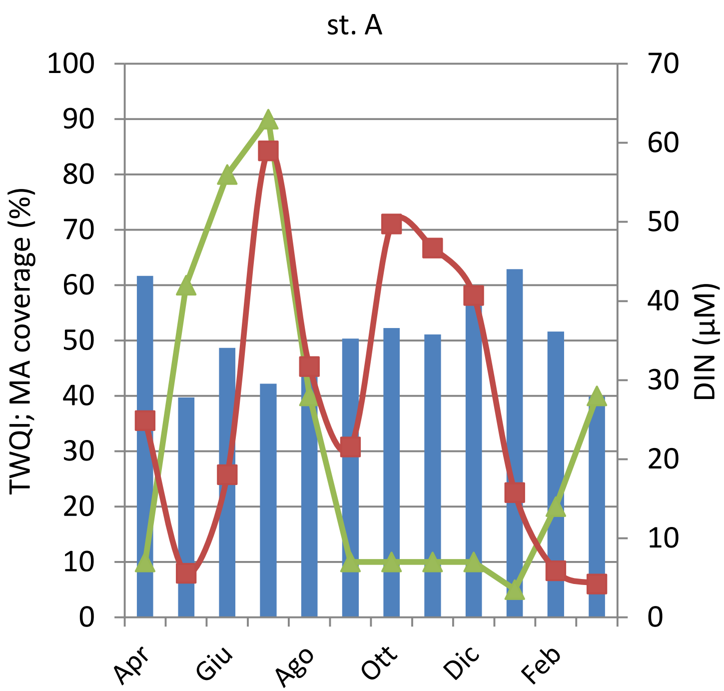
R_j<1 in all stations; mean R = 0.59 → **Reduction of 40% of temporal fluctuations**

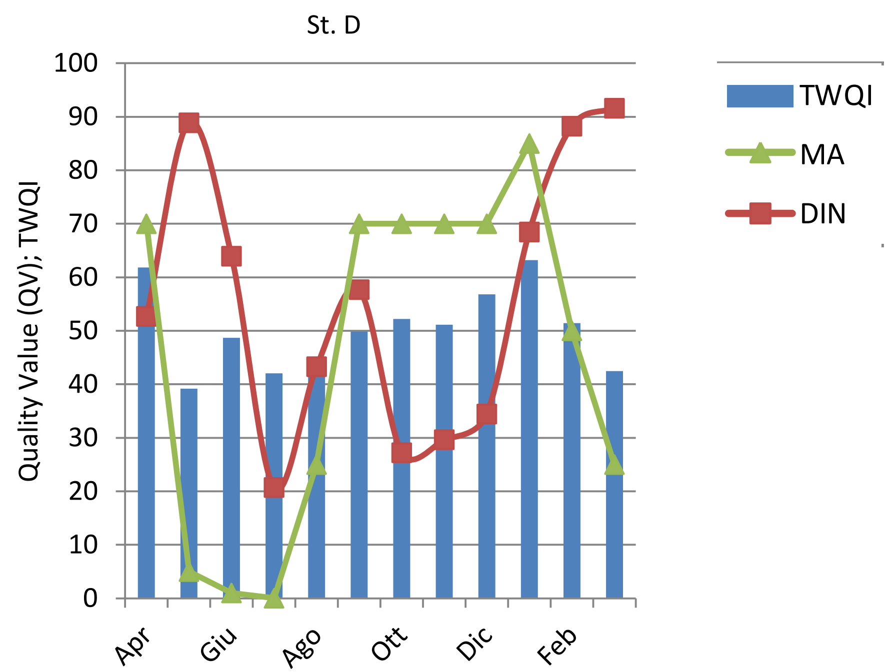
TWQI st.dev is 40% lower than mean of single metrics (58%lower than DIN; 68% lower than Ma)

DO, DIN and Ma resulted the most variable metrics

RESULTS

The reduction of variability could be explained from a ecological point of view considering the **opposite fluctuation of different variables** included in the index.





For example, macroalgal blooms can induce large oscillations in nitrogen and phosphorus availability, with strong uptake periods followed by sudden releases.

RESULTS

SAMPLING FREQUENCY VS ASSESSMENT CONFIDENCE

METHOD

e.g. for DIN

		monthly
months		µM
2014	**Apr**	**24,8**
2014	**May**	**5,5**
2014	**Jun**	**18,0**
2014	**Jul**	**58,9**
2014	**Aug**	**31,7**
2014	**Sep**	**21,5**
2014	**Oct**	**49,7**
2014	**Nov**	**46,6**
2014	**Dec**	**40,6**
2015	**Jan**	**15,7**
2015	**Feb**	**5,8**
2015	**Mar**	**4,2**
	mean	26.9

RESULTS

SAMPLING FREQUENCY VS ASSESSMENT CONFIDENCE

METHOD

e.g. for DIN

		monthly	4 times/year		
months		µM	Months combination	µM	err%
2014	**Apr**	24,8	**Apr-Jul-Oct-Jan**	**37,3**	**38,4**
2014	**May**	5,5	**May-Aug-Nov-Feb**	**22,5**	**16,7**
2014	**Jun**	18,0	**Jun-Sep-Dec-Mar**	**21,1**	**21,7**
2014	**Jul**	58,9			**mean**
2014	**Aug**	31,7			**25,6**
2014	**Sep**	21,5			
2014	**Oct**	49,7			
2014	**Nov**	46,6			
2014	**Dec**	40,6			
2015	**Jan**	15,7			
2015	**Feb**	5,8			
2015	**Mar**	4,2			
	mean	**26.9**			

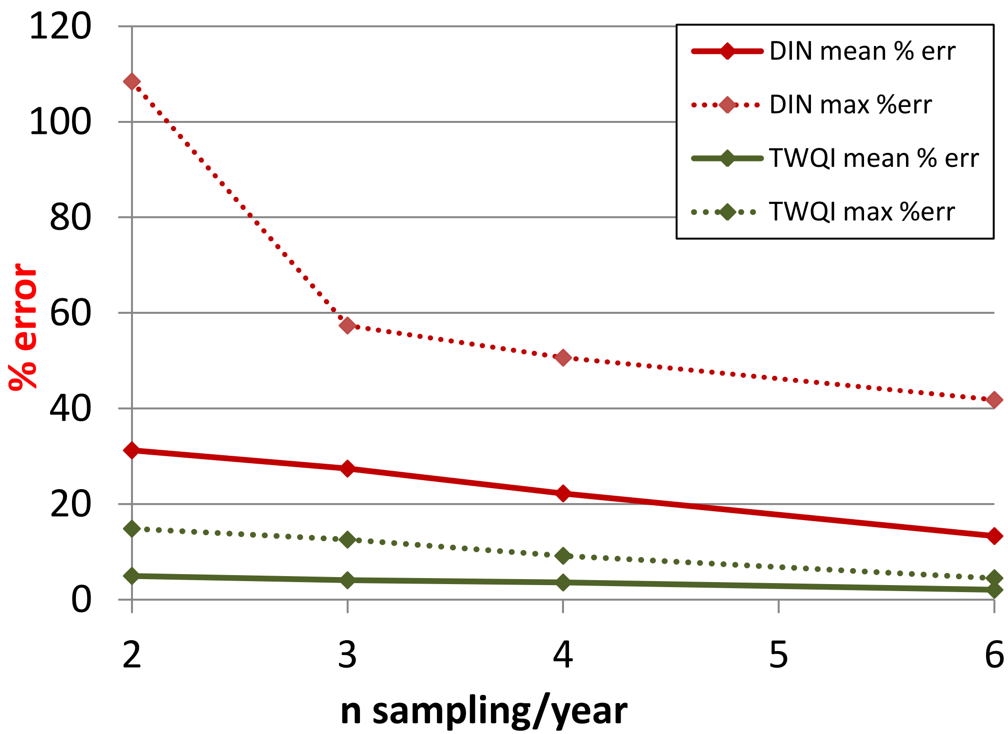
Deviation (%) from the annual mean values **(%error)** computed by monthly sampling (12sampl/year)

METHOD

For each station, the mean values that would have been obtained using a lower monitoring frequency (6, 4, 3, 2 times a year) was computed considering **all possible combinations** with regular time. The deviation of these values from the annual mean derived from monthly sampling was estimated (in the following called "**%error**").

RESULTS

SAMPLING FREQUENCY VS CONFIDENCE



Results confirm that the estimation of the annual mean value of **TWQI is less affected by the sampling frequency than DIN.**

By averaging the values of the 8 stations the mean TWQI % error ranges between 2% and 5, while the mean DIN %error is between 13% and 31%.

The different sensitivity to the sampling is even more evident by observing the **maximum %error**, ranging from 4.5% to 15% for TWQI and from 42% to more than 100% for DIN.

CONCLUSIONS

- ✓ TWQI is a simple tool for combining the information from different abiotic and biotic measurements and provide a integrated **evaluation of trophic status quantitatively expressed**.

- ✓ Multimetric index TWQI demonstrated to be **less affected by temporal variations** than the average of the single parameters integrated in the index.

- ✓ The estimation of trophic status by TWQI is **less affected by the sampling frequency** than single abiotic and biotic metrics (e.g. DIN).

- ✓ Most of the **measurements are generally already considered in the standard monitoring** activities of transitional ecosystems

- ✓ The TWQI could be a **smart indicator for eutrophication risk assessment** for Institutional monitoring carried out by Environmental Agencies

Thanks for your attention

Most data used in this study have been collected during LIFE SERESTO monitoring activities. The SERESTO project is funded by European Union's LIFE+ financial instrument and contributes to the environmental recovery of a Natura 2000 site (SIC IT3250031 - Northern Venice Lagoon).

[www.lifeseresto.eu,](http://www.lifeseresto.eu) serestoinlife@unive.it

RESULTS

SAMPLING FREQUENCY VS CONFIDENCE

% error

		DIN µM				TWQI			
		n sampling/year				n sampling/year			
		6	**4**	**3**	**2**	**6**	**4**	**3**	**2**
stations	A	5,6	25,6	28,0	28,6	4,5	6,1	5,0	7,8
	B	41,8	14,6	41,8	41,8	3,6	2,7	3,7	5,4
	C	17,3	29,7	17,3	33,6	0,2	2,5	3,8	3,9
	D	18,7	24,3	25,5	31,0	3,4	5,2	6,8	6,4
	E	10,3	11,1	23,0	16,5	0,0	2,2	3,7	2,9
	F	8,8	5,0	18,7	16,2	1,3	3,7	3,1	5,9
	G	3,6	33,6	33,3	34,6	3,0	3,8	3,1	4,9
	H	0,1	33,7	31,6	47,5	0,0	2,3	3,1	2,4
	mean	**13,3**	**22,2**	**27,4**	**31,2**	**2,0**	**3,6**	**4,0**	**4,9**
	max	**41,8**	**50,6**	**57,3**	**108,4**	**4,5**	**9,1**	**12,5**	**14,8**

Results confirm that the estimation of the annual mean value of **TWQI is less affected by the sampling frequency than DIN.**

By averaging the values of the 8 stations the mean TWQI % error ranges between 2% and 5, while the mean DIN %error is between 13% and 31%.

The different sensitivity to the sampling is even more evident by observing the **maximum %error**, ranging from 4.5% to 15% for TWQI and from 42% to over 100% for DIN.